TREATMENT AND STANDARDIZATION OF FIBEROUS BY-PRODUCTS FOR FINISHING BEEF CATTLE

by

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ABSTRACT

Cereal grain production and the wet and dry milling industries have yielded a plentiful supply of fibrous by-products for use in livestock production. These by-products can be treated both chemically and physically to alter their digestibility, and effects on animal performance and rumination behavior. Three experiments were conducted to evaluate the treatment of fibrous by-products in steam-flaked corn (**SFC**)-based diets on *in situ* digestibility, animal metabolism, animal performance, carcass characteristics, and rumination behavior. Experiment 1 utilized three ruminally cannulated steers (621 ± 3.6 kg of BW) to evaluate *in situ* digestibility of calcium hydroxide (**CH**) treated corn stalks and sorghum wet distillers grains plus solubles (**SWDGS**). Treatments included: untreated SWDGS (**S**), CH treated SWDGS (2.67 % DM basis; **S-CH**), untreated corn stalks (**C**), and CH treated corn stalks (**C-CH**). All treatments were placed at once in the ventral rumen space three ruminally cannulated steers and incubated in the rumen for 0, 6, 12, 24, 36, and 48 h. Effective ruminal degradability (**ERD**) of DM was greater ($P <$ 0.01) for C-CH than C, with no difference (P = 0.38) between S and S-CH. No differences (P = 0.27) were observed for ERD of OM between S and S-CH. However, S was greater (P = 0.04) than S-CH for ERD of NDF. Experiment 2 utilized six ruminally cannulated steers (444 ± 4.0 kg of BW) in a 3 × 3 replicated Latin Square design to evaluate the effects of treating 30% SWDGS in finishing diets. Treatment diets were SFC-based and included: 30% corn wet distillers grains plus solubles (**CDG**), 30% SWDGS (**SDG**), and 30% CH treated SWDGS (2.67 DM basis; **SDG-CH**). Periods included 17 d of diet adaptation and 4 d of subsequent fecal and rumen fluid collection.

No differences were observed for DM intake (P = 0.47) or apparent total tract digestibility of DM, OM, ADF, starch, or nitrogen ($P \geq 0.15$) for steers consuming CDG, SDG, or SDG-CH. However, steers consuming SDG-CH tended (P = 0.07) to have a greater apparent total tract digestibility of NDF. Steers consuming CDG had the greatest ($P < 0.01$) total ruminal VFA concentration, followed by steers consuming SDG-CH, with steers consuming SDG having the lowest. Experiment 3 utilized fifty-one individually fed steers (initial BW = 385 ± 3.6 kg) to evaluate the effects of corn stalk (**CS**) particle size and inclusion rate in SFC-based finishing diets on animal performance and rumination behavior. Corn stalks were passed through a tub grinder equipped with a 7.62 cm screen once (**LG-CS**), or twice (**SG-CS**) to achieve different particles sizes. Dietary treatments included: 30% wet corn gluten feed (**WCGF**) and 5% SG-CS (**5SG**), 30% WCGF and 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**). Steers were outfitted with continuous rumination and activity monitoring collars on d 70. Long grind corn stalks 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 was greatest ($P \leq 0.03$) for steers consuming 5LG and 5SG compared to 10SG. Hot carcass weight tended (P = 0.10) to be greatest for steers consuming 5LG, and least for steers consuming 10SG with 5SG being intermediate. Dressing percent was greater (P = 0.01) for steers consuming 5LG and 5SG than 10SG. Minutes of rumination per day were greatest (P = 0.01) for steers consuming

10SG, followed by 5LG, and lowest for 5SG. Treating SWDGS with CH showed improvement compared to untreated SWDGS in finishing diets. Increasing particle size of roughage may be a means to decrease roughage inclusion rate while maintaining rumination and performance.

Key words: distillers grains, calcium hydroxide, particle size, rumination, corn stalks

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CDS = condensed distillers solubles
CGF = corn gluten feed
CH = calcium hydroxide
CWDGS = corn wet distillers grains plus solubles
DDG = dried distillers grains
DG = distillers grains
DDGS = dried distillers grains plus solubles
DOF = days on feed
DP = dressing percent
DRC = dry-rolled corn
EE = ether extract
eNDF = effective neutral detergent fiber
HMC = high-moisture corn
ISD = *in situ* digestibility
LG = long grind
pef = physical effective factor
peNDF = physically effective neutral detergent fiber
PSPS = Penn State particle separator
SBW = shrunk body weight
SFC = steam-flaked corn
SG = short grind
SWDGS = sorghum wet distillers grains plus solubles
WCGF = wet corn gluten feed
WDG = wet distillers grains
WDGS = wet distillers grains plus solubles
WSC = whole-shell corn

CHAPER I

REVIEW OF LITERATURE

Introduction

A by-product or co-product is an incidental or secondary product made in the synthesis or manufacture of a primary product. Common feedstuff by-products produced today include those from the wet and dry milling of grain. Other by-products that have been utilized include crop residues remaining after the harvest of cereal grains, such as corn and sorghum stover. A relatively large portion of the by-products listed above is in the form of fiber, therefore they hold minimal nutritional value for humans and monogastric livestock. A ruminant animal has the ability to digest the fiber through rumen microbes such as bacteria and protozoa. The mutualistic relationship between the fiber digesting microbes and the ruminant animal provides a means to utilize these otherwise wasteful fibrous by-products.

According to the Renewable Fuels Association, 14,300 million gallons of ethanol, and approximately 39 million metric tons of distillers grains (**DG**) were produced in 2014 (RFA, 2014). The USDA National Agriculture Statistics Service Grain Crushing and Co-Products Production Report stated that 1.94 million tons of dried distillers grains with solubles (**DDGS**) were produced along with 1.13 million tons of wet distillers grains with solubles (**WDGS**) containing more than 65 percent moisture, in November 2015 (NASS, 2016). The report also stated that 322.7 thousand tons of corn gluten feed (**CGF**) was produced along with 289.2 thousand tons of wet corn gluten feed (**WCGF**), containing

40 to 60 percent moisture, in November 2015 (NASS, 2016). The USDA World Agricultural Supply and Demand Estimates Report (WASDE) estimate corn production from 2015-2016 to be 13.6 billion bushels (USDA, 2016). If corn grain accounts for approximately 45% of the total dry matter yield of a corn field, then 55% can be considered residue. Using the production estimates from the USDA WASDE report, approximately 16.6 billion tons of corn stover resides in the field. If the farmer practices the "take half, leave half" method, 8.3 billion tons of corn stover are potentially available for use in livestock production.

Cereal grain production and the grain milling industry have yielded a plentiful supply of fibrous by-products for use in ruminant diets. An understanding of the physical and chemical nature of these by-products as well as how they behave in the rumen, and furthermore affect animal performance, is crucial to using these by-products efficiently.

Distillers Grains

Dry Milling Process

The dry milling industry converts the starch in grain to alcohol as well as yielding by-products such as condensed distillers solubles, wet and dry distillers grains, and potentially corn oil if the ethanol plant is equipped to extract the oil from the thin stillage portion. The process is relatively simple when comparing the dry and wet milling industries. The grain is first ground by a hammer mill and placed into a fermentation vessel where water, enzymes, and yeast are added to create a mash and facilitate fermentation. After fermentation is complete the alcohol is distilled out of the mash, the remaining product is referred to as whole stillage. Some ethanol plants remove the larger, coarser feed particles before distillation so that only the liquid fraction is distilled, but this typically results in a lower ethanol yield compared to distilling the entire mash (Stock et al., 2000). The whole stillage is then screened and pressed or centrifuged to further partition the whole stillage into wet distillers grains (**WDG**) and the liquid fraction or thin stillage. Wet distillers grains can be sold as is, or dried and sold as dried distillers grains (**DDG**). The thin stillage is then evaporated to remove a large portion of the water; this creates syrup that contains approximately 20 to 35% DM that is called condensed distillers solubles (**CDS**) (Stock et al., 2000). The CDS can be sold as an individual feed product, or can be added back to the DDG or WDG to produce DDG plus solubles (**DDGS**) and WDG plus solubles (**WDGS**), respectively. Since approximately two-thirds of corn and sorghum grain are starch, and most of the starch is removed in the dry milling process, the other chemical constituents of the grain are concentrated threefold (Owens, 2008). The WDG contain approximately 30 to 35 % DM, 30 % crude protein, 10 % fat, 40 % neutral detergent fiber, 0.40 % sulfur and 1.40 % phosphorus (NRC, 2000).

Nutrient Content and Variability

Routine analysis of DG products is recommended; these values can vary between plants and vary within plant especially with regards to fat content (Bruckner et al., 2011). Holt and Pritchard (2004) analyzed the composition and nutritive value of corn co-products produced from several dry milling ethanol plants in the upper Midwest. Four plants were sampled four times a day over a duration of four consecutive days. Variability between plants as well as variability within plant each day were analyzed. A significant day effect within plant ($P < 0.05$) was reported for crude fat content, which would coincide with results from Bruckner et al. (2011). Neutral detergent fiber content differed ($P < 0.05$) among all ethanol plants with a range from 37.3 to 49.3 %. Holt and

Pritchard (2004) proposed that heat damage was a possible explanation for the differences observed in NDF since there was no apparent dilution of CP or ether extract (**EE**) associated with differences in NDF. A composite value from all four plants was compared to the tabular values found in the NRC (2000). For WDGS, DM was 25 and 31.4%, CP was 29.7 and 35.5%, NDF was 40 and 42.3%, and EE was 9.9 and 12.1% for the NRC tabular values and the values observed in this study, respectively.

Corn Processing and Distillers Grains

When DG are fed at levels less than approximately 15% dietary DM, they are fed as a protein source, at levels greater than approximately 15% they are fed as a protein and energy source (Klopfenstein et al., 2008). If DG exceeds 15% of dietary DM inclusion in a finishing diet, DG replaces corn in most cases (Klopfenstein et al., 2008). If corn is replaced, it is crucial to understand the energy value of corn, whether or not it is processed, and what it is replaced with. In the feedlot industry, corn is routinely processed to increase the accessibility and utilization of starch by rumen microbes, thereby increasing animal performance (Armbruster, 2006; Owens, 1997; Zinn; 2002). Accessibility is the most frequent limitation for digestion of incompletely processed grains (Owens, 2008). Grain processing also may improve mixing characteristics to improve bunk management and thereby enhance animal performance (Owens et al., 1997). Across the United States corn is processed differently, predominantly due to differences in price due to location, supply of corn and price of natural gas. In the Midwest it is common for feedlots to feed whole shell corn (**WSC**), dry-rolled corn (**DRC**), and high-moisture corn (**HMC**), alone or in combination. In the Southern High Plains region of the U.S., it is common for feedlots to feed steam-flaked corn (**SFC**).

Zinn et al. (2002) summarized four trials comparing SFC, DRC, and ground corn and concluded that flaking increased NEg values from 15.9 to 25.9%. If energy values vary relative to grain processing, and DG generally replaces grain in the diet, one would expect grain processing to influence the overall feeding value of DG.

There could be several reasons for WDGS to interact with grain processing including: differences in caloric densities of the different grains (DRC vs. SFC), differential responses to added EE, protein, yeast, ethanol contamination, minerals especially concerning sulfur, physical characteristics of the diet and methane production (Cole et al., 2009). Supplemental EE can be a cofounding factor when comparing the energy value of DG in diets based on DRC or SFC. Typically, supplemental EE is not fed in the Northern Great Plains where corn is generally dry rolled, compared to the Southern Great Plains where corn is steam-flaked (Cole et al., 2009). Owens (2008) reviewed the feeding value and energy content of distillers co-products, and reported ruminal pH is lower with cattle fed SFC-based diets compared to cattle consuming DRC-based diet, and the reduced pH may reduce the digestion of NDF. Therefore, this would decrease the amount of energy available from NDF in DG. This would partially explain greater energy values of DG fed in DRC-based diets compared to DG fed in SFC-based diets. Since fiber generally replaces starch when DG are included in finishing diets, fiber digestibility is centrally important in the incorporation of DG into finishing diets (MacDonald, 2011).

Vander Pol et al. (2006) conducted a pen based performance study to determine the optimum inclusion level of corn WDGS in diets that contained a 1:1 mixture of DRC and HMC, while feeding distillers grains at 0, 10, 20, 30, 40, and 50% of dietary DM. Dry matter intake and ADG increased ($P < 0.01$) quadratically as WDGS inclusion increased, with the cattle receiving 30% WDGS achieving the highest DMI. A quadratic (*P* < 0.01) decrease was observed for feed: gain conversion as WDGS inclusion increased from 0 to 50% dietary DM. Cattle consuming 40% WDGS had the most favorable feed conversion. Hot carcass weight and carcass adjusted final body weight increased (*P* < 0.01) increased quadratically as WDGS inclusion increased in the diet. The greatest HCW were observed in the animals consuming 30% WDGS. Energy values of WDGS relative to the corn mixture in this experiment were 144 and 137%, for the 30 and 40% WDGS diets, respectively.

Luebbe et al. (2012) fed 600 steers over a two year period to evaluate the effects of WDGS in SFC based diets. Two control diets were fed, one based on DRC and the other based on SFC with no WDGS. The remaining treatment diets contained 15, 30, 45, or 60% WDGS all containing SFC. The WDGS replaced cottonseed meal, and supplemental fat in all diets that contained WDGS, and also replaced urea in the 30, 45, and 60% WDGS diets. A quadratic response (*P* < 0.01) was observed for DMI as WDGS concentration in the diet increased, with maximum DMI occurring at 15 and 30% WDGS. Final body weight and ADG decreased linearly (*P* < 0.01) with increasing WDGS concentration. Efficiency of gain decreased linearly (*P* < 0.01) and tended to decrease quadratically (*P* = 0.07) with increasing concentration of WDGS. Marbling score, HCW and 12th-rib fat depth decreased linearly (*P* < 0.01) with increasing concentration of WDGS.

In addition to the performance trial, Luebbe et al. (2012) conducted a digestibility trial utilizing six ruminally and duodenally cannulated steers, with the same dietary treatments as the performance trial. Dry matter, OM, NDF, and starch intake were not different ($P \geq 0.54$) between corn processing methods. Apparent and true ruminal OM digestibility decreased linearly ($P < 0.01$) with increasing concentration of WDGS. Digestibility of NDF in the rumen increased linearly ($P < 0.01$) with increasing WDGS inclusion. True ruminal starch digestibility was least ($P < 0.01$) for steers consuming SFC and 15% WDGS, intermediate for 30 and 45% WDGS, and greatest for steers consuming 60% WDGS. Postruminal starch digestion responded in a quadratic ($P = 0.02$) manner, and was maximized in steers consuming 15 and 30% WDGS. Total tract starch digestibility decreased quadratically ($P < 0.01$) with increasing WDGS concentration. Total VFA concentrations decreased linearly ($P < 0.01$) with increasing WDGS concentration. Molar proportions of acetate increased linearly ($P < 0.01$), while molar proportions of propionate decreased linearly ($P < 0.01$) with increasing WDGS concentration. Molar proportions of butyrate also increased linearly ($P < 0.01$) with increasing concentration of WDGS.

Based on the results of Luebbe et al. (2012) it was determined 15% WDGS was the optimum inclusion rate compared to 30, 45, and 60% WDGS for diets based on SFC. The cattle consuming 15% WDGS had a more favorable final BW, ADG, G:F, HCW, total tract digestibility, and rumen fermentation characteristics compared to the other WDGS treatment diets. The SFC diet with no WDGS was superior to the 15% WDGS diet with respect to animal performance, but taking into consideration the potential economic cost of WDGS, feeding 15% WDGS may be superior to feeding no WDGS in SFC based on cost of gain. When comparing the results of Luebbe et al. (2012) with the results of Vander Pol et al. (2006) is that Luebbe et al. (2012) used a blend of corn and sorghum WDGS (< 15% sorghum) while Vander Pol et al. used 100% corn WDGS.

Corrigan et al. (2009) conducted two experiments to examine the effects of corn processing method and corn WDGS inclusion level on feedlot performance, nutrient digestibility and rumen metabolism of finishing steers. A 168 day finishing experiment utilized 480 steers with corn processing method (DRC, HMC, SFC) and WDGS concentration (0, 15, 27.5, 40% DM basis) as two factors in the study. The optimum inclusion level of WDGS in HMC-based diets was 15 and 27.5%. Maximum ADG for steers consuming SFC-based diets was observed when 15% WDGS were included in the diet. An interaction between corn processing method and WDGS inclusion level ($P \leq 0.08$) was observed for HCW, dressing percentage, 12th rib fat thickness, KPH, USDA yield grade, and prevalence of liver abscess (Corrigan et al. 2009).

In experiment two of Corrigan et al. (2009), seven ruminally cannulated steers were used to compare corn processing method (DRC, HMC, or SFC) and WDGS inclusion (0 or 40% DM basis; Corrigan et al., 2009). Steers consuming DRC, and HMC with 0% WDGS had lower molar proportions of ruminal propionate than steers fed any other treatment diets. No differences ($P \geq 0.49$) in total ruminal VFA concentrations occurred in this study. In contrast, Luebbe et al. (2012) who reported a difference in total molar proportions of VFA as well as molar proportions of ruminal acetate. Results from Corrigan et al. (2009) show an interaction between corn processing method and WDGS concentration in finishing diets does exist. Results of this study suggest that optimal inclusion of WDGS occurs at 40, 15-27.5, and 15% of dietary DM for DRC, HMC, and SFC-based diets, respectively.

Corn vs. Sorghum Distillers Grains

Corn and sorghum are the predominate grains fermented to produce ethanol in the United States and the use of each is predominantly determined by geographical location of the ethanol plant, and the grain produced in that area. Corn is the primary grain crop in the Midwest, while sorghum is largely produced in the High Plains region of the United States. Expansion of the ethanol industry into the Southern High Plains region has caused an increase in the fermentation of sorghum grain. Depenbusch et al. (2009) conducted a study utilizing 299 steers comparing the effects of feeding 15% wet or dry corn WDGS, or 15% wet or dry sorghum WDGS with or without 6% alfalfa hay in SFC-based diets. Both the wet and dry corn WDGS treatment diets contained 6% alfalfa hay. Dry matter intake, ADG, and G: F were not different ($P \geq 0.33$) for steers consuming a diet with or without WDGS. Dry matter intake, ADG, G:F and apparent total tract digestibility were not different ($P \geq 0.12$) for steers consuming corn or sorghum WDGS. Hot carcass weight, LM, KPH and 12th rib fat thickness were not different ($P \geq 0.46$) for steers consuming corn or sorghum WDGS. Also, no difference ($P \geq 0.09$) was observed for marbling score, USDA yield and quality grade in steers fed corn or sorghum WDGS. Based on these results, the authors concluded that geographical location and distance from ethanol plants is the primary driver in type (corn or sorghum) of WDGS that will be utilized in feedlots.

Al-Suwaiegh et al. (2002) conducted an experiment to evaluate the energy values of 100% sorghum and 100% corn WDGS in finishing beef steers. The study utilized 60 yearlings steers fed DRC-based finishing diets that contained 0% WDGS, 30% corn or 30% sorghum WDGS. Dry matter intake for steers fed sorghum WDGS was greater (*P* <

0.02) than that of steers fed corn WDGS or the DRC-based control diet. No differences were observed for ADG or G: F ($P \geq 0.19$) for steers consuming either corn or sorghum WDGS. Furthermore, there was no difference ($P = 0.15$) in the NEg content between the corn WDGS and sorghum WDGS diet. While HCW differed ($P = 0.03$) between the control diet vs the corn and sorghum WDGS diets, there was no difference ($P = 0.37$) between the corn and sorghum WDGS diets. Source of DG did not seem to affect animal performance, even though the calculated NEg of the treatment diets were 1.43 and 1.39 Mcal/kg for the corn and sorghum WDGS treatment diets, respectively (Al-Suwaiegh et al., 2002).

May et al. (2010) conducted an experiment with 240 steers to evaluate the effects of adding 15 or 30% corn, sorghum, or a 50:50 blend of corn and sorghum WDGS as a source of protein and energy in SFC-based diets on feedlot cattle performance and carcass characteristics. Treatment diets were balanced for EE so that energy concentrations were not greater for diets containing WDGS, due to DG containing more EE than the ingredients that it replaces in the diet (cotton seed meal, SFC). Final BW and carcass adjusted final BW did not differ ($P = 0.13$) between corn and sorghum WDGS. However, cattle fed 15% WDGS had greater ($P = 0.04$) final BW and carcass adjusted final BW than cattle fed 30% WDGS. No differences were observed in ADG between sources of WDGS, which would concur with results of Al-Suwaiegh et al. (2002). Cattle consuming sorghum WDGS had greater DMI ($P = 0.05$) than cattle consuming the blended WDGS. Cattle consuming blended WDGS tended ($P = 0.09$) to have greater G:F than cattle consuming sorghum WDGS. Greater G:F was observed for the 15% WDGS compared to 30% regardless of source. Hot carcass weight decreased ($P = 0.03$) when

WDGS was increased from 15 to 30% of diet DM. However, feeding corn WDGS compared to sorghum or blended WDGS resulted in greater dressing percent. No differences were observed for marbling score, quality grade, or abscessed livers ($P >$ 0.10). Feeding corn WDGS resulted in greater calculated dietary NEm and NEg values than feeding sorghum and blended WDGS ($P = 0.05$). Also, feeding blended WDGS resulted in greater NEm and NEg values than feeding sorghum WDGS ($P < 0.01$; May et al. 2010). The authors concluded that with respect to DG source, the calculated net energy values for blended WDGS diet were greater than the values of sorghum WDGS alone but were numerically similar to corn WDGS and 0% WDGS control diet. The reason for the improved response by blending corn and sorghum WDGS remained unclear.

Owens (2008) stated that the increased lignin content of NDF from sorghum compared to corn grain may explain why NEg of the DG is lower. Conflicting research involving the energy content, and feeding value of corn compared to sorghum DG, warrants further research.

Corn Gluten Feed

Wet Milling Process

Corn gluten feed is a product of the wet milling industry and is considered a more complex process compared to dry milling (Stock et al. 2000). Corn gluten feed is not to be confused with corn gluten meal, which contains a much greater proportion of CP (~ 60%) that is primarily rumen undegradable protein, while the CP in CGF is highly degradable in the rumen (Stock et al. 2000). The primary goal of the wet milling process is to separate the starch from the corn grain. Starch can be sold as-is, or can be converted into corn syrup or high-fructose corn sweetener (Stock et al. 2000). Two fractions that are produced in the wet milling process are corn bran, and steep liquor. The bran and steep are combined to produce CGF that can be dried and sold, or sold as WCGF. Nutrient content of CGF can be variable due to different proportions of steep and bran used to produce CGF, due to these possible differences in production practices, CP in CGF can vary from 14 to 24% (Stock et al. 2000). Corn gluten feed also may contain distillers solubles, germ meal, and cracked corn screenings. Nutrient composition of CGF can vary widely yet tabular values from the NRC (2000) are as follows; 23.8% CP, 36.2% NDF, 3.9% fat, 0.07 % calcium, 0.95 % phosphorus, and 0.47% sulfur.

Krehbiel et al. (1995) conducted an acidosis challenge utilizing three ruminally fistulated steers. On the first day of each period, 10L of fluid was removed from the rumen of the steers and replaced with pooled rumen fluid from donor steers. During diet adaptation (d 1-11) steers were fed 3 different treatment diets; DRC-based diet with no WCGF, 50% DRC and 50% WCGF, and WCGF with no DRC. Corn silage and alfalfa were held constant across treatment diets (20% of diet DM). Donor steers were fed a diet of 33% DRC, 33% WCGF, 33% corn silage, and 1% supplement. A pH below 6.0 was used as a baseline to quantify total decrease in ruminal pH. Ruminal pH of steers dosed with 100% DRC declined from 3 to 15 h and did not return to initial values by 24h. Ruminal concentrations of acetate or butyrate were not different ($P > 0.10$) according to treatment. However, ruminal concentrations of propionate were greater ($P < 0.01$) for cattle dosed with 100% DRC compared to 100% WCGF or 50% DRC: 50% WCGF. Total decrease in ruminal pH over the 24-h sampling period was greater ($P < 0.05$) in steers dosed with 100% DRC than steers receiving 100% WCGF and 50% DRC: 50%

WCGF when pH was below 6.0. While WCGF did not completely eliminate the acidotic insult caused by dosing the concentrate, cattle dosed with 50 or 100% WCGF seemed to endure a shorter acidosis event compared to cattle dosed with 100% DRC. Substituting grain with highly digestible fiber found in WCGF reduced the time ruminal pH was below the threshold of 6.0 (Krehbiel et al., 1995).

Feeding Value

As previously discussed, grain processing has a significant impact on the feeding value of WDGS as grain is generally replaced in the diet. Scott et al. (2003) conducted two studies to determine the effect of corn processing method on performance and carcass traits in finishing steers fed WCGF. All treatment diets in trial one, excluding the DRC and SFC control diets, contained 32% WCGF (DM basis). Treatment diets in trial two, excluding the DRC and SFC control diets contained 22% WCGF. A total of 768 steers were used in the two experiments. Steers consuming WCGF had increased (P < 0.10) DMI and ADG compared to cattle consuming DRC or SFC without WCGF. Stock et al. (2003) reported feed efficiency was similar (P > 0.10) for cattle consuming SFC and SFC + WCGF, which could be cost effective when formulating diets due to the higher price of corn. Hot carcass weight also was increased (P < 0.10) by feeding WCGF. Furthermore, feeding SFC results in an increase (P < 0.10) in feed efficiency with or without the addition of WCGF compared with feeding DRC (Scott et al., 2003). However, results from Ponce et al. (2013) suggest that different bulk density of SFC (283, 335, or 386 g/L) does not affect animal performance when diets containing 25% WCGF are fed.

Fiber in Ruminant Diets

Characterization of Fiber

Cattle are far less efficient when compared to swine or poultry in terms of feed consumed per pound of gain (6:1, 3.4:1, 2:1, respectively; Reuter et al. 2013). Basal metabolism rate and maintenance energy requirements, primarily those associated with digestive metabolism is much greater for ruminants than for non-ruminants (Owens, 2008). Reduced gain efficiencies of ruminants compared to non-ruminants also exist due to inefficiencies of microbial fermentation when converting feed into volatile fatty acids, where approximately 6% of gross energy is lost as methane during the fermentation process (Owens, 2008). However, unlike mammals, microbes contain enzymes that cleave beta-bonds which are abundant in fibrous feedstuffs. A ruminant animal's ability to digest and furthermore utilize fiber is what makes the ruminant animal competitive with more efficient non-ruminant animals. Unrelated to feed efficiency, roughages may not be palatable for nonruminant species while palatability does not seem to be a limiting factor for ruminants consuming traditional roughage.

Fiber is an intricate matrix comprised primarily of cellulose, hemicellulose, lignin, and secondary components such as pectin, cutin, and silica. The concentrations of these compounds vary widely depending on species and maturity of plant. Cellulose digestibility is variable primarily due to the degree of lignification, and hemicellulose is more digestible than both cellulose and lignin (Van Soest, 1982). Like cellulose, the digestion and utilization of hemicellulose by ruminants is dependent upon the degree of lignification of the hemicellulose, in other words lignin is most closely associated with hemicellulose (Van Soest, 1982). Lignin is the chemical component of fiber that is most frequently associated with nutrient indigestibility (Church, 1988). Lignin is a rigid molecule that gives plant cell walls structure and stability, thus lignin content is typically increased as plants mature.

Today we use the detergent system to measure fiber in a laboratory setting (Van Soest, 1982). The detergent portions of fiber are in two distinct classifications, NDF and ADF. Residue from NDF analysis is primarily composed of hemicellulose, cellulose, and lignin, while ADF residue is primarily composed of cellulose and lignin. Neutral detergent fiber is viewed as a more accurate representation of whole fiber when compared to crude fiber, which does not completely recover cellulose (Van Soest, 1982). Acid detergent fiber residue represents a less digestible portion of the fiber fraction and is useful for sequential estimations of lignin and cellulose (Van Soest, 1982).

The detergent fiber system has allowed the further classification fiber and generation of accurate and repeatable results in a laboratory setting. While the proportions of hemicellulose, cellulose, and lignin are useful for obtaining an estimate of digestibility, they do not attempt to make any explanation of the effectiveness of fiber in ruminant diets. Effectiveness can be defined simply as the fiber's ability to cause the animal to ruminate, which is necessary for proper rumen function, and maximum digestibility of fiber (Mertens 1997). Rumination through mastication physically breaks down feed, increasing the surface area for microbial attack in the rumen, as well as stimulates saliva production which buffers the rumen environment. Attempts have been made to classify the effectiveness of fiber, primarily in the dairy industry where roughage and fiber are much larger constituents of the diet compared to diets fed in beef finishing diets. Mertens (1997) proposed definitions for effective NDF (**eNDF**) as the sum total ability of a feed to replace roughage so that the percentage of fat in milk is effectively maintained, and physically effective NDF (**peNDF**) as the physical properties of a fiber within a feed (primarily particle size) that stimulates chewing activity and establishes the biphasic stratification of ruminal contents, or the fiber mat.

Roughage Fiber vs. By-product Fiber

The above discussion regards the fiber found in plant material. One could argue that ruminants today live in the "by-product era" where many fibrous by-products are available to producers, such as WDGS and WCGF. The by-products are derived from multiple plant and grain species, and their fiber characteristics may not be the same as traditional roughage sources. Firkins (1997) indicated that rates of NDF digestibility from by-products such as WDGS and WCGF are similar to or less than the NDF digestibly from traditional sources of roughage such as silage and alfalfa hay. One possible explanation for this is differences in retention time in the rumen. More or less, roughages are bulky feed ingredients that require mastication and digestive break down to escape from the rumen, while fibrous by-products have a small particle size that may require little to no mastication to escape the rumen.

Galyean and Hubbert (2014) stated that based on changes in DMI when by-products are added to feedlot diets, fiber in WCGF seems to have more roughage value than fiber in WDGS, but neither are capable of fully replacing traditional roughages without sacrificing animal performance, especially in diets containing rapidly fermentable grains such as SFC.

Fiber in Beef Growing Diets

In most cases, roughage has been the primary constituent of the diet consumed by cattle entering the feedlot. Once in the feedlot, cattle are adapted to grain over a 21-28 d period, generally by replacing roughage in the diet with grain, but other adaptation methods exist (Krehbiel, 2006). Adapting cattle to grain over a shorter period of time (i.e., 14 d) has proved to detrimentally impact feedlot performance (Brown et al., 2006). However, some cattle received into the feedlot are not immediately adapted to a high concentrate diet, as it may be beneficial to temper growth of cattle for a period of time to not fatten them too early. Swingle (1995) stated dietary energy concentration needs to match production goals. If production goals are to temper growth, roughage can be included in the diet to dilute dietary energy density (Galyean and Hubbert, 2014). In most cases, roughage is included in greater amounts in growing diets compared to finishing diets, but there are now exceptions, such as feeding high levels of WCGF in the place of roughage (MacDonald and Luebbe, 2012; Galyean and Hubbert, 2014).

Fiber in Beef Finishing Diets

Forages are more expensive than concentrates on an energy basis, therefore to increase the energy density of feedlot diets lower amounts of roughages are fed (0-13% DM basis; Vasconcelos and Galyean, 2007). Compared to forages, concentrates yield a greater amount of propionate, which is more metabolically favorable compared to acetate, with no carbon from glucose lost as methane (Owens, 2008). Also, propionate can lead to intramuscular fat deposition while acetate can lead to intermuscular fat deposition with little intramuscular fat deposition (Fluharty, 2003; Smith and Crouse, 1985). Beef with a greater degree of intramuscular fat deposition, enough to grade USDA

Choice or greater, has significant price premiums and increased consumer demand compared to beef that does not contain sufficient intramuscular fat to grade USDA Choice or greater. Increasing roughage content of the diet (up to 24% DM basis) has shown to increase DMI (Galyean and Defoor, 2003). In diets without the addition of distillers grains, adding roughage up to approximately 15% of dietary DM typically results in increased DMI (Kreikemeier et al. 1990; Defoor et al. 2002). With efficiency of gain held constant, as DMI increases, ADG increases; therefore, DMI can significantly impact feedlot profitability.

Effects of Fiber on Intake

Many factors influence intake of ruminants such as: palatability, passage rate, and digestibility (Church, 1988). Nonetheless, intake is essentially controlled by: 1) physical fill (in the case of high roughage diets) or 2) energy density of the diet (high concentrate diets; Church, 1988). It is thought that distension of the reticulum provides a satiety signal with roughage diets, while acetate in digesta and propionate in ruminal veins or in the liver trigger a satiety signal in high quality roughage and high concentrate diets (Church, 1988). Adding roughage (NDF) to a high concentrate diet essentially dilutes the energy density of the diet. Swingle (1995) stated that energy density must meet production goals and allow cattle to fulfill their genetic potential. Swingle (1995) outlined energy density and its relation to DMI by dividing dietary energy density into three distinct zones. In the first zone energy density is low, and intake cannot increase enough to meet the animal's gain potential. This would be the case of high roughage diets where physical fill is the limiting factor. In the second zone, intake can change to compensate for variation in dietary energy density. In this zone, as energy density increases, efficiency of gain also increases. In the third zone, dry matter intake compensation relative to energy density is imperfect. In this zone cattle can potentially overconsume feed, which can create digestive upset and a reduction in feed intake. Galyean and Hubbert (2014) stated that the roughage (or NDF) concentration at which physical fill restricts intake is not well defined, and research is needed to identify the level below the point of physical restriction so that small changes in NDF will stimulate DMI and NEg intake.

Depenbusch et al. (2009) fed 0 or 6% alfalfa hay in SFC-based diets with 15% wet or dry sorghum WDGS and reported that final BW, ADG, and DMI were decreased ($P = 0.01$) when roughage was removed from the diet. These results would indicate that the NDF in DG cannot replace the NDF in alfalfa completely without sacrificing performance. May et al. (2011) fed three levels of alfalfa hay (7.5, 10, or 12.5% DM basis) in SFC based diets with 15 or 30% WDGS along with a control diet that contained 10% alfalfa and no WDGS. Dry matter intake increased ($P = 0.05$) with increasing amounts of alfalfa hay with no effect on ADG. Quinn et al. (2011) fed SFC-based diets with 15 or 30% WDGS. Roughages included alfalfa hay, bermudagrass hay, and sorghum silage. They were included in the diet to match the NDF (from alfalfa) of the 7.5% alfalfa hay diet in May et al. (2011). DMI did not differ ($P > 0.10$) among the three roughage sources in diets containing 30% WDGS. However, cattle fed the 15% WDGS diet with sorghum silage had greater ($P = 0.02$) DMI than those fed alfalfa or bermudagrass hay with 15 or 30% WDGS (Quinn et al., 2011). Overall, cattle fed 15% WDGS had greater DMI than those consuming 30% WDGS (Quinn et al., 2011).

Parsons et al. (2007) fed 40% WCGF in SFC-based diets with 0, 4.5, or 9% alfalfa hay. As roughage was removed from the diet, DMI and ADG decreased linearly ($P = 0.01$). Using diets based on DRC, Farran et al. (2006) fed 0 or 35% WCGF with 0, 3.75, or 7.5% alfalfa hay. Dry matter intake and ADG linearly increased ($P = 0.01$, 0.03, respectively) as dietary inclusion of alfalfa hay increased. Dry matter intake was greater ($P < 0.01$) for steers consuming 35% WCGF compared to steers fed 0% WCGF. These results indicate that WCGF can partially, but not fully, replace roughage in the diet. Galyean and Hubbert (2014) concluded in their review that NDF from WDGS or WCGF did not seem to have a large enough roughage replacement value to warrant removing substantial portions of traditional fiber from the diet, especially in diets based on SFC.

Forage Processing

Mechanical Processing of Forage

As previously stated, roughages are included in low amounts in finishing diets to stimulate rumination and promote rumen health. Long bulky forages do not mix well with grains and by-products, compared to roughages that are much smaller in particle size, and also require greater input cost, larger storage space, and less efficient transportation from field to feedlot. Roughages included in feedlot rations at any amount are generally mechanically processed by grinding to improve mixing characteristics, and decrease sorting at the bunk. In addition to improving mixing characteristics, grinding also improves digestibility of roughages, increasing surface area and allowing microbes in the rumen more sites of attachment, much like the action of mastication (Church, 1988).

Minimal feedlot research has been devoted to evaluating the particle size of ground roughages, which remains primarily dairy based information. Woodford and

Murphy (1988) fed three 60% concentrate diets to multiparous Holstein dairy cows with dietary roughage consisted of: 40% alfalfa haylage; 28% alfalfa haylage and 12% alfalfa pellets; or 12% alfalfa haylage and 28% alfalfa pellets on a DM basis. The alfalfa haylage and pellet were similar in gross chemical composition, but were very different in physical form. Cows consuming all haylage and 28% haylage and 12% pellet consumed similar ($P > 0.05$) amounts of DM, but more DM ($P < 0.05$) than cows consuming 12% haylage and 28% pellet (23.2, 23.1, 18.8 kg, respectively). Total chewing time also was different ($P < 0.05$). Cows consuming only haylage as a roughage source chewed for 650 min/d and produced 33.7 kg of milk a day, while cows consuming 28% haylage and 12% pellet chewed for 560 min/d and produced 35.5 kg of milk a day, and cows consuming 12% haylage and 28% pellet chewed for 380 min/d and produced 31.8 kg of milk a day. These results indicate that dairy cattle in early lactation require effective dietary fiber, and chewing time positively correlated to haylage intake. Alfalfa haylage proved to be more effective at stimulating chewing activity compared to alfalfa pellets. A clear relationship between chewing time and milk production was not evident in this study; however, results suggest that cattle require effective fiber to increase milk with the cattle consuming the least amount of haylage producing the lowest quantity of milk (Woodford and Murphy 1988).

Shain et al. (1999) conducted two feeding experiments to evaluate forage source and particle size on performance and ruminal metabolism of beef steers. In the first experiment, treatment diets consisted of cattle receiving an all-concentrate DRC-based diet or diets containing 10% alfalfa hay or 5.2% wheat straw with each forage ground to pass through a 0.95, 7.6, or 12.7 cm screen. Diets containing roughage were balanced to provide equal NDF concentrations. Cattle consuming all concentrate consumed less ($P < 0.05$) DM than cattle consuming wheat straw or alfalfa hay (10.43, 11.66, and 11.59 kg, respectively). Daily gain was greatest ($P < 0.05$) for cattle consuming alfalfa hay compared to cattle consuming wheat straw or all-concentrate (1.74, 1.61, and 1.52 kg, respectively). Steers consuming alfalfa hay were more efficient ($P < 0.05$) than steers consuming wheat straw. Hot carcass weight also was greater ($P < 0.05$) for steers consuming alfalfa, intermediate for steers consuming wheat straw, and lowest for steers consuming all-concentrate (321, 314, 308 kg, respectively). No differences were observed in DMI, daily gain, or HCW for steers fed roughages ground to pass through a 0.95, 7.6, or 12.7 cm screen. In the second experiment of Shain et al. (1999), two treatment diets were fed that consisted of: 80% DRC, 5% molasses, 5% dry supplement, and 10% alfalfa ground to pass through either a 0.95 or 7.6 cm screen. No differences in DMI, daily gain, gain efficiency, or HCW were observed for steers fed 0.95 or 7.6 cm ground alfalfa hay. Results indicate that forage particle size did not affect animal performance, while forage source did (Shain et al., 1999).

Chemical Processing of Forage

In addition to mechanical processing, or grinding, roughages also have been chemically processed, or treated to improve their digestibility. Most research that has been devoted to treating roughages has been applied to “low-quality” varieties, or those that are known to have a low digestibility (Klopfenstein, 1978). Chemicals used to treat roughages include: sodium hydroxide, ammonium hydroxide, calcium hydroxide, potassium hydroxide (Klopfenstein, 1978) and calcium oxide (Shreck et al., 2015). Modes of action of chemical treatment include: 1) solubilization of hemicellulose, 2) increasing the extent of cellulose and hemicellulose digestion, and 3) increasing the rate of cellulose and hemicellulose digestion, possibly by swelling (Klopfenstein, 1978). Research has shown that different plant residues may respond differently to chemical treatment (Klopfenstein, 1978).This is largely due to the degree of lignification of cellulose and hemicellulose (Van Soest, 1982). Furthermore, total lignin is not always a good indicator of lignification, such as in the case of legumes and grasses. Legumes contain more total lignin compared to grasses, but the lignin in legumes is more closely associated to the stem of the plant rather than the leaf, whereas in grasses the lignin is more or less distributed throughout the entire plant (Van Soest, 1982). Sodium hydroxide has been used more extensively than other hydroxide treatments (Klopfenstein, 1978), but its caustic nature could limit its acceptability in the feedlot industry due to growing safety concerns.

Shreck et al. (2015) utilized 336 yearling crossbred steers fed finishing diets with various crop residues (wheat straw, corn stover, or corn cobs) with or without chemical treatment (5% CaO DM basis). Treated crop residues were first mixed with water to increase the moisture content. The authors recommended that a feedstuff must have moisture content of 50% or greater to facilitate chemical treatment. The additional diet was a control with 46% DRC and 10% roughage (equal parts untreated wheat straw, corn stover, and corn cobs). All diets contained 40% WDGS and 20% treated or untreated crop residues, excluding the control. Treated crop residues were allowed to set for 30 d before feeding began to allow adequate time for chemical breakdown of the fiber portion of the crop residues. There was an interaction between chemical treatment and crop residue ($P <$ 0.01) for carcass adjusted final BW, ADG, G:F, and HCW. No differences ($P = 0.12$) in

DMI was observed between all diets. Steers fed treated straw had 9.7% greater ADG, and steers fed treated corn stover had 12.5% greater ADG compared to untreated controls, respectively ($P < 0.05$). Steers fed treated straw and corn stover had greater ($P < 0.05$) final BW than steers fed untreated control diets. No difference in ADG or final BW was observed for steers fed treated or untreated corn cobs. Feed efficiency was greater ($P < 0.01$) for treated straw and stover compared to untreated controls. Hot carcass weight was greater ($P < 0.01$) for steers fed treated straw and corn stover compared to untreated controls. Diets containing corn cobs did not respond in the same manner to calcium oxide treatment. These results would agree with Klopfenstein (1978) that different residues may respond differently to chemical treatment.

In further consideration of Shreck et al. (2015), treated roughages were fed at 20% of dietary DM, which is greater than that seen in industry (Vasconcelos and Galyean, 2007). Roughage is included in finishing diets to promote rumination, buffering and rumen health. In low forage diets (< 15% diet DM), increased digestibility may not be favorable for proper rumen function. Chemical processing may be more desirable for high forage diets in growing or backgrounding beef cattle diets.

Chemical Processing of Grain

Berger et al. (1981) treated whole wheat, oats, barley, corn, and sorghum with 3 and 6% sodium hydroxide to determine the effects on *in situ* digestibility. The grains chosen were representative of grains fed across the feedlot industry. The authors hypothesized that chemical treatment would improve digestibility of whole grains due to hemicellulose being a large portion of the seed coat of most cereal grains. At the 3% treatment level, *in situ* digestibility (**ISD**) was increased by 64 % for treated compared to untreated wheat. Treated sorghum grain showed the least amount of improvement, with an 11% increase in ISD compared to untreated sorghum grain. Treated corn, oats, and barley showed an approximate 20% increase in ISD compared to untreated controls. Across grain type when treated with 6% NaOH, ISD increased 28% compared to the 3% treatment level. The results indicate that alkali treatment allowed better access to the starch within the grain by rumen microbes. Alkali treatment has shown promising results in regards to treating fiber found in forages, as well as breaking down fiber in the seed coat of cereal grains. One can speculate the potential benefits in alkali treatment of fibrous by-products, knowing that a considerable portion of these by-products are the seed coats of grains remaining after the removal of starch.

Standardization of Roughage for Finishing Cattle

Characterization of Fiber

Dietary NDF does not always elicit the same responses (Mertens 1997; Galyean and Hubbert, 2014). Dietary NDF can be provided by multiple fibrous by-products, traditional roughages, and most likely a combination of both. From a chemical sense, NDF from by-products is the same as NDF from forage. However, the differences in physical structure play a large role in the ultimate effectiveness of the fiber (Mertens, 1997). When considering traditional fiber sources, variation is present in the physical form of the roughage. Consider ground alfalfa compared to ground corn stalks, or the variability within corn stalks that were ground through a commercial tub grinder.

This variability has led to a need to further classify and standardize fiber characteristics for finishing cattle. Again, eNDF is the sum total ability of a feed to replace roughage so that the percentage of fat in milk is effectively maintained, and peNDF is the physical properties of fiber within a feed (primarily particle size) that stimulates chewing activity and establishes the biphasic stratification of ruminal contents, or the fiber mat (Mertens, 1997). Effective NDF is a unique concept in that it does not take into consideration the physical attributes of the fiber. Examining tabular feedstuff values in the NRC (2000), most traditional forages such as corn stalks, alfalfa hay, and various silages have relatively high (>80%) eNDF value. This is not surprising relative to standard roughages, but feedstuffs such as CGF have an eNDF of 36% when they appear very similar to the physical from of WDGS, and WDGS have an eNDF of 4% (NRC, 2000). Both are high protein, fibrous by-products that result from the wet or dry milling of corn, yet replace fiber and effect milk fat percentage very differently (Armentano and Pereira, 1997; Mertens, 1997).With extensive forage research available, the dairy industry has a far better understanding of fiber than the beef industry. If the best characterization of forage that is required by a finishing animal can be determined, profits can potentially be maximized due to the cost of roughage compared to concentrates on the basis of energy. However, this is a very complex situation. The effectiveness of roughage is not only dependent on roughage inclusion rate but is also dependent on other factors such as source and particle size (Mertens, 1997).

Due to the fact that feedlot cattle may not fit equations modeled with dairy cattle, eNDF cannot be directly measured in a feedlot setting. Of course, one could argue that if a feed is able to maintain milk fat percentage in dairy cattle, the feed may be able to maintain growth performance in beef cattle, but the assumption is inaccurate. Physically effective NDF, can be measured in both dairy and beef cattle directly by chewing activity, and estimated by particle size determination through sieving techniques (Mertens, 1997); however minimal research contains these specific measurements.

Estimating peNDF

True peNDF can only be measured through live animal observation and chewing time; however, it is possible to estimate peNDF in a laboratory setting (Mertens, 1997). Estimation of peNDF can be obtained by using sieving mechanisms such as the Penn State Particle Seperator (**PSPS**; Heinrichs and Kononoff, 2002; Mertens, 1997; Beauchemin and Yang, 2005). The amount of feed that remains above the 1.18 mm screen (as a percentage of the total; the third sieve of the PSPS) is termed the physical effective factor (**pef**) and multiplied by percent NDF of the feedstuff. The 1.18 mm sieve was chosen due to Poppi and Norton (1980) concluding that 1.18 mm is the critical size for particles to be retained in the reticulorumen, and 1 to 3% of particles in feces were greater than 1.18 mm.

Chewing Activity

Neutral detergent fiber content of a diet is not the best indicator of how much the existing fiber will stimulate the animal to chew (Armentano and Pereira, 1997); therefore, chewing activity must be directly measured. Shain et al. (1999) conducted a metabolism study to evaluate the effects of forage source (alfalfa or wheat straw) and particle size (2.54 or 12.7 cm) on rumination behavior. Particle size did not affect chewing time; however, chewing time for alfalfa hay and wheat straw were different ($P < 0.10$). Cattle that consumed all-concentrate with no dietary roughage only chewed for 177 min/d while cattle consuming alfalfa chewed for approximately 300 min/d and cattle consuming wheat straw chewed for approximately 360 min/d. These results suggest that concentrate has little roughage value, and that wheat straw is a more physically effective form of fiber compared to alfalfa hay.

Cows consuming sufficient dietary NDF without a sufficient proportion of long roughage particles can exhibit the same metabolic disorders as cows consuming a diet deficient in dietary NDF (Fahey and Berger, 1988). This emphasizes the importance of peNDF in ruminant diets. Beauchemin and Yang (2005) used 6 lactating ruminally cannulated Holstein cows to determine the effects of peNDF on intake, chewing activity, and ruminal acidosis. Diets contained corn silage that was processed to 3 different lengths (long, medium, and fine) to represent 3 different values for peNDF. All diets were compositionally identical and contained 58% concentrate and 42% corn silage. The estimated peNDF (determined by sieving and corrected for orts) was 12.3, 11.1, and 10.1% for the long, medium, and fine corn silage diets, respectively. One could speculate that these peNDF values for the treatment diets may not be different enough to elicit a detectible animal response. Dry matter intake was not affected ($P > 0.15$) by peNDF, however total chewing time within a day was different ($P < 0.10$) for cows consuming long, medium, or fine corn silage. Total chewing time decreased linearly ($P = 0.02$) as corn silage particle size was decreased (783.3, 768.1, and 701.8 min/d for the long, medium, and short corn silage, respectively). Ruminal pH was not affected ($P > 0.15$) by corn silage particle size. Results indicate that chewing time increased as particle size increased, but did not affect ruminal buffering capacity. However, the concentrate level used in this study may have not been high enough for a substantial decrease in rumen pH. Further research is needed to standardize roughage in finishing diets; chewing and particle separation are needed to further classify fiber, since observed animal responses, rather than laboratory assumptions have proven to be more accurate in predicting animal performance. This information will guide us to more efficiently utilize our fiber resources.

Therefore the objectives of the current thesis research presented in subsequent chapters are to:

1) Determine the effects of treating sorghum WDGS with an alkaline chemical on nutrient digestibility and fermentation characteristics of beef steers.
2) Examine the effects of performance, carcass characteristics, and rumination behavior in finishing beef cattle fed various inclusion rates and particle sizes of corn stalks.
3) Begin to standardize the appropriate level of peNDF for finishing beef cattle to optimize performance while maintaining rumen health.

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CHAPTER II

INVESTIGATING RUMINANT DIGESTIVE CHARACTERISTICS OF CALCIUM HYDROXIDE TREATED SORGHUM WET DISTILLERS GRAINS AND CORN STALKS

Introduction

Ethanol production utilizes various grain sources across the United States. Ethanol plants in the upper Midwest utilize primarily corn grain, whereas ethanol plants in the Southern Great Plains utilize both corn and sorghum grain. One explanation is that sorghum is routinely grown in the Southern Great Plains largely due to lower annual precipitation, and decreased water requirements of sorghum vs. corn (Ahamadou et al., 2012). While there is conflicting research, it is generally accepted that wet distillers grains (**WDG**) produced from the fermentation of sorghum has a lower feeding value than WDG produced from the fermentation of corn (Owens, 2008). Owens (2008) suggested this may be partially due to the lower digestibility of the fiber fraction in sorghum wet distillers grains plus solubles **(SWDGS**) than corn wet distillers grains plus solubles (**CWDGS**). Chemical treatment of low-quality forage or crop residues has increased DM and OM digestibility, which is the result of breaking hemicellulose and cellulose-lignin bonds in the fiber fraction of the crop residues (Klopfenstein, 1978). Shreck et al. (2015) fed dry rolled corn (**DRC**) -based diets with 40% WDGS and 20% roughage treated with calcium oxide (5% DM basis), or untreated roughage to finishing beef steers and observed a 9.7 and 12.5% increase in ADG for steers consuming calcium oxide treated wheat straw and corn stover, respectively. The feeding value of SWDGS has the potential to be increased by chemical treatments sometimes used for forage. Berger et al. (1981) demonstrated an 11 and 28% increase in digestibility of whole sorghum grain treated with 3 and 6% sodium hydroxide, respectively. In beef finishing diets, wet distillers grain (**WDG**) frequently replaces grain in the diet. As a result, starch is replaced by fiber which makes fiber digestibility of WDG critical to its feeding value (MacDonald, 2011). Wet DG is composed primarily of the grain seed coat which is high in hemicellulose content after removal of starch (Berger et al., 1981). This makes WDG a good candidate for alkali treatment to increase fiber digestibility. Due to being partially hydrated, calcium hydroxide (**CH**) may be a safer alkaline compound to utilize than CaO, because combustion is less likely to occur when added to hydrated biomass. Therefore, the objectives of this study were to evaluate the effects of treating SWDGS and corn stalks with CH on nutrient digestibility in diets based on steam-flaked corn (**SFC**).

Materials and Methods

Experiment 1

All procedures involving live animals were approved by the West Texas A&M University-CREET Animal Care and Use Committee (approval # 01-12-14).

Animals. This experiment was conducted at the Texas A&M AgriLife Research/ USDA-ARS Feedlot in Bushland TX. Three ruminally cannulated crossbred steers (BW = 621 ± 3.6 kg) were used to evaluate *in situ* digestibility of CH-treated or untreated corn stalks and SWDGS. Steers consumed a 65% concentrate SFC-based diet. Steers were individually fed twice daily in equal amounts so that BW was maintained (NRC, 2000) at 0700 and 1900 h, and had ad libitum access to water.

Dietary Treatments. The SWDGS used in this study were produced at Diamond Ethanol LLC in Levelland, TX from the fermentation of ≥ 90% sorghum grain. Treatments were arranged in a 2 × 2 factorial treatment structure with ingredient and CH treatment as factors. Treatments included: untreated SWDGS (**S**), CH-treated SWDGS (2.67 % DM basis; **S-CH**), untreated corn stalks (**C**), and CH-treated corn stalks (6.5% DM basis; **C-CH**). The SWDGS contained the necessary moisture (65%), to facilitate a chemical reaction whereas the corn stalks did not (8%). Shreck et al. (2015) recommended a moisture level of at least 50% when treating crop residues with CaO. Therefore, water was added to the corn stalks to achieve a 50% moisture concentration before the CH was applied. Potential effects on intake were taken into consideration when determining treatment level; therefore, the ingredients were treated at a level that corresponded to their expected DM inclusion rate in a finishing diet. The inclusion rate of SWDGS would likely be higher than that of corn stalks in a finishing diet, so they were treated at a lower level (2.67 vs. 6.5 %). Treatment ingredients were allowed to sit in sealed containers for 7 days befor use. The *in situ* procedures in this experiment were adapted from Vanzant et al. (1998). Forage bags (Ankom Technology, Macedon NY; 10 x 20 cm, 53 ± 15 μm pore size) were individually labeled with a solvent resistant permanent marker, and weights of the bag recorded. All samples were dried for 72 h in a forced-air oven at 55 °C (Despatch model LBB2-18-1, Minneapolis, MN). Samples were ground in a Wiley Mill (model 4, Thomas Scientific, Swedesboro, NJ) to pass a 2-mm screen, and then weighed into a forage bag (Ankom Technology). Five grams of ground sample were weighed in triplicate into forage bags and then sealed using an impulse sealer (American International Electric, model AIE-200). Triplicate forage bags containing each treatment were placed in mesh laundry bags for each steer according to time-point; therefore, there were three forage bags per treatment, per incubation time-point, per steer. Before ruminal incubation, bags were soaked in 39°C water for 20 min to decrease wetting lag time. After the soaking procedure, all bags (excluding 0 h) were placed in the ventral rumen space of three ruminally cannulated steers all at once. Bags were removed at 0, 6, 12, 24, 36, and 48 h of incubation. After removal from rumen, bags were rinsed until the water remained clear. The 0 h bag was rinsed after removal from the pre-incubation soak in water. All bags were dried for 72 h in a forced air oven at 55 °C and then placed in a desiccator before weighing. Triplicate bags from each incubation time, as well as samples that were not subject to incubation, were composited within animal for subsequent analysis of DM, OM, and NDF. Dry matter analysis was conducted by drying the sample in an oven (Precision Thelco, model 17, Precision Scientific, Chennai, India) at 100°C for 24 h. Samples were ashed in a muffle furnace (Thermolyne, model F-A730, Dubuque, IA) at 500 °C for 6 h to determine OM. Neutral detergent fiber concentration was analyzed using an Ankom fiber analyzer with sodium sulfite and amylase (model 200, Ankom Technologies, Fairport, NY). Prior to analyzing for NDF and ADF, S and S-CH samples were submerged in acetone for 10 minutes twice, due to EE being ≥ 5% in SWDGS.

Statistical Analysis. Compositing the sample bags within animal resulted in three observations per treatment per incubation time-point. *In situ* rumen DM, OM, and NDF degradation data were fitted into the first order exponential model with discrete lag (Mertens, 1977) using the iterative Marquardt method and the NLIN procedure of SAS (SAS Institute, Cary, NC). The model is as follows:

$$R_{(t)} = b \times \left(e^{-k_d\,(t-L)} \right) + c$$

Explanatory variables included: $R_{(t)}$ = total undigested residue at any time, t = time incubated in the rumen in h, b = potentially degradable fraction, c = undegradable fraction (fraction not digested after 48 h ruminal incubation), L = lag time, and k_d = fractional rate of digestion. Effective ruminal degradability (extent of digestion, **ERD**) was calculated using the model of Ørskov and McDonald (1979):

$$\text{ERD} = a + \{b \times \left[\frac{k_d}{k_d + k_p}\right]\}$$

Where k_p = assumed ruminal passage rate of 0.05, and a = immediately soluble fraction (percentage of substrate washed out of the bag at 0 h; b and k_d described above). The GLIMMIX procedure of SAS was utilized to compare $a, b, c, L, k,$ and ERD. Treatments means of each explanatory variable were separated by the LSMEANS statement with the PDIFF option with a protected F-test ($P \leq 0.05$), $P \leq 0.05$ was considered significant, and $P \leq 0.10$ to $P > 0.05$ were considered statistical trends. Main effects for this research were ingredient and CH treatment, and their interaction was included in the statistical model. However, corn stalks and SWDGS were assumed to degrade differently in the rumen. Therefore, comparisons within ingredient (untreated or treated) will be discussed.

Experiment 2

All procedures involving live animals were approved by the West Texas A&M University-CREET Animal Care and Use Committee (approval # 03-01-14).

Animals and Dietary Treatments. Six ruminally cannulated crossbred steers (444 ± 4.0 kg of BW) were used in a 3 × 3 replicated Latin square design with 21 d periods consisting of a 17 d adaptation period followed by a 4 d collection period. Dietary treatments (Table 2.4) were SFC-based finishing diets with 30% corn WDGS (**CDG**), sorghum WDGS (**SDG**), or CH-treated sorghum WDGS (2.67% DM basis CH; **SDG-CH**). The supplement did not contain calcium; therefore, limestone was included to supply calcium in the diets. The CH added to the SWDGS did not supply adequate calcium to meet animal requirements (NRC, 2000), or achieve calcium: phosphorus ratio of 2:1, so limestone was added to the SDG-CH diet as well. All of the WDG fed in this experiment were received in one day. The corn WDG were stored in a large plastic ag bag (Up North Plastics; Bag Man LLC, Hammond, WI), whereas SWDGS, and CH-treated SWDGS were stored in sealed plastic drums with liners and allowed to sit for 7 days before being fed. Diets were offered once daily at 0700 in an amount to achieve *ad libitum* intake. Steers were individually fed in 3.7 × 3.7-m concrete surface pens with a 2.4 × 3.7-m rubber mat placed for animal comfort. Pens were cleaned every day to eliminate manure build-up. Steers remained in the individual pens throughout the entire study. Animals were weighed at the beginning and end of each 21-d period.

Sampling. Diet samples and Orts were collected on d 17 through 21. Feed refusals were collected, weighed, and subsampled for nutrient analysis. Fecal output was estimated by dosing a 5-g bolus of chromic oxide twice daily (0700 and 1900 h) via the rumen cannula on d 13 through 21. Fecal samples were collected at 0600 and 1800 h on d 18 and 20, and at 1200 and 2400 h on d 19 and 21. Fecal samples were wet composited across the entire collection period by animal. Three 250-mL aliquots were prepared from the wet composite, and frozen at -4°C. Ruminal fluid samples also were collected on the same schedule, and strained through 4 layers of cheese cloth. Sample pH was immediately measured using a portable pH meter (VWR symphony, model H10P, Radnor, PA) and three 50-mL aliquots were retained and frozen at -4°C. Sampling was conducted in this manner so that the rumen cannula was only opened twice daily, with twelve hours between, to reduce the amount of oxygen that entered the rumen environment, and so that the rumen environment may stabilize between each sampling time-point.

Diet and Ort samples were dried in a forced air oven at 55°C for 48 h and fecal aliquots were lyophilized (Labconco, Kansas City, MO). Diet, Ort, and fecal samples were ground in a Wiley mill (model 4, Thomas Scientific, Swedesboro, NJ) to pass a 1-mm screen, and the remaining one-third was ground through a Cyclotec mill (Cyclotec CT 193, Foss, Hoganas, Sweden) to pass through a 0.5-mm screen.

Laboratory Analysis. Laboratory DM of diet, Ort, and fecal samples were determined by drying at 100°C for 24 h. Organic matter was determined by ashing samples in a muffle furnace (Thermolyne, model F-A730, Dubuque, IA) at 500 °C for 6 h. Starch content of diet, Ort, and fecal samples was determined using spectrophotometry (PowerWave-XS Spectrometer, Bio Tek US, Winooski, VT) after converting starch to glucose using an enzyme kit (Megazyme International Ireland Ltd., Wicklow, Ireland). Diet, Ort, and fecal samples were analyzed for NDF and ADF concentration using an Ankom fiber analyzer with sodium sulfite and amylase (Model 200, Ankom Technologies, Fairport, NY). Before analyzing for NDF and ADF, diet and ORT samples were submerged in acetone for 10 minutes twice because EE was assumed to be greater than 5%. Determination of EE was conducted on the feed and ort samples using petroleum ether in an automated EE extraction system (Ankom XT15 Extraction System, Ankom Technologies). Chromium concentration of fecal samples was determined by Inductively Coupled Plasma Mass Spectrometry (ICP-MS; Qtegra, ThermoFisher Scientific, Waltham MA). Fecal output (g/d) was calculated as chromium dose (g/d) divided by the fecal chromium concentration (g/g; Owens and Hanson, 1992). Ruminal fluid samples were analyzed for VFA using gas chromatography (Varian 3900, Varian Inc. Palo Alto, CA) according to the procedures of Erwin et al. (1961). Ruminal ammonia concentration was determined using procedures outlined by Broderick and Kang (1980) and quantified using a spectrophotometer (PowerWave-XS Spectrometer, Bio Tek US, Winooski, VT) at a wavelength of 550 nm. Total N concentration was determined using the Dumas combustion method for N analysis (Vario Max CN, Elementar Americas Inc., Mt. Laurel, NJ).

Statistical Analysis. One animal was removed from period three of the experiment due to cannula issues unrelated to treatment. To account for missing observations, the Kenward Roger denominator degrees of freedom method was used. Nutrient digestibility data were analyzed as a replicated Latin square with three dietary treatments and three periods using the MIXED procedure of SAS (SAS Institute, Cary, NC) with animal within square as the experimental unit. The LSMEANS statement with PDIFF option was used to separate treatment means with a protected F-test ($P \leq 0.05$). The model consisted of animal, square, period, and dietary treatment. Square and animal within square were random effects. Because ruminal fluid samples were kept separate according to time-point, the pH, VFA, and ruminal ammonia model additionally contained time and treatment × time effects. Effects were considered significant at a $P \leq 0.05$, and $P \leq 0.10$ to $P > 0.05$ considered a trend.

Results and Discussion

Experiment 1

Dry Matter Degradability. Dry matter degradation data is presented in Table 2.1. Due to a concentrate and roughage comparison, relationships between S vs. S-CH and C vs. C-CH will be discussed. No differences were observed for the immediately soluble fraction (*a*) of DM for C and C-CH ($P = 0.19$) or for S and S-CH ($P = 0.99$). The potentially degradable fraction (*b*) of DM was similar for S and S-CH ($P = 0.75$), but tended to be greater for C-CH than C ($P = 0.06$). Untreated corn stalks contained a greater ($P = 0.01$) undegradable fraction (*c*) of DM than C-CH, with no differences ($P = 0.67$) between S and S-CH. No difference was observed for discrete lag time (*L*) of DM between C and C-CH ($P = 0.27$) or for S and S-CH ($P = 0.91$). Fractional rate of digestion (k_d) of DM was greater ($P = 0.01$) for C than C-CH, with no difference ($P = 0.99$) between S and S-CH. Effective ruminal degradability (ERD) of DM was greater ($P < 0.01$) for C-CH than C, with no difference ($P = 0.38$) between S and S-CH. Effective ruminal degradability of C-CH and C reported in this study agree with the results of Shreck et al. (2015). They reported an increase in DM apparent total tract digestibility of treated corn stover (5% CaO, DM basis) compared to untreated corn stover (74.5, and 63.2 %, respectively). Overall, no differences ($P > 0.05$) were observed between S and S-CH, while differences between C and C-CH for the undegradable fraction (*c*) of DM, fractional rate of digestion (k_d) of DM, and ERD were observed ($P < 0.01$).

Increases in degradability and digestibility are well documented in corn stalks treated with alkaline bases (Klopfenstein, 1978), but to our knowledge this is the first attempt at treating sorghum WDG chemically. Using an alkaline compound may provide benefits other than treating the fiber fraction of the feedstuff; it may also be used as a buffering agent to increase the pH of the feedstuff. Berger et al. (1981) observed an 11% increase in the *in situ* digestibility of sorghum grain treated with 3% sodium hydroxide compared to reconstituted sorghum grain (31.7, and 20.3 % respectively). The increase in digestibility observed by Berger et al. (1981) is likely due to the increased accessibility of microbial enzymes to starch within the grain; whereas, in this study DG were used which are assumed to contain little to no starch. Ethanol production may maximize fiber break down to a point where further chemical treatment has little notable effect on the fiber portion of SWDGS, or chemical treatment concentration need to be increased. Increasing the concentration of alkali treatment may negatively affect palatability and mineral content of the ingredient or diet.

Organic Matter Degradability. We were unable to fit the model correctly for C OM and C NDF, the parameters converged, but overestimated k_d to nonrealistic values, therefore we could not calculate ERD for untreated corn stalks. For this reason values for k_d and ERD for C were not reported. Organic matter degradation data is presented in Table 2.2. No differences were observed for the immediately soluble fraction (a) of OM between S and S-CH ($P = 0.64$) or between C and C-CH ($P = 0.58$). The potentially degradable fraction (b) of OM was greater ($P = 0.02$) for C-CH than C, with no differences ($P = 0.50$) between S-CH and S. No differences ($P = 0.31$) were observed for the undegradable fraction (c) of OM between S and S-CH, however C was more undegradable ($P = 0.02$) than C-CH. Discrete lag time (L) of OM was greater ($P < 0.01$) for C than C-CH, with no difference ($P = 0.99$) between S and S-CH. No differences ($P \geq 0.27$) in fractional rate of digestion (k) or ERD of OM between S and S-CH were observed. Similar to that of DM, no differences ($P > 0.05$) were observed for any parameter of OM digestion between S and S-CH; whereas, increases in degradability were evident when comparing C-CH to C. Following the same trend as the values reported for DM apparent total tract digestibility, Shreck et al. (2015) reported an increase in OM apparent total tract digestibility for treated (5% CaO DM basis) corn stover compared to an untreated control (78.4, and 66.3 %, respectively). Interestingly, the values observed for C-CH were often intermediate of those observed for C and S or S-CH (Table 2.2) which illustrates that degradability of corn stalks, can be increased by CH treatment; whereas, SWDGS did not benefit from 2.67 % CH treatment. This may have been a result of the corn stalks being treated at a higher rate (6.5% DM basis) than SWDGS.

Neutral Detergent Fiber Degradability. Neutral detergent fiber degradation data is presented in Table 2.3. No differences ($P = 0.45$) were observed for the immediately soluble fraction (a) of NDF between S and S-CH or C and C-CH. Similarly, no differences were observed for the potentially degradable fraction (b) of NDF for S and S-CH ($P = 0.22$) or between C and C-CH ($P = 0.14$). The undegradable fraction (c) was not different ($P = 0.22$) for S and S-CH, but a tendency ($P = 0.06$) was observed for C to be greater than C-CH. Discrete lag time (L) of NDF for C was greater ($P < 0.01$) than C-CH, with no difference between S and S-CH. As noted previously, we did not obtain values for fractional rate of digestion and ERD of NDF for C due to non-convergence of the model. No differences (P = 0.73) were observed in the fractional rate of digestion (k) of NDF for S and S-CH. Effective ruminal degradation of NDF was greater (P = 0.04) for S than S-CH. Luebbe et al. (2012) reported a linear increase in ruminal NDF digestibility as WDGS concentration increased from 15 to 60 % dietary DM (30.6, and 43.7%, respectively). The linear increase in ruminal NDF digestibility may have been a product of a linear increase in NDF intake (1.74, and 2.63 kg/d, respectively). It is puzzling why this response occurred in our study. According to the mechanisms of action of alkaline treatment of fiber outlined by Klopfenstein (1978), alkaline treatment should increase the digestibility of NDF. One potential explanation could be that the SWDGS were not treated at a high enough level with CH (treatment level was 2.67% DM basis) for increases in ERD to occur. Data utilizing sodium hydroxide and roughage suggest that the level of treatment for best response in the animal ranges from 3 to 5% (DM basis; Klopfenstein, 1978). Minimal research exists with alkali treatment of WDGS to increase their feeding value. Inclusion rate of the treated ingredient restricts chemical treatment concentration. For example, WDGS included in the diet at a rate of 15% dietary DM could be chemically treated to a greater degree than WDGS included in the diet at a rate of 40% dietary DM. Treating an ingredient at a high level with an alkaline bases such as CH coupled with a high dietary inclusion rate may result in over supply of calcium or potential depression in feed intake.

Experiment 2

Nutrient Intake and Digestibility. Nutrient intake, output, and digestibility are presented in Table 2.5. Dry matter intake, was not different (P = 0.47) for steers consuming CDG, SDG, or SDG-CH. Similar intakes of steers consuming CDG and SDG agree with those of steers consuming the 30% WDGS in Luebbe et al. (2012), and May et al. (2010). There also were no differences ($P \geq 0.13$) in OM, NDF, starch, or nitrogen intake of steers consuming CDG, SDG, or SDG-CH. However, ADF intake was greater ($P < 0.01$) for steers consuming SDG and SDG-CH than steers consuming CDG. This difference was most likely due to the greater ADF content of SWDGS compared to CWDGS.

No differences ($P \geq 0.16$) were observed for fecal output of DM, OM, ADF, starch or nitrogen for steers consuming CDG, SDG, or SDG-CH diets. Fecal OM for steers consuming SDG-CH is similar to fecal outputs reported by Luebbe et al. (2012). However, a tendency ($P = 0.07$) was observed for steers consuming SDG-CH having lower fecal NDF excretion than steers consuming CDG, and steers consuming SDG-CH tended ($P = 0.07$) to have a lower fecal NDF excretion than steers consuming SDG. Overall, the values for fecal output of NDF in this study were lower than those observed by Luebbe et al. (2012) for steers consuming 30% WDGS (1.20 kg/d).

No differences ($P \geq 0.15$) were observed for apparent total tract digestibility of DM, OM, ADF, starch, or nitrogen for steers consuming CDG, SDG, or SDG-CH. May et al. (2010) observed no differences in apparent total tract digestibility of DM, OM, and starch for steers consuming 15% corn or sorghum WDGS in SFC-based diets. Similarly, Depenbusch et al. (2009) reported no difference in apparent total tract digestibility of DM or OM for steers consuming 15% corn or sorghum WDGS in SFC-based diets. Luebbe et al. (2012) reported a linear decrease in apparent total tract digestibility of OM as WDGS concentration in the diet increased. It seems that concentration, rather than source, impacts the apparent total tract digestibility of WDGS. Steers consuming SDG-CH tended ($P = 0.07$) to have a greater apparent total tract digestibility of NDF than steers consuming CDG, with steers consuming SDG being intermediate of the two. The values for apparent total tract digestibility of NDF for the steers consuming CDG and SDG in this study align closely with those reported in Luebbe et al. (2012). Furthermore, Shreck et al. (2015) reported an increase in apparent total tract digestibility for steers consuming 20% treated (5% CaO, DM basis) wheat straw and corn stover compared to untreated controls.

Ruminal Fermentation Characteristics. A treatment effect for ruminal pH was observed ($P < 0.01$). Steers consuming SDG had the greatest ruminal pH; whereas, steers consuming CDG had the least, with steers consuming SDG-CH being intermediate. In contrast, other studies where multiple levels of WDGS and different corn processing methods were used reported no difference in average ruminal pH (Corrigan et al, 2009; Luebbe et al. 2012). The differences in pH indicate a greater ruminal acid concentration, as noted in total VFA concentration. Steers consuming CDG had the greatest ($P < 0.01$) total VFA concentration, followed by steers consuming SDG-CH and SDG. Total VFA concentrations for steers consuming SDG-CH are similar to those reported by Corrigan et al. (2009).

Ruminal acetate molar proportions were greater ($P < 0.01$) for steers consuming SDG and SDG-CH than steers fed CDG. Ruminal acetate molar proportions for SDG and SDG-CH are similar to those reported by Luebbe et al. (2012). In contrast, Al-Suwaiegh et al. (2002) reported no difference in ruminal acetate concentration between corn and sorghum WDGS fed at 15% diet DM in DRC-based diets. Ruminal propionate molar proportion was greatest ($P < 0.01$) for steers fed CDG compared to steers fed SDG or

SDG-CH. Furthermore, a significant difference (*P* < 0.01) in the acetate: propionate (A:P) ratio with steers consuming CDG having the lowest, steers fed SDG the highest, and steers consuming SDG-CH being intermediate of the two. No difference (*P* = 0.22) was observed for isobutyrate molar proportions for steers fed CDG, SDG, or SDG-CH. Steers fed CDG had a greater (*P* < 0.01) ruminal butyrate molar proportion than steers fed SDG or SDG-CH. Steers consuming SDG had the greatest (P < 0.01) ruminal isovalerate molar proportion than SDG-CH and CDG (4.5, 3.5, and 1.8 mol/100 mol, respectively). Steers consuming CDG and SDG-CH had a greater (*P* < 0.01) ruminal valerate concentration compared to steers fed SDG. Of the resulting ruminal fermentation parameters, propionate is the most energetically favorable VFA (Smith and Crouse, 1985) which contributes to intramuscular fat deposition, and may partially explain the greater NEg content of corn compared to sorghum WDGS reported by Owens (2008) in SFC-based diets because no energy is lost in the form of methane.

Ruminal ammonia concentration was greatest (*P* < 0.01) for steers consuming CDG compared to SDG and SDG-CH. This difference is not easily explained. May et al. (2009) reported that ruminal ammonia concentrations were less for steers fed 25% dried distillers grains (**DDG**) than steers fed 0% DDG, however, soybean meal was used as a protein source in the 0% DDG diet.

Conclusions

Treating corn stalks with calcium hydroxide showed greater increases in degradability than did treating sorghum wet distillers grains plus solubles. This may be due to the difference in calcium hydroxide treatment concentration used on corn stalks and sorghum wet distillers grains plus solubles in this study (6.5 and 2.67 % DM basis, respectively) however, inclusion rate of ingredient restricts chemical treatment concentration. Treating sorghum wet distillers grains plus solubles tended to increase NDF digestibility and increased total ruminal VFA concentration compared to untreated sorghum wet distillers grains plus solubles in Exp. 2. Therefore, treating sorghum wet distillers grains plus solubles with calcium hydroxide shows promise. Wet distillers grains are a great candidate for alkali treatment as they contain the necessary moisture to facilitate the chemical reaction without additional water, versus treating dry crop residues. This practice may be favorable in drought restricted areas. Further research is warranted to investigate the effects of higher concentrations of calcium hydroxide treatment on digestibility characteristics of SWDGS and subsequent effects on animal performance and carcass characteristics.

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Table 2.1 Ruminal *in situ* DM degradability characteristics of calcium hydroxide treated sorghum wet distillers grains plus solubles and corn stalks in Exp. 1.

	Treatment[1]				
Item[2]	C	C-CH	S	S-CH	SEM
a, %	18.6^{e}	21.5^{d,e}	23.7^{d}	23.7^{d}	1.99
b, %	5.3^{b,e}	14.7^{b,d}	34.7^{a}	33.3^{a}	4.25
c, %	77.0^{a}	64.0^{b}	41.2^{c}	43.0^{c}	3.92
L, h	9.52	6.17	2.54	2.14	3.068
k_d, h	2.28^{a}	0.58^{b}	0.05^{b}	0.05^{b}	0.546
ERD, %	23.8^{c}	33.2^{b}	39.2^{a}	37.2^{a,b}	2.17

[1]C = corn stalks, C-CH = corn stalks treated with 6.5% calcium hydroxide (DM basis), S = sorghum wet distillers grains plus solubles, S-CH = sorghum wet distillers grains plus solubles treated with 2.67% calcium hydroxide (DM basis).

[2] a=immediately soluble fraction, b=potentially degradable fraction, c=undegradable fraction, L=discrete lag time, k_d= fractional rate of digestion, and ERD = effective ruminal degradability.

Within a row, means without a common superscript ^{a,b,c} differ ($P \leq 0.05$).

Within a row, means without a common superscript ^{d,e} tend to differ ($P \leq 0.10$).

Table 2.2 Ruminal *in situ* OM degradability characteristics of calcium hydroxide treated sorghum wet distillers grains plus solubles and corn stalks in Exp. 1.

	Treatment[1]				
Item[2]	C	C-CH	S	S-CH	SEM
a, %	16.9[b]	18.1[b]	25.0[a]	24.0[a]	2.04
b, %	4.1[c]	14.5[b]	34.4[a]	31.8[a]	3.75
c, %	79.4[a]	67.9[b]	40.2[c]	44.3[c]	3.71
L, h	11.72[a]	5.60[b]	1.73[c]	1.76[c]	1.434
k_d, h	-	0.14[a]	0.05[b]	0.05[b]	0.036
ERD, %	-	28.3[b]	40.5[a]	37.4[a]	2.56

[1]C = corn stalks, C-CH = corn stalks treated with 6.5% calcium hydroxide (DM basis), S = sorghum wet distillers grains plus solubles, S-CH = sorghum wet distillers grains plus solubles treated with 2.67% calcium hydroxide (DM basis).

[2] *a*=immediately soluble fraction, *b*=potentially degradable fraction, *c*=undegradable fraction, *L*=discrete lag time, k_d= fractional rate of digestion, and ERD = effective ruminal degradability.

Within a row, means without a common superscript [a,b,c] differ ($P \leq 0.05$).

Table 2.3 Ruminal *in situ* NDF degradability characteristics of calcium hydroxide treated sorghum wet distillers grains plus solubles and corn stalks in Exp. 1.

	Treatment[1]				
Item[2]	C	C-CH	S	S-CH	SEM
a, %	6.4	6.8	3.1	5.2	2.35
b, %	5.5[b]	15.5[b]	46.7[a]	38.6[a]	6.04
c, %	88.2[a,d]	77.7[a,e]	49.9[b]	56.2[b]	4.73
L, h	11.93[a]	4.63[b]	3.18[b]	3.33[b]	1.046
k_d, h	-	0.13	0.09	0.15	0.075
ERD, %	-	17.2[c]	32.9[a]	28.6[b]	1.64

[1]C = corn stalks, C-CH = corn stalks treated with 6.5% calcium hydroxide (DM basis), S = sorghum wet distillers grains plus solubles, S-CH = sorghum wet distillers grains plus solubles treated with 2.67% calcium hydroxide (DM basis).

[2] *a*=immediately soluble fraction, *b*=potentially degradable fraction, *c*=undegradable fraction, *L*=discrete lag time, k_d= fractional rate of digestion, and ERD = effective ruminal degradability.

Within a row, means without a common superscript [a,b,c] differ ($P \leq 0.05$).

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

Table 2.4 Dry matter composition and nutrient analysis of finishing diets fed to steers in Exp. 2.

	Dietary Treatment[1]		
Item	**CDG**	**SDG**	**SDG-CH**
Ingredient			
Steam-flaked corn	56.60	56.77	58.04
Corn WDG	30.09	-	-
Sorghum WDG	-	29.74	-
Treated sorghum WDG	-	-	29.68
Sorghum stalks	8.52	8.69	8.72
Urea	0.30	0.30	0.33
Limestone	2.00	2.00	0.75
Supplement[2]	2.49	2.50	2.47
Analyzed values			
CP, %	17.31	17.86	18.20
NDF, %	17.98	17.02	17.64
ADF, %	7.87	10.82	10.78
EE, %	6.32	6.29	5.60
Ca, %	0.77	0.80	0.73
P, %	0.41	0.43	0.43
Calculated values			
NEm, Mcal/kg	2.09	2.03	2.05
NEg, Mcal/kg	1.23	1.19	1.21

[1]CDG = 30% corn wet distillers grains plus solubles diet, SDG = 30% sorghum wet distillers grains plus solubles diet, SDG-CH = calcium hydroxide treated sorghum wet distillers grains plus solubles diet (2.67% $Ca(OH)_2$ DM basis).

[2] Provided vitamins and minerals to meet or exceed NRC (2000) requirements. Monensin and Tylosin were included at a rate to provide 22.2 and 5.0 mg/kg, respectively.

Table 2.5 Effects of calcium hydroxide treated sorghum wet distillers grains plus solubles on intake, fecal output, and apparent total tract digestibility in Exp. 2.

	Dietary Treatment[1]				
Item	**CDG**	**SDG**	**SDG-CH**	**SEM**	***P*-value[2]**
Steers, n	5	6	6	-	-
Intake, kg/d					
DM	9.2	9.7	9.7	0.42	0.47
OM	8.6	9.0	9.0	0.40	0.46
NDF	1.4	1.6	1.7	0.17	0.38
ADF	0.7[b]	1.0[a]	1.0[a]	0.05	<0.01
Starch	3.8	3.8	4.2	0.19	0.13
Nitrogen, g/d	254	276	282	12.00	0.12
Fecal output, kg/d					
DM	2.6	2.7	1.9	0.48	0.22
OM	2.2	2.3	1.6	0.41	0.22
NDF	1.0[a]	0.9[a,d]	0.6[e]	0.16	0.07
ADF	0.5	0.6	0.4	0.12	0.37
Starch	0.06	0.10	0.05	0.03	0.16
Nitrogen, g/d	73	111	82	19.12	0.18
Apparent total tract digestibility, %					
DM	71.5	71.6	80.3	5.12	0.20
OM	75.0	74.4	82.6	4.63	0.19
NDF	40.1[b,c]	43.8[a,c,e]	65.0[a,d]	10.00	0.07
ADF	36.3	41.5	58.3	13.02	0.24
Starch	98.4	97.4	98.9	0.71	0.15
Nitrogen	71.6	59.8	70.5	7.18	0.24

[1]CDG = 30% corn wet distillers grains plus solubles diet, SDG = 30% sorghum wet distillers grains plus solubles diet, SDG-CH = calcium hydroxide treated sorghum wet distillers grains plus solubles diet (2.67% $Ca(OH)_2$ DM basis).

[2]Means without a common superscript differ [a,b,c] ($P \leq 0.05$); Means without a common superscript tend to differ [d,e] ($P \leq 0.10$).

Table 2.6 Effects of calcium hydroxide treated sorghum wet distillers grains plus solubles on fermentation characteristics in Exp. 2.

	Dietary Treatment[1]				*P*-value[2]		
Item	**CDG**	**SDG**	**SDG-CH**	**SEM**	**Treatment**	**Time**	**Treatment x time**
Steers, n	5	6	6	-	-	-	-
pH	5.37^{c}	5.80^{a}	5.68^{b}	0.057	<0.01	<0.01	0.33
NH_3, mg/dL	5.82^{a}	3.64^{b}	3.65^{b}	0.547	<0.01	<0.01	0.30
Volatile Fatty Acid Concentration[3]							
Total	141.5^{a}	116.2^{c}	126.6^{b}	4.95	<0.01	<0.01	0.68
Acetate	38.5^{b}	46.7^{a}	46.0^{a}	0.82	<0.01	<0.01	0.48
Propionate	41.9^{a}	34.8^{b}	36.0^{b}	1.04	<0.01	0.01	0.94
Isobutyrate	0.7	1.0	0.7	0.21	0.22	0.10	0.38
Butyrate	13.7^{a}	10.2^{b}	10.3^{b}	0.77	<0.01	0.08	0.67
Isovalerate	1.8^{c}	4.5^{a}	3.5^{b}	0.33	<0.01	<0.01	0.85
Valerate	3.6^{a}	2.9^{b}	3.4^{a}	0.22	<0.01	0.44	0.99
A:P[4]	0.88^{c}	1.56^{a}	1.33^{b}	0.091	<0.01	0.09	0.74

[1]CDG = 30% corn wet distillers grains plus solubles diet, SDG = 30% sorghum wet distillers grains plus solubles diet, SDG-CH = calcium hydroxide treated sorghum wet distillers grains plus solubles diet (2.67% $Ca(OH)_2$ DM basis).

[2]Treatment means without a common superscript differ ^{a,b,c} ($P \leq 0.05$); Treatment means without a common superscript tend to differ ^{d,e} ($P \leq 0.10$).

[3]Total VFA concentration is reported in millimoles. Individual VFAs are reported in mol/100mol.

[4]A:P = acetate to propionate ratio.

CHAPTER III

EFFECTS OF ROUGHAGE INCLUSION AND PARTICLE SIZE ON PERFORMANCE AND RUMINATION BEHAVIOR OF FINISHING BEEF STEERS

Introduction

Roughage is fed in finishing beef diets to maintain rumen health and function. On an energy basis, roughages are relatively expensive when compared to concentrates such as grain (Galyean and Hubbert, 2014). To increase efficiency of growth during the finishing phase, roughage inclusion rate is decreased, but is not completely removed from the diet due to increased risk of digestive upset. This is especially the case for diets based on rapidly fermentable grains such as steam-flaked corn (**SFC**; Depenbusch et al., 2009; Galyean and Hubbert, 2014). An additional benefit of roughage in finishing diets is increased DMI, and subsequently, NEg intake (Galyean and Defoor, 2003). However, the inclusion rate at which roughage restricts intake by physical fill is not well defined, and the inclusion of fibrous by-products such as distillers grains (**DG**) and corn gluten feed (**CGF**) potentially cofound the issue. In most cases, roughages from different sources are not equal on a chemical NDF basis. Benton et al. (2015) fed low (3, 4, 6% DM basis, respectively) or standard (6, 8, 12 % DM basis, respectively) inclusions of corn stalks, alfalfa hay, or corn silage in dry-rolled (**DRC**) and high-moisture corn (**HMC**)-based diets with 30% wet distillers grains plus solubles (**WDGS**). Diets also were balanced for equal dietary NDF, Benton et al. (2015) concluded performance was greater when feeding a low inclusion of corn stalks compared to a low inclusion of alfalfa or corn silage. This suggests that high quality roughage may not be needed in finishing diets; whereas, low quality roughages may provide the appropriate stimulation for proper rumen function. Lower quality roughage also may be more cost effective.

Mertens (1997) proposed physically effective NDF (**peNDF**) as a means to quantify different roughage sources and particle sizes. Physically effective NDF relates to the roughage's ability to stimulate rumination. Benton et al. (2015) reported NDF in corn stalks may have been more physically effective than the NDF in alfalfa hay or corn silage. Shain et al. (1999) noted cattle consuming 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 lower inclusion rates. Particle size also affects rumination time, as increased particle size increases time spent ruminating (Beauchemin and Yang, 2005).

The interactions between roughage source, quantity, and particle length has been more thoroughly researched in dairy cattle than in beef. Beef cattle research has focused primarily on roughage source and inclusion, whereas very little has been devoted to particle size and its effects on rumination. Further research is needed to standardize rumination behavior and classify roughage in the finishing phase. However, factors affecting rumination behavior of beef cattle are complex and relative to fiber type and amount, rate of digestion and passage, ingredient particle size, and ruminal pH (Fox and Tedeschi, 2002). Physically effective NDF may be a means to standardize fiber and fiber requirements (Fox and Tedeschi, 2002; Mertens, 1997). Therefore, the objectives of this study were to: 1) Examine the effects of various inclusion rates and particle sizes of corn stalks on performance, carcass characteristics, and rumination behavior in finishing beef cattle and 2) begin to understand the appropriate level of peNDF for finishing beef cattle to achieve maximum performance while maintaining rumen health.

Materials and Methods

All procedures involving live animals were approved by the West Texas A&M-CREET University Animal Care and Use Committee (approval # 04-01-14).

Animals. Fifty-four crossbred steers (arrival BW = 337 kg) were received at the Texas A&M AgriLife Research/ USDA-ARS Feedlot in Bushland, TX on April 13th, 2015. Steers were placed into six pens equipped with nine 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 454 kg with certified weights before each use), and an uniquely numbered ear tag was placed in the right ear of each animal. Initial processing included: vaccination for viral and clostridial disease (Bovi-Shield Gold 5; Ultra-Choice 7; Zoetis, 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) and subcutaneous injection with tulathromycin (Draxxin; Zoetis). Following processing, steers were returned to the pens and offered a 40 % roughage: 60 % concentrate grower diet and trained to use the individual head gates. At the beginning of the trial, two consecutive weights were collected and averaged to determine initial BW (n = 51; initial BW = 385 ± 3.6 kg). Steers were stratified by initial BW and assigned into two 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). 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) and outfitted with collars that continually monitored rumination time and activity. Activity is defined as minutes the animal spent moving.

Treatment and Experimental Design. To achieve different particle sizes of corn stalks, corn stalks were passed through a commercial tub grinder equipped with a 7.62 cm screen once (long grind; **LG**) or twice (short grind; **SG**). Particle size of individual ingredients and treatment diets were quantified using the Penn State Particle Separator (**PSPS**). Three treatment diets were fed in a completely randomized block design. The treatment diets (Table 3.1) were SFC-based and included: 5% SG corn stalks (**5SG**), 5% LG corn stalks (**5LG**), or 10% SG corn stalks (**10SG**).

Feed Managment. 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, Fort Atkinson, WI, readability ± 0.45 kg), and timed to allow 3 minutes 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) to the nearest 0.05 kg of the feed call and delivered to each individual bunk. Individual BW's were collected at 35-d intervals, and two-day consecutive weights were collected and averaged for final BW.

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 set at 55°C for 48 h (Despatch Model LBB2-18-1, Minneapolis, MN). Samples of individual feed ingredients and mixed diets were separated using the PSPS as described by Heinrichs and Kononoff (2002) by wet-sieving. Physically effective NDF was estimated by multiplying the quantity (as a percentage of the total sample) of sample larger than 1.18 mm in particle size by the NDF content of that sample as described by Mertens (1997). 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 Labratories, Amarillo, TX).

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 days on feed; **DOF**). Trained personnel from the West Texas A&M University Beef Carcass Research Center 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 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 DOF, with carcass-adjusted G:F calculated as carcass-adjusted ADG divided by average DMI. Metabolizable energy and net energy for maintenance and gain were calculated using methods described by Zinn and Shen (1998).

Statistical Analysis. Animal performance, fecal starch and NDF, carcass characteristics, and rumination and activity data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with animal as the experimental unit, and weight block considered a random effect. The model included effects of treatment, day, and treatment x day. 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 three standard deviations of the mean was considered an outlier, and removed from the data set. The Kenward Roger denominator degrees of freedom method was utilized when a data set contained missing observations. Particle separation and estimated peNDF data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc.). For all analyses, effects were considered significant at a $P \leq 0.05$, and tendencies declared at $P \leq 0.10$ to $P > 0.05$.

Results and Discussion

Particle separation. Particle separation results using the PSPS for individual feed ingredients are presented in Table 3.2. The proportion of particles that were larger than 19.05 mm was greatest ($P < 0.01$) for LG- CS, followed by SG-CS, and lastly WCGF and SFC. Wet corn gluten feed tended ($P = 0.10$) to contain more particles greater than 19.05 mm than SFC. Steam-flaked corn contained the greatest ($P < 0.01$) proportion of particles that were retained on the 7.87 mm sieve, followed by LG-CS, SG-CS, and WCGF. Long grind corn stalks and SG-CS had similar (*P* = 0.19) proportions that were retained on the 7.87 mm sieve; whereas SG-CS and WGCF also retained similar (*P* = 0.45) weights on the 7.87 mm sieve. Particles retained on the 1.18 mm sieve were greatest (*P* < 0.01) for WGCF compared to SG-CS, LG-CS, and SFC with the latter three exhibiting similar values (*P* > 0.17). Wet corn gluten feed and SG-CS contained the greatest (*P* < 0.01) proportion of small particles (< 1.18 mm) compared to LG-CS and SFC. Particles shorter 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). Particles longer than 1.18 mm (sum of particles retained on the top 3 sieves of the PSPS) were greatest (*P* < 0.01) for SFC and LG-CS compared to SG-CS and WCGF. Estimated peNDF using particle separation was greatest (*P* < 0.01) for LG-CS, followed by SG-CS, WCGF, and SFC.

Results of particle separation data using the PSPS for the treatment diets are presented in Table 3.3. The 10SG diet contained the greatest (*P* < 0.01) proportion of particles larger than 19.05 mm, followed by 5LG, and 5SG. No differences (*P* = 0.13) were observed for particles retained on the 7.87 mm sieve between the treatment diets. Although similar (*P* = 0.59), more particles were retained on the 1.18 mm screen for the 5SG and 5LG diets than the 10SG diet. No differences (*P* = 0.25) were observed for particles less or greater than 1.18 mm between the treatment diets. Estimated peNDF was greatest (*P* < 0.01) for the 10SG diet compared to the 5SG and 5LG diets (13.00, 11.40, and 11.29 %, respectively). Taking into consideration the estimated peNDF of the ingredients, and that the diets were balanced to a similar nutrient composition, we attribute the peNDF differences of the treatment diets to corn stalk inclusion rate rather than particle size. It seems that the differences ($P < 0.01$) 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 pulveration of the larger particles during mixing could have further affected separation difference within treatment diets.

Animal performance. 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. Treatment means for feedlot performance are presented in Table 3.4. No differences ($P = 0.52$) were observed for final shrunk BW (**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% corn stalks in DRC and HMC-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, 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. However, Benton et al. (2015) observed no differences (P > 0.05) in DMI for steers consuming 3 or 6% corn stalks. Shain et al. (1999) observed no difference in DMI for steers consuming DRC-based diets with 5.2 % wheat straw or 10% alfalfa. This similar intake response 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 (Galyean and Hubbert, 2014; Kreikemeier et al. 1990). The small sample size in this study may not have been able to capture this pattern of intake. In this study DMI as a percent of shrunk BW was 1.79, 1.83, and 1.78% for steers consuming 5SG, 5LG, and 10SG, respectively. Cattle consuming 5LG had a greater ($P \leq 0.05$) DMI as a percent of shrunk BW than cattle consuming 5SG or 10SG, with no difference (P = 0.55) between cattle consuming 5SG and 10SG. Intake as a percent of shrunk BW was statistically different in this study; however, this difference may have little biological significance as all were consuming diets *ad libitum*.

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. 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 for 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 to concentrates. Observed ADG in cattle consuming higher levels of roughage are 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% corn stalk diets. Therefore, NEg intake was not increased compared to the steers fed 5% corn stalks, and this was evident in carcass-adjusted ADG.

Gain efficiency tended ($P = 0.10$) to be greatest for cattle consuming 5SG compared to cattle consuming 5LG or 10SG. Benton et al. (2015) observed no difference in G:F for steers consuming 3 or 6% corn stalks. Carcass-adjusted G:F was greater ($P = 0.01$) for steers consuming 5SG and 5LG diets compared to steers consuming 10SG diet. In contrast, Parsons et al. (2007) observed no differences in G:F or carcass adjusted G:F for cattle consuming 0, 4.5, or 9 % alfalfa in diets containing 40% WCGF. May et al. (2011) reported a quadratic tendency ($P \leq 0.10$) 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 (6.14, and 12.26 %, respectively), or corn stalks (3.04, and 6.08 %, 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.

Energy values calculated from performance data using methods described by Zinn and Shen (1998) and fecal NDF and starch are presented in Table 3.5. No differences ($P \geq 0.49$) were observed for ME, NEm, or NEg values calculated from animal performance (Zinn and Shen, 1998). Steers fed 5SG had a greater ($P = 0.03$) concentration of NDF in the feces compared to steers fed 5LG or 10SG. This could be due to the increased ($P = 0.01$) rumination time (Figure 3.1) observed for cattle consuming 5LG and 10SG compared to cattle consuming 5SG. We did not measure ruminal pH in this study, but Church (1988) suggests that cattle that ruminate more often increase salivary flow and rumen buffering capacity. A higher rumen 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 yielded a value of 99.5 % for this study, which suggests that cattle efficiently utilized starch across treatments (Zinn et al. 2007).

Carcass characteristics. Carcass characteristics are presented in Table 3.6. Hot carcass weight tended to be greater ($P = 0.10$) for steers fed 5LG compared to steers fed 10SG, with steers fed 5SG being intermediate. In contrast, Parsons et al. (2007) reported a linear increase in HCW as roughage inclusion was increased from 0 to 9% of dietary DM. Farran et al. (2006) also reported a linear increase in HCW as inclusion of roughage was increased. In these two studies, DMI, and ADG also increased as percent roughage in the diet increased. Overall, previous research demonstrated increased HCW of cattle consuming more roughage; however, this was not the case in the current study. Dressing percent was greatest ($P = 0.01$) for the steers consuming 5% roughage, regardless of corn stalk grind size, compared to cattle consuming 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, corn stalks, or corn silage in DRC and HMC-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 current study, that steers consuming approximately 5% roughage had the greatest DP. Sometimes thought to be a concern when decreasing roughage inclusion in finishing diets, no differences ($P = 0.76$) were observed for normal or abscessed livers in this study. No other differences ($P \geq 0.43$) were observed in the carcass measurements.

Rumination Behavior. Rumination and DMI by day are illustrated in Figure 3.1. Steers consuming the 10SG diet ruminated the most (min/d), followed by steers consuming the 5LG, and steers consuming the 5SG diet ruminated the least ($P = 0.01$; 307, 289, and 245 min/d, respectively). Daily rumination did not visibly separate according to dietary treatment until approximately d 112. This suggests that rumination time may be most important towards the end of the feeding period. To further this point, death loss from digestive origin can occur in the last portion of the feeding period, and it may be the last 30 d on feed where rumination time is most important. Dry matter intake was not different across day ($P = 0.46$), while rumination time was different ($P < 0.01$) across day, DMI 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 one single day. This rumination data conflicts with the estimated peNDF derived from the total diet particle separation analysis (Table 3.3). 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 showed characteristics of greater peNDF compared to 5SG. Again, peNDF is defined as the portion of NDF that requires further mastication to allow passage out of the rumen (Mertens, 1997). The 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) was more sensitive to particle size than were sieving techniques. Beauchemin and Yang (2005) fed three different particle sizes of corn silage at approximately 42% dietary DM to six lactating Holstein cows, to test the effects of feeding different amounts of peNDF (12.3, 11.1, and 10.1 % peNDF). As particle size (and peNDF) increased in the diet, daily rumination also increased. Shain et al. (1999) fed 10% alfalfa or 5% wheat straw to beef steers and observed a greater rumination time for steers consuming wheat straw than 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 only did so for individual roughage ingredients, not the mixed diets. Increasing particle size increased rumination time, and in theory increased salivary flow to the rumen. Approximately half the bicarbonate that enters the rumen comes from saliva during eating and ruminating (Owens, 1998), therefore increasing rumination time should increase the buffering capacity of the rumen, and may aid in controlling acidotic events in feedlot cattle.

Rumination minutes by hour within day are reported in Figure 3.2. Rumination by hour was greatest ($P = 0.04$) for steers consuming 10SG and 5LG compared to steers consuming 5SG (12.4, 12.0, and 10.1 min/h, respectively). 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 to steers consuming 5SG, with no difference ($P = 0.48$) between 5LG and 10SG (21.9, 21.0, and 18.6 minutes, 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 minutes, 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 ($P = 0.01$), while steers consuming 10SG and 5SG rumination times 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 minutes, 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 for similar minutes ($P = 0.81$) and more ($P \leq 0.01$) than steers consuming 5SG (18.2, 17.9, and 14.8 minutes, respectively). Rumination followed a similar pattern at 2400 h with steers consuming 10SG and 5LG ruminating for similar minutes ($P = 0.99$) and more ($P = 0.01$) than steers consuming 5SG (19.9, 19.9, and 16.8 minutes, respectively).

Activity minutes by hour within day are reported in Figure 3.3. No differences ($P = 0.44$) in activity were observed in this study. Behavioral observations would suggest that cattle seem to ruminate during lower activity, especially during the nighttime when they are most likely lying down.

A tendency ($P = 0.06$) was observed for rumination time per kg of DM with steers consuming 10SG ruminating more than steers consuming 5SG ($P = 0.03$; Table 3.7). This can be explained by the greater rumination time and lower DMI of the steers fed 10SG compared to steers consuming 5SG. Steers consuming 5LG ruminated for a similar amount ($P = 0.59$) of time per kg of DM as the steers fed 10SG, but tended ($P = 0.07$) to ruminate more per kg of DM than steers fed 5SG. Rumination per kg of NDF was not different for steers consuming 5SG, 5LG, or 10SG. Also, Beauchemin and Yang (2005) observed no differences in rumination per kg 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 kg of peNDF in this study. In contrast, Beauchemin and Yang (2005) reported a linear decrease in rumination minutes per kg of peNDF as particle size increased, it is unclear why this response was observed.

Overall, cattle consuming 5LG showed optimal carcass gain. The estimated peNDF values of the current study were 11.40, 11.29, and 13.00 % for 5SG, 5LG, and

10SG, respectively. To maximize ADG, Mertens (2002) recommends a dietary peNDF value of 12 to 15%, and 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 two, which further illustrates the need to refine the peNDF requirements of feedlot cattle.

Conclusions

Minimal research is available that compares roughage amount and particle size in 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 peNDF and NDF digestibility are inversely related. If an ingredient is highly digestible, it does not stimulate or require increased rumination compared to low quality roughages. Therefore, higher quality forages or smaller particle sizes 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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Table 3.1 Ingredient and nutrient composition of dietary treatments (DM basis, excluding DM).

	Dietary Treatments[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, Mcal/kg[4]	2.93	2.93	2.89
NEm, Mcal/kg[4]	2.23	2.23	2.16
NEg, Mcal/kg[4]	1.32	1.32	1.28

[1]5SG = 5% short grind corn stalks with 30% wet corn gluten feed, 5LG = 5% long grind corn stalks with 30% wet corn gluten feed, 10SG = 10% short grind corn stalks with 25% wet corn gluten feed.
[2]Short grind corn stalks = passed through a commercial tub grinder twice, long grind corn stalks = passed through a commercial tub grinder once; 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.
[4]Values for the experimental diets were calculated from NRC tabular degradable intake protein (DIP) and NE values based on proximate analysis of ingredients.

Table 3.2 Particle separation analysis and estimated physically effective neutral detergent fiber (peNDF) of feed ingredients.

Item	Ingredient[1]				SEM	*P*-value[2]
	SFC	**WCGF**	**SG-CS**	**LG-CS**		
NDF, % DM	8.40	33.80	70.76	73.00	-	-
	------------------------Retained/screen,%--------------------					
Sieve screen size, mm						
19.05	1.04[c,f]	5.46[c,e]	21.88[b]	30.60[a]	2.617	<0.01
7.87	75.25[a]	30.32[c]	33.38[b,c]	38.76[b]	4.060	<0.01
1.18	13.26[b]	32.83[a]	16.12[b]	15.44[b]	2.067	<0.01
Particles less than 1.18 mm	10.45[b]	31.40[a]	28.62[a]	15.20[b]	3.332	<0.01
Particles greater than 1.18 mm	89.55[a]	68.60[b]	71.38[b]	84.80[a]	3.332	<0.01
Estimated peNDF, % DM[3]	7.52[d]	23.19[c]	50.51[b]	61.91[a]	1.895	<0.01

[1]SFC = steam-flaked corn, WCGF = wet corn gluten feed, SG-CS = short grind corn stalks that were passed through a commercial tub grinder twice, LG-CS = long grind corn stalks that were passed through a commercial tub grinder once; Tub grinder was equipped with a 7.62 cm screen.
[2]Means without a common superscript differ [a,b,c] ($P \leq 0.05$); Means without a common superscript tend to differ [e,f] ($P \leq 0.10$).
[3]Calculated by multiplying the particles that greater than 1.18 mm (as a percent of the total sample) by the NDF content of the sample.

Table 3.3 Particle separation analysis and estimated physically effective neutral detergent fiber (peNDF) of treatment diets.

Item	Dietary Treatment[1] 5SG	5LG	10SG	SEM	*P*-value[2]
NDF, % DM	18.00	18.00	20.00	-	-
	-----------------Retained/screen,%---------------				
Sieve screen size, mm					
19.05	1.56[c]	2.47[b]	3.27[a]	0.386	<0.01
7.87	39.93	38.74	41.70	1.464	0.13
1.18	21.82[a]	21.52[a]	20.05[b]	0.562	0.01
Particles less than 1.18 mm	36.69	37.26	34.98	1.409	0.25
Particles greater than 1.18 mm	63.31	62.74	65.02	1.409	0.25
Estimated peNDF, % DM[3]	11.40[b]	11.29[b]	13.00[a]	0.260	<0.01

[1]5SG = 5% short grind corn stalks with 30% wet corn gluten feed, 5LG = 5% long grind corn stalks with 30% wet corn gluten feed, 10SG = 10% short grind corn stalks with 25% wet corn gluten feed.
[2]Means without a common superscript differ [a,b,c] ($P \leq 0.05$).
[3]Calculated by multiplying the particles greater than 1.18 mm (as a percent of the total sample) by the NDF content of the sample.

Table 3.4 Effect of corn stalk particle size and inclusion rate on finishing steer performance.

	Dietary Treatment[1]				*P*-value[2]		
Item	**5SG**	**5LG**	**10SG**	**SEM**	**Treatment**	**Day**	**Treatment × Day**
N, steers	18	17	16	-	-	-	-
DOF[3]	155	155	155	-	-	-	-
Initial SBW, kg[4]	386	385	383	6.7	0.95	-	-
Final SBW, kg[4]	635	632	622	11.6	0.52	-	-
DMI, kg/d	$9.73^{a,c}$	9.92^{a}	$9.54^{b,c}$	0.14	0.03	0.46	0.97
ADG, kg/d	1.67	1.66	1.61	0.03	0.17	0.05	0.96
G:F, kg/kg	0.173^{d}	0.168^{e}	0.168^{e}	0.003	0.10	<0.01	0.90
Carcass-adjusted performance[5]							
Final SBW, kg	$631^{a,c}$	639^{a}	$614^{b,c}$	11.8	0.10	-	-
ADG, kg/d	1.5^{a}	1.5^{a}	1.4^{b}	0.06	0.03	-	-
G:F	0.156^{a}	0.155^{a}	0.142^{b}	0.005	0.01	-	-

[1]5SG = 5% short grind corn stalks with 30% wet corn gluten feed, 5LG = 5% long grind corn stalks with 30% wet corn gluten feed, 10SG = 10% short grind corn stalks with 25% wet corn gluten feed.
[2]Means without a common superscript differ ^{a,b,c} ($P \leq 0.05$); Means without a common superscript tend to differ ^{d,e} ($P \leq 0.10$).
[3]Days on feed; Block 1 = 162, Block 2 = 148
[4]A 4% shrink was applied to BW.
[5]Carcass-adjusted final shrunk BW (Car-adj. final SBW) was calculated from HCW divided by the average DP across treatments (63.52%) and carcass-adjusted ADG (Car-adj. ADG) was calculated from carcass-adjusted final shrunk BW, initial BW, and days on feed, with carcass-adjusted G:F (Car-adj. G:F) calculated as carcass-adjusted ADG divided by average DMI.

Table 3.5 Effect of corn stalk particle size and inclusion rate on energy values calculate from animal performance, and fecal neutral detergent fiber and starch concentrations.

	Dietary Treatment[1]				***P*-value**[2]		
Item	**5SG**	**5LG**	**10SG**	**SEM**	**Treatment**	**Day**	**Treatment × Day**
Calculated energy values, Mcal/kg of DM[3]							
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	-	-
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

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

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

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

Table 3.6 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[2]**
HCW, kg	401[a,b]	406[a]	390[b]	7.5	0.10
DP[3]	63.59[a]	64.32[a]	62.49[b]	0.586	0.01
Marbling Score[4]	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 YG	3.11	3.11	3.02	0.247	0.92
Choice or greater, %	37.5	47.9	35.7	0.13	0.65
Select or less, %	62.5	52.1	64.3	0.13	0.65
Normal livers,%	94.4	88.9	92.9	0.07	0.76
Abscessed livers, %	5.6	11.1	7.1	0.07	0.76

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

[2]Means without a common superscript [a,b,c] differ ($P \leq 0.05$); Means without a common superscript [d,e] tend to differ ($P \leq 0.10$).

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

[4]300 = Slight[0]; 400 = Small[0].

Table 3.7 Effect of corn stalk particle size and inclusion rate on rumination time per kilogram of dry matter (DM), neutral detergent fiber (NDF), and physically effective neutral detergent fiber (peNDF).

	Dietary Treatment[1]				*P*-value[2]		
Item	**5SG**	**5LG**	**10SG**	**SEM**	**Treatment**	**Day**	**Treatment × Day**
Rumination, min/d	245.44	288.74	307.16	20.504	0.01	<0.01	<0.01
Rumination, min/kg							
DM	25.35[b,e]	29.31[a,d]	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

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

[2]Treatment means without a common superscript [a,b] differ ($P \leq 0.05$); Treatment means without a common superscript [d,e] tend to differ ($P \leq 0.10$).

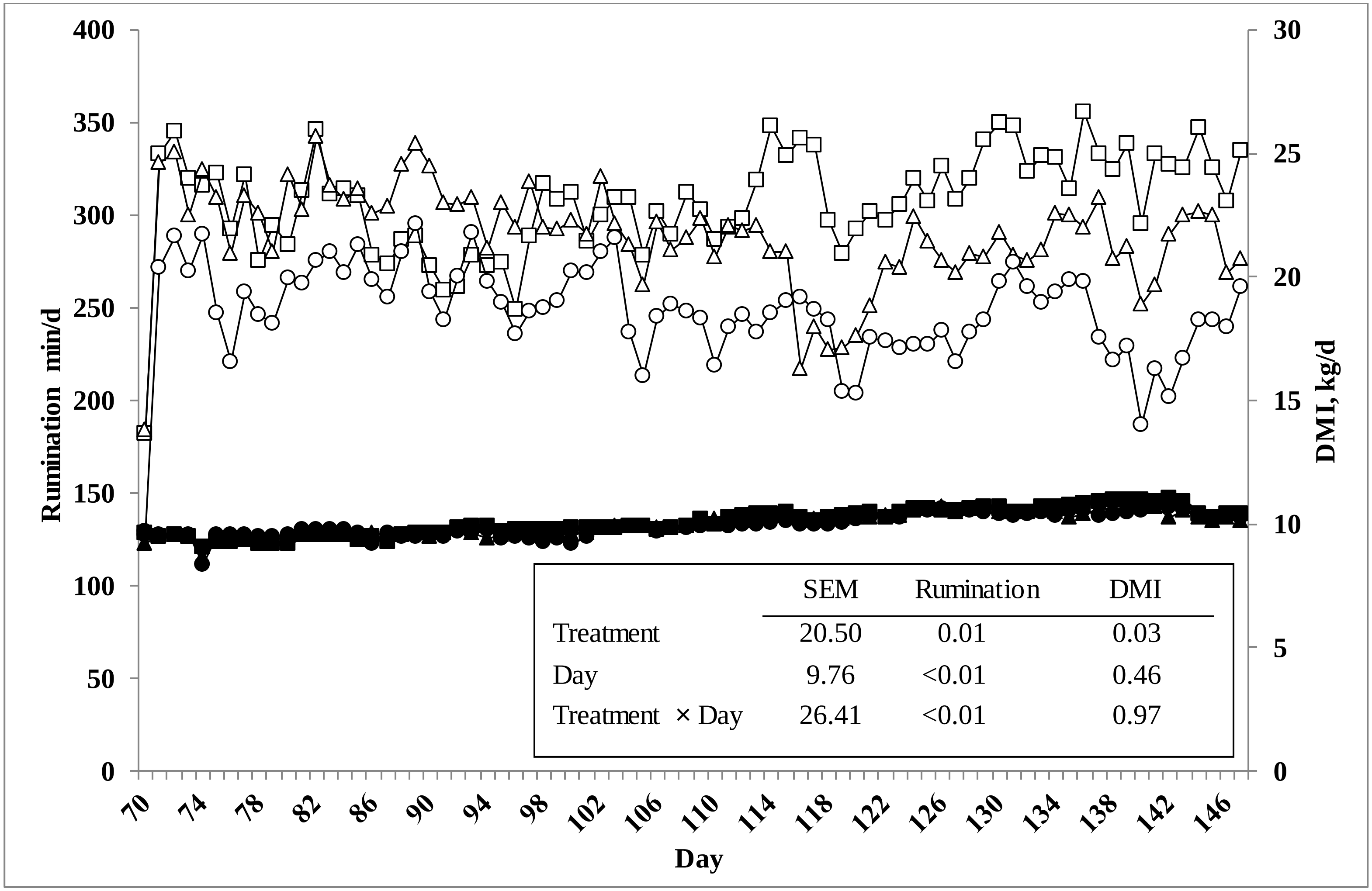

Figure 3.1 Effects of corn stalk particle size and inclusion rate on rumination behavior in finishing beef steers. Open shapes (○, Δ, □) represent rumination (min/d), while filled shapes (●, ▲, ■) represent DMI (kg/d). 5SG = 5% short grind corn stalks with 30% wet corn gluten feed(-○-), 5LG = 5% long grind corn stalks with 30% wet corn gluten feed (-Δ-), 10SG = 10% short grind corn stalks with 25% wet corn gluten feed (-□-).

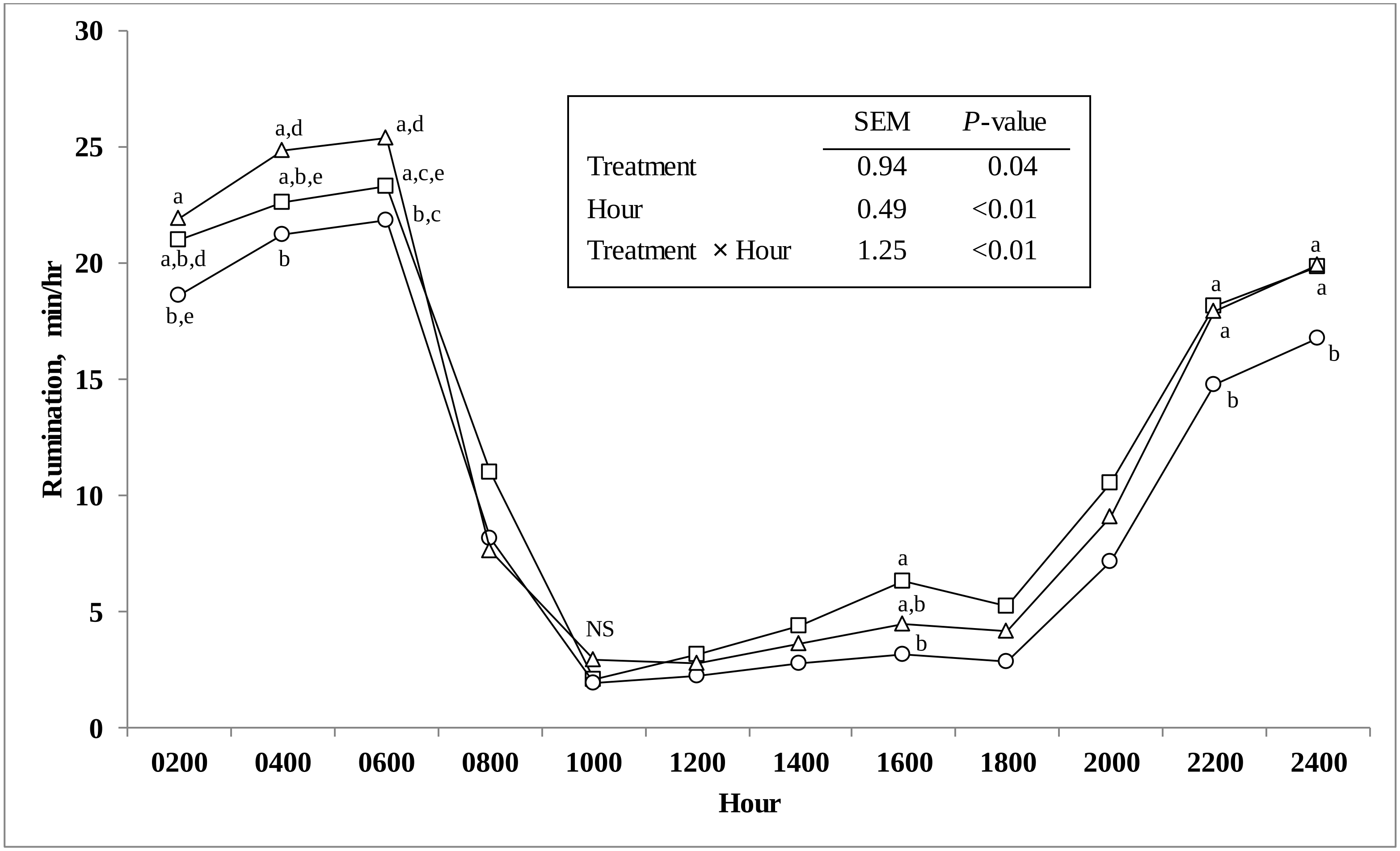

Figure 3.2 Effects of corn stalk particle size and inclusion rate on rumination behavior in finishing beef steers. 5SG = 5% short grind corn stalks with 30% wet corn gluten feed(-○-), 5LG = 5% long grind corn stalks with 30% wet corn gluten feed (-Δ-), 10SG = 10% short grind corn stalks with 25% wet corn gluten feed (-□-).Within an hour, treatment means without a common superscript [a,b,c] differ ($P \leq 0.05$); Within an hour treatment means without a common superscript [d,e] tend to differ ($P \leq 0.10$).

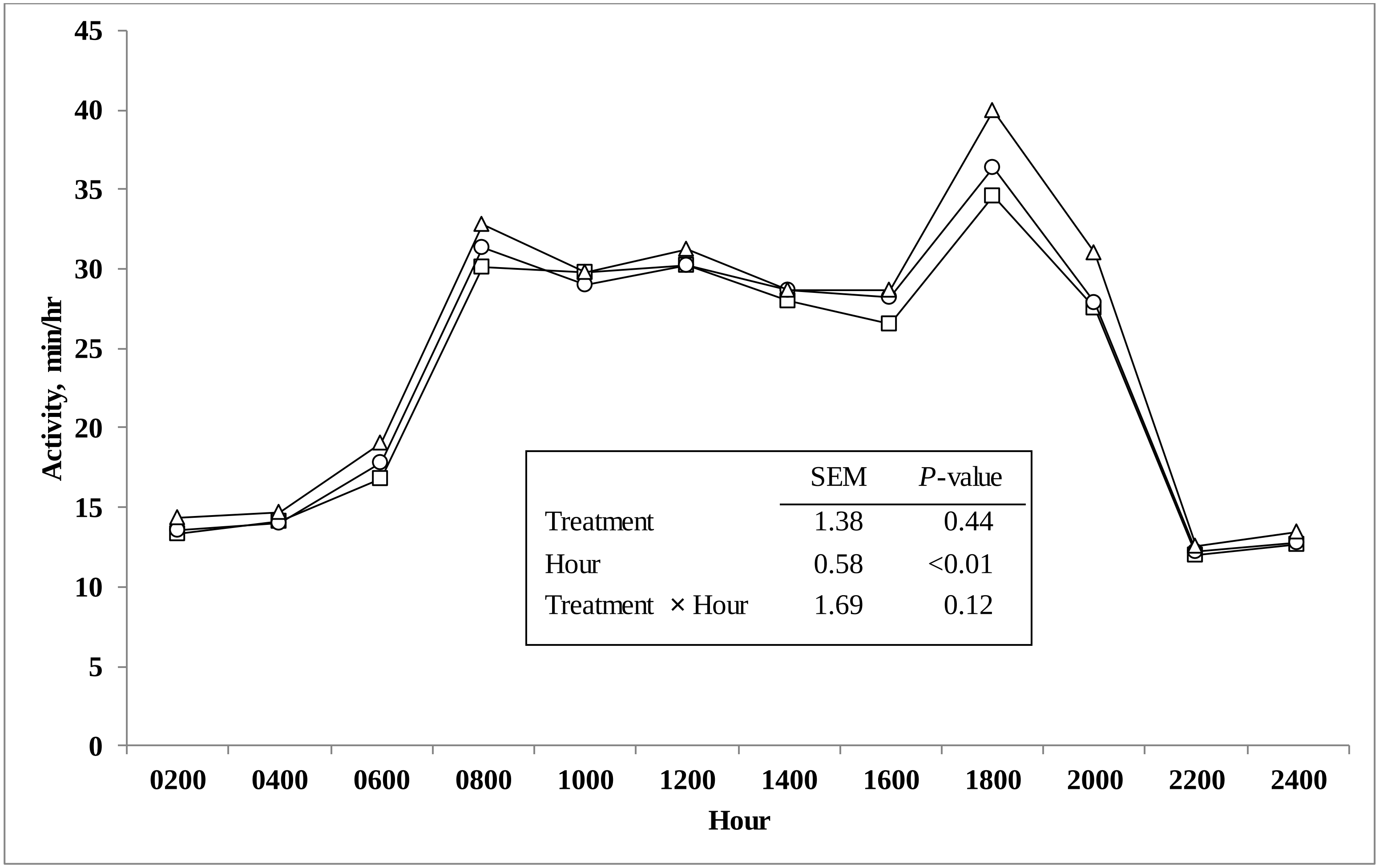

Figure 3.3 Effects of corn stalk particle size and inclusion rate on activity in finishing beef steers. 5SG = 5% short grind corn stalks with 30% wet corn gluten feed(-○-), 5LG = 5% long grind corn stalks with 30% wet corn gluten feed (-Δ-), 10SG = 10% short grind corn stalks with 25% wet corn gluten feed (-□-).