

EFFECTS OF REPLACING CORN IN BEEF FEEDLOT DIETS WITH CHEMICALLY OR
THERMOCHEMICALLY TREATED CORN STOVER AND DISTILLERS GRAINS ON
GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND RUMINAL
METABOLISM

BY

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THESIS

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ABSTRACT

Ethanol expansion in the U. S. has increased the competition for corn grain to be used as food, fuel, and feed. Although this has increased availability of ethanol co-products, such as modified wet distillers grains with solubles (**MWDGS**), finding reduced-cost alternative feeds when corn grain and ethanol co-product price are expensive, due to season and demand, is still a challenge for producers. One alternative feedstuff that is inexpensive and easily accessible is corn stover (**CS**); however, CS is poorly digested due to its advanced physiological maturity. Therefore, the objectives of this research were to evaluate the effects of replacing corn in feedlot finishing diets with CS treated by various methods, chemically (with calcium oxide (**CaO**), sodium hydroxide (**NaOH**), or both CaO and NaOH) and physically (anaerobic or extrusion), and included in diets containing MWDGS on: (1) growth performance, carcass characteristics, and feedlot economics; and (2) diet digestibility and ruminal metabolism of beef cattle. These objectives were evaluated in a series of 3 experiments. In the first experiment, Angus × Simmental steers were allotted in a completely randomized design to 1 of 3 dietary treatments: (1) 55% corn, 35% MWDGS, 5% vitamin/mineral supplement, and 5% untreated, ground CS on a DM basis (**CON**), (2) CS treated with 5% CaO (DM basis) and stored in an Ag Bag (**BGCS**), or (3) CS treated with 5% CaO (DM basis) and extruded (**EXCS**). Both treated CS diets contained 20% CS, 40% MWDGS, 35% corn, and 5% vitamin/mineral supplement (DM basis). There were no differences ($P \geq 0.11$) in feedlot performance or carcass traits between BGCS and EXCS throughout the study; therefore, only the contrast of CON versus BGCS and EXCS (combined) are discussed for these parameters. Feeding CaO-treated CS reduced ($P \leq 0.03$) average daily gain (**ADG**), dry matter intake (**DMI**), gain:feed ratio (**G:F**), and final body weight (**BW**) when compared to steers fed CON. Carcasses from steers fed either BGCS or EXCS diets

had decreased ($P \leq 0.03$) backfat (**BF**), yield grade (**YG**), and hot carcass weight (**HCW**) and tended ($P = 0.07$) to have a decreased percentage of kidney, pelvic, and heart fat (**KPH**) when compared to carcasses from steers fed CON. There were no differences ($P \geq 0.16$) among dietary treatments for longissimus muscle (**LM**) area or marbling score (**MS**), regardless of dietary treatment. Cattle fed BGCS had a less expensive ($P < 0.01$) cost of gain when compared to cattle fed EXCS. There were no differences ($P = 0.11$) in cost of gain for cattle fed the treated CS diets compared to steers fed the corn-based ration, CON. Total feed costs per head were less ($P < 0.01$) for cattle fed treated CS diets, and BGCS in particular. In Chapter 3, 2 experiments were conducted to evaluate the effects of chemical and thermochemical treatment of CS, treated with CaO or a combination of CaO and NaOH, on feedlot growth performance, carcass traits, and ruminal metabolism. In Experiment 1, cattle were allotted in a completely randomized design to 1 of 5 dietary treatments: (1) CON, (2) BGCS, (3) CS treated with 5% CaO (DM basis) and extruded (**5 EXCS**), (4) CS treated with 4% CaO and 1% NaOH (DM Basis) and extruded (**4,1 EXCS**), or (5) CS treated with 3% CaO and 2% NaOH (DM Basis) and extruded (**3,2 EXCS**). All treated CS diets contained 20% CS, 40% MWDGS, 35% corn, and 5% vitamin/mineral supplement (DM basis). There were no differences ($P \geq 0.20$) in ADG, G:F, BF, MS, LM, or YG among dietary treatments. However, cattle fed CON had increased ($P = 0.02$) DMI compared to cattle fed the treated CS diets. A second experiment was conducted to evaluate the effects of the aforementioned diets on apparent digestibility and ruminal metabolism. Apparent total tract digestibility of NDF and ADF increased ($P < 0.01$) for cattle fed treated CS diets compared to cattle fed the control diet, regardless of the treatment applied. There was a time \times treatment interaction ($P < 0.01$) for ruminal pH. Ruminal pH was lowest in cattle fed BGCS from 0 to 6 hours post-feeding compared to cattle fed all other diets. Cattle fed the BGCS and EXCS diets

had the greatest ($P < 0.01$) mean acetate concentrations, resulting in increased ($P = 0.01$) total VFA concentrations. Furthermore, there was a time \times treatment interaction ($P < 0.01$) for acetate: propionate (A:P) ratio. At 0 h, A:P ratio for cattle fed all treated CS diets was greater ($P = 0.01$) when compared to cattle fed CON. After 3 and 6 h post-feeding, A:P ratio for treated CS diets decreased, and did not differ ($P = 0.47$ and $P = 0.16$, respectively) from the CON diet. This effect in A:P ratio was primarily driven by the shift in acetate, as there was no effect ($P = 0.31$) of treatment on propionate concentrations. These data indicate that replacement of corn in beef feedlot diets with bagged, CaO-treated CS, when fed in combination with MWDGS, may offer lower feed costs. However, these reductions in total feed costs were caused from the reductions in feedlot gain. Although growth performance was inconsistent in our feedlot experiments, it appears that LM area and MS are unaffected by feeding treated CS in beef feedlot diets during the finishing phase. Additionally, treating CS with either CaO or NaOH improved apparent total tract fiber digestibility, regardless of chemical or physical processing method. This improvement in digestibility also increased acetate concentrations. Therefore, treated CS, fed in combination with MWDGS, may be an alternative feed for cattle when corn grain is expensive or unavailable. Further validation of the input costs of this feed associated with feeding treated CS in feedlot rations appears warranted.

Key Words: calcium oxide, corn stover, digestibility, distillers grains, feedlot cattle

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TABLE OF CONTENTS

List of Tables	viii
List of Figures	ix
CHAPTER 1: LITERATURE REVIEW	1
LITERATURE CITED	22
CHAPTER 2: EFFECTS OF REPLACING CORN IN FEEDLOT CATTLE DIETS WITH TREATED CORN STOVER AND DISTILLERS GRAINS ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND ECONOMICS	37
ABSTRACT.....	37
INTRODUCTION	39
MATERIALS AND METHODS.....	40
RESULTS AND DISCUSSION.....	45
IMPLICATIONS	49
LITERATURE CITED.....	50
CHAPTER 3: EFFECTS OF TREATMENT METHOD OF CORN STOVER ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, DIGESTIBILITY, AND RUMINAL METABOLISM WHEN FED TO CATTLE	56
ABSTRACT.....	56
INRODUCTION.....	58
MATERIALS AND METHODS.....	59
RESULTS AND DISCUSSION.....	65
CONCLUSIONS.....	71
LITERATURE CITED	72

CHAPTER 4: CONCLUSIONS.....83

**APPENDIX A: CHARACTERISTICS OF CORN STOVER AND EQUIPMENT USED FOR
CORN STOVER TREATMENT86**

LIST OF TABLES

CHAPTER 2

Table 2.1	Ingredient and analyzed nutrient composition of diets (% DM basis) fed to steers	52
Table 2.2	Effects of feeding CaO treated or thermochemically-treated corn stover on feedlot growth performance of finishing steers	53
Table 2.3	Effects of feeding CaO treated or thermochemically-treated corn stover on carcass characteristics of finishing steers	54
Table 2.4	Effects of feeding CaO treated or thermochemically-treated corn stover on economics of finishing steers.....	55

CHAPTER 3

Table 3.1	Ingredient and analyzed nutrient composition (% DM basis) of diets fed to cattle in Experiment 1.....	75
Table 3.2	Ingredient and analyzed nutrient composition of diets (% DM basis) fed to steers in Experiment 2.....	76
Table 3.3	Effects of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on growth performance of cattle in Experiment 1	77
Table 3.4	Effects of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on carcass characteristics of cattle in Experiment 1	78
Table 3.5	Effect of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on total tract apparent digestibility in Experiment 2.....	79
Table 3.6	Effect of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on ruminal VFA concentrations over time in Experiment 2	80

LIST OF FIGURES

CHAPTER 3

Figure 3.1	Effect of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on ruminal pH change over time in Experiment 2.....	81
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CHAPTER 1

LITERATURE REVIEW

Introduction

Expansion of the corn ethanol industry has created increased competition for corn grain to be used for fuel, feed, and food. The dependency for corn grain to be consumed as feed in beef finishing rations can be partially reduced by feeding dried distillers grains with solubles (**DDGS**; Ham et al., 1994), a co-product of the ethanol industry. Stock et al. (2000) suggest that each cattle feeder should assess the value of the co-products fed in their operation to determine the optimum feeding level and the economic value of those feeds. Producers have been able to economically feed combinations of corn grain and co-products to finishing beef cattle. However, when costs of corn grain and ethanol co-products increase, producers resort to alternative feedstuffs to remain profitable.

One alternative feedstuff is corn stover. Corn stover is a crop residue that is a co-product of the corn grain industry. Corn stover consists of non-grain components of the corn plant that remain in the field after harvest. Pordesimo et al. (2004) demonstrated the amount of dry matter in stover averaged 50% of the total aboveground dry plant mass, when harvested. With the U.S. corn production of 10.8 billion bushels in 2012 and an estimated 13.8 billion bushels produced in 2013 (USDA, 2013), the potential volume of corn stover that could be harvested is substantial. The challenge with crop residues is that at the time of grain harvest, the residue has a high fiber content that is highly lignified (Klopfenstein, 1978). Furthermore, the residue has low protein and energy content (Klopfenstein et al., 1987). If corn stover and other crop residues are to be included in beef finishing diets, additional protein and energy supplementation would be necessary. One possibility is to incorporate feedstuffs that are protein and energy dense into

feedlot rations to compliment the poor nutrient profile of mature forages. With expansion of the ethanol industry in the Midwest and Great Plains, the availability of ethanol co-products, such as DDGS and wet distillers grains with solubles (**WDGS**), are complimentary protein and energy sources for beef finishing rations and are accessible.

Another possible way to use crop residues is to increase their digestibility. To increase digestibility, chemical and physical processing of corn stover, and other poor quality roughages, is employed and has been in practice for many years (Burdick et al., 1963; Kerley et al., 1985a; Sewell et al., 2009). Chemicals like urea, anhydrous ammonia, and various alkaline compounds disrupt intracellular bonds between cell wall components, cellulose, hemicellulose, and lignin, to increase surface area and microbial attachment and, ultimately, improve digestibility of the forage (Barton et al., 1971; Hunt et al., 1984; Gates et al., 1987). In addition to chemical treatment of poor quality roughages, physical processing methods such as grinding, steam application, irradiation, and milling are effective at increasing the substrate surface area to increase enzymatic and microbial attack (Gharpuray et al., 1983; Satter, 1983; Williams et al., 1995). However, the cost of processing techniques is often not practical, particularly for small-scaled operations. However, greater corn prices, especially from 2008 to 2012, made chemical treatment of corn stover and other crop residues a potential consideration. Few publications have reported the effects of both physical and chemical processing of corn stover and its use in cattle rations commonly fed in commercial practice today. Furthermore, the specific combinations of physical and chemical processing methods to maximize the digestibility of crop residues are not well defined.

Poor Quality Forages

Many factors determine forage quality. In general, poor quality forages are characterized by containing less than 6% crude protein (**CP**), greater than 70% neutral detergent fiber (**NDF**), and less than 45% total digestible nutrients (**TDN**; Wiedmeier et al., 2001). Forage species, harvesting and storing methods, temperature, and climate are several other crucial elements that contribute to the overall quality of the forage. One of the most influential factors to determine forage quality, however, is the stage of maturity in which the particular forage is harvested or grazed.

With increasing forage maturity, changes in the composition of the cell wall occur, including increases in the overall concentration of cellulose, hemicellulose, and lignin, which constitute the NDF portion of the plant. As forages mature and NDF increases, more structural carbohydrates are deposited within the cell wall. Jung and Vogel (1986) investigated the relationship of lignin content and dry matter, cellulose, and hemicellulose digestibility. They discovered that lignin has a greater effect on digestibility when lignin concentrations are lower, as in immature forages, and that the influence of lignin on digestibility lessens as plants mature and lignin increases. Furthermore, they concluded that lignin had a greater effect on the digestibility of other cell wall components (cellulose and hemicellulose) than on total DM digestibility (**DMD**). Results from Jung and Vogel (1986) indicated that lignin inhibition of cell wall digestibility may not follow the linear pattern commonly hypothesized.

These results conflict with a large body of literature that suggest with increasing NDF content in relation to forage maturity, the acid detergent fiber (**ADF**) content of forages also increases, which negatively affects dry matter digestibility (Cherney et al., 1993). However, as forages mature, the increase in ADF concentration over time may vary widely among individual

plant species. Allinson and Osbourn (1970) investigated the digestibility of cellulose and lignin fractions of grasses and legumes harvested at varying maturities. In their study, they concluded that ADF content of grasses remained constant as maturity of the forage increased, while the ADF content of legumes increased more dramatically with forage maturity. They further summarized differences in DMD for both grasses and legumes and concluded that increasing maturities are more positively correlated with lignin content. Smith et al. (1972) analyzed a variety of forages harvested in 1 week intervals to determine the role of lignification on cell wall digestion and reported rates of digestion for cell wall contents were more significantly correlated with the percentage of soluble DM than with lignin concentration. They also concluded that the percentage of soluble DM was greater in legumes than in grasses, which is consistent with the findings from other studies (Hoffman et al., 1993; Elizalde et al., 1999). This may be why researchers have arrived at different conclusions. Jung and Vogel (1986) had based their conclusions on 8 different grass species and had not included legumes in their research.

Regardless of the variation in digestibility, sources agree that the increase in NDF and ADF fractions in mature, poor quality forages can have adverse effects on dry matter intake (DMI). The increasing NDF concentration of mature forages may limit the total amount of DM that can be consumed (Van Soest, 1965). With fibrous diets, ruminal distension may reduce intake due to the increased volume of digesta in the gastrointestinal tract (Allen, 1996). Prigge et al. (1990) demonstrated a linear decrease in DMI for fistulated steers fed increasing levels of switchgrass (100% DM basis) hay when compared to diets containing either a combination of alfalfa and switchgrass (50:50 and 25:75, DM basis) or alfalfa fed as the single forage source (100% DM basis). They concluded that this difference in DMI was due to the difference in NDF content between their alfalfa and switchgrass (51% NDF versus 78% NDF, respectively). Even

though the steers varied in DMI as NDF differed, overall NDF intake did not differ among dietary treatments.

Increasing NDF and ADF concentrations are only part of the concerns with mature, poor quality forages. Protein and energy follow the opposite trend in maturity patterns when compared to fiber; they steadily decrease with increasing maturity. According to the NRC (1996), timothy hay harvested in the late vegetative stage (less mature) contains 14% CP and 62% TDN on a DM basis, whereas timothy hay harvested in the seed stage (more mature) contains 6% CP and 47% TDN. This reduction in both protein and energy, with relation to forage maturity, limits animal performance. Cattle fed forages that contain insufficient protein concentrations for animal growth, may benefit from supplementation of degradable intake protein (**DIP**). Studies have shown that DMI can be increased when protein is supplemented to cattle fed poor quality roughages (McCollum and Galyean, 1985; Sanson et al., 2003; Bohnert et al., 2011). A metabolism trial conducted by Köster et al. (1996) investigated 5 different levels (0, 180, 360, 540, or 720 g/d) of intraruminally infused DIP supplementation (sodium caseinate; 90% CP) to cows with ad libitum access to poor quality prairie-grass hay (1.9% CP, 77% NDF). They observed a quadratic increase in the total forage OM intake with increasing DIP; 29.3, 48.1, 57.3, 64.7, and 61.6 g/kg BW^{.75} for 0, 180, 360, 540 and 720 g of DIP/d supplementation, respectively. Furthermore, they found that the greatest OM and NDF digestibility occurred when DIP was supplemented at 180 g/d. They concluded that forage utilization was maximized, in relation to intake of digestible OM, when the diet contained 11% DIP.

Poor quality forages are widely used worldwide for livestock production. Ruminants are the primary species that are able to utilize these fibrous, highly lignified plant materials. The availability and relatively cheap cost of these feedstuffs have allowed these forage sources to be

a common diet practice for wintering beef cows as well as serve as a supplemental roughage source in feedlot rations. Some of the predominant poor quality forages that are used are crop residues.

Crop Residues

Crop residues are unique when compared to other traditional, mature forages, in that they are only used (grazed or harvested) after the main crop has been removed. This, once again, results in mature, lignified forages that contain minimal amounts of protein and energy but also may represent a substantial potential feed source in the United States (Males, 1987).

Crop residues are widely available across the Midwest. Corn stover is the most abundant crop residue in the United States (Glassner et al., 1998), but other crop residues, such as various cereal grain straws, are more regionally available in the Northwest and the Southeast where corn is not as prevalent. The most economical harvesting method for crop residues, such as corn stover and cereal grain straws, is livestock grazing (Lamm and Ward, 1981). Crop residue grazing is often sufficient to provide maintenance for gestating beef cows, providing that they are at a desirable body condition score (**BCS**); although, environmental conditions and nutrient requirements for a given stage of production may require additional protein or energy supplementation. Ward et al. (1979) found that supplementing cows with protein while grazing grain sorghum residue experienced a 60.9% increase in average daily gain (**ADG**) when compared to cows without additional supplementation of protein. Even though Ward et al. (1979) found differences in gain for cows that were supplemented with protein, cows grazing crop residue that were not supplemented still gained 0.09 kg per day. However, in order to fully use crop residues in beef *feedlot* rations, mechanical harvesting is necessary to collect residue

and provide accessibility year round. From an economical perspective, the mechanical harvesting of crop residues represents considerable costs relative to the overall cost of the material.

Even with mechanical harvesting, there are still potential issues with feeding crop residues to feedlot cattle. Foremost, crop residues vary in nutrient composition by individual plant species, for instance, the NRC (1996) states that oat straw contains 4.40% CP and 45% TDN. Whereas wheat straw contains 3.50% CP and 41% TDN and barley straw is composed of 4.40% CP and 40% TDN. According to Perry and Olsen (1975), grain sorghum crop residue is generally greater in CP than corn crop residue, and plant CP tends to increase with nitrogen fertilizer application rate. While these differences, with regards to CP and TDN, seem relatively small, they are influential when determining possible sources of energy and protein to pair with particular plant species and how much crop residue to ultimately include in the total ration.

One of the most influential determinants of nutrient composition in crop residues is environmental conditions that decrease nutrient availability after the grain is harvested (Ward, 1978). Ward et al. (1979) indicated that weathering of grain sorghum residue during wintering months caused by snow cover resulted in a 27% and 15.9% increase in ADF concentration (expressed as % OM basis) in the leaf and stalk portion of grain sorghum residue. Additionally, Ward et al. (1979) observed a 40% reduction (% OM basis) in CP and a 45.7% reduction in vitro organic matter disappearance (**IVOMD**) in the grain sorghum residue analyzed after the grazing season (March 21) when compared to the residue analyzed immediately post-harvest (November 18). Environmental and physical factors that affect crop residue quality between grain harvest and crop residue harvest are difficult to control and arise due to fluctuations in weather and the need for drastic, often unfeasible, modifications to crop production management to control pre-grain harvest crop residue quality.

Therefore, even though harvesting and storing crop residues is necessary to use them in a feedlot system, harvested crop residues present limitations when added as part of a total mixed finishing ration including: rumen fill, decreased digestibility, and decreased protein content. While the previous research indicates that animals grazing corn residue *may* benefit from protein or energy supplementation with regards to ADG response (Lamm et al., 1977; Anderson et al., 1988; Fernandez-Rivera and Klopfenstein, 1989), growing cattle *require* additional supplementation when fed crop residues. Forbes et al. (1969) evaluated growth performance in cattle fed high concentrate finishing rations containing 0%, 20%, or 40% coarsely chopped barley straw. With increasing inclusion rates of barley straw, Forbes et al. (1969) observed a linear decrease in ADG, with a 47% reduction in gain for steers fed 40% barley straw when compared to steers fed 0% barley straw. These researchers used regression to show that there was a decrease in daily gain of 0.136 kg for every 10% increase in dietary inclusion rate of chopped barley straw. The results from Forbes et al. (1969) illustrate the effects of decreasing energy intake by increasing crop residues in the diet can have on growth performance in feedlot steers fed high forage rations, even though protein was similar among dietary treatments (15.36 to 15.75% CP). Although, Lesoing et al. (1980) observed no significant differences in DMI between growing steers fed increasing levels of wheat straw (0, 10, 20, 30, and 40%), all cattle fed wheat straw had decreased feed efficiency when compared to cattle not fed wheat straw. These data suggest that energy intake was limited despite the lack of difference in overall DMI. As for the effects of protein supplementation for crop residue-based diets, Zorrilla-Rios et al. (1991) supplemented protein in the form of soybean meal (**SBM**; 49% CP) to growing cattle fed wheat straw-based diets at 150 and 500 g/d. They noticed a 50% increase in ADG for protein supplemented steers when compared to the un-supplemented control diets. Even with all

treatment diets containing similar energy (0.73 to 0.77 Mcal NE_g /kg DM) from corn supplementation to meet animal requirements, DMI increased by 5% for SBM supplemented diets. Data from these studies illustrate the need for crop residues to be supplemented with protein and energy to support sufficient performance in growing cattle.

In summary, crop residues are generally bulky and have been shown to reduce intake and gain when fed to growing and finishing beef cattle. Furthermore, growing cattle may benefit from protein and energy supplementation when fed crop residues due to their poor CP and TDN values. Mechanical harvesting of crop residues allows for easier transportation and prolonged storage of crop residues. Feeding value of harvested crop residues may be improved by further physical and chemical processing, thus making them more suitable feeds in beef finishing diets.

Physical Processing of Forages

Physical processing is one of the means used to add feeding value to harvested crop residues. Bale feeders have long been used to reduce the amount of forage that is wasted when feeding unprocessed bales of forage (Buskirk et al., 2003). An alternative method to reduce forage loss is to physically process forages and either limit feed them or incorporate them into a total mixed ration (**TMR**; Braungardt et al., 2010). Physically processing forages not only reduces feed waste, but it also increases DMI of poor quality forages by addressing factors that affect forage digestibility (Beardsley, 1964).

While several factors affect forage digestibility in ruminants, 2 of the main factors are rate of passage from the rumen and the forage to concentrate ratio of the diet. When forages are fed in elevated dietary concentrations, forage type and mean particle size can greatly affect the passage rate of digesta (Prigge et al., 1993). Particle size is one of the main factors that producers

control via physical processing. There are a multitude of physical processing methods for forages, including chopping, milling, grinding, pelleting, steam explosion, and extrusion. All reduce particle size and increase surface area of the forage. Previous studies have determined that reducing the mean particle size of forages increases rate of passage (Pritchard and Heaney, 1963; Meyer et al., 1969; Girard, 1990) but may decrease fiber digestibility.

Other reports have shown that physical processing techniques *can* enhance forage digestibility. For instance, Dehority and Johnson (1961) investigated the effects of duration of ball-milling (0, 6, 24, and 72 h) mature timothy hay on in vitro cellulose digestion (6, 12, 24, 30, and 48 h). They concluded that regardless of ball-milling duration, in vitro cellulose digestibility plateaued by 30 h. As for the effect of ball-milling on cellulose digestion, Dehority and Johnson (1961) observed a 114% increase in cellulose digestion for hay ball-milled for 72 h when compared to the un-milled control. Even though the researchers did not report mean forage particle size, Dehority and Johnson (1961) were still able to illustrate the phenomenon that lignin acts as a physical barrier to cellulolytic bacteria and that reduction in particle size increases cellulose digestibility in mature, poor quality forages.

Pelleting forages, as a means of processing, may affect DMI and digestibility of poor quality forages; however, results are conflicting. Some research has shown that pelleting poor quality forages has a greater impact (increase) on DMI than does pelleting good quality forages (Heaney et al., 1963; Udén, 1988; Lintzenich et al., 1995). Other research suggests that pelleting increases DMI regardless of the quality of forage (Mertens and Ely, 1979, Castrillo et al., 2013), which may be due to increasing ruminal turnover rate from increasing particle density. Coleman et al. (1978) observed that the pelleting of 2 different species of sub-tropical grasses (Paragrass and St. Augustinegrass) at differing stages of maturity (4 and 8 weeks of re-growth) resulted in a

23% increase in OM intake when compared to feeding the forages fresh (green-chopped). Ware and Zinn (2005) studied the effects of replacing sudangrass hay with ground or pelleted rice straw in steam-flaked corn based finishing diets on ruminal metabolism. They reported an 8.8% reduction in ruminal pH of steers fed diets containing pelleted rice straw when compared to steers fed the control diet that contained 12.1% sudangrass hay (DM basis). Additionally, they saw a 24% and 47% increase in total ruminal VFA and propionate concentration, respectively, in cattle fed the pelleted rice straw diet compared to those fed the control diet. No differences were observed in OM digestibility among dietary treatments and these authors concluded that decreased effective neutral detergent fiber (**eNDF**) in the pelleted diets attributed to an acidotic rumen environment (5.43) in cattle fed pelleted diets.

Along with potentially reducing forage digestibility, pelleting may have other adverse effects with regards to decreasing the rumen fiber mat (Liboux and Peyraud, 1997), particularly when intakes are lower (Kovács et al., 1997). Although pellet quality (density and binding properties) is influential in nutrient availability (Thomas et al, 1998), responses in ruminal retention time appear to be dependent on forage species and stage of physiological maturity (Coleman et al., 1978). The reduction in rumen fiber mat may be explained by several digestive factors that occur when pelleted forages are fed. Lintzenich et al. (1995) noticed a 64% increase in fluid dilution rate (%/h) for diets supplemented with pelleted alfalfa hay when compared to their control (100% Bluestem-range forage, DM basis). Increasing fluid dilution and turnover rate of the rumen inherently decreases the overall digestibility of pelleted forages by reducing the retention time in the rumen.

Pelleting can be expensive and requires substantial energy for processing (Thomas and van der Poel, 1996). Steam treatment requires less energy inputs and produces similar results

(Bender et al., 1970). Although much research has been concentrated to investigate the combination of steam treatment of forages with chemical treatment (Hart et al., 1980, Garrett et al., 1980, Williams et al., 1995), which will be discussed later in this review, several studies have demonstrated that steam treatment alone with no chemical addition can increase DMI by up to 50% (Oji and Mowat, 1978) and improve the energy availability of poor quality roughages (Bender et al., 1970). The treatment of forages by steam has not been used as much commercially as other physical processing methods, such as grinding, milling, and pelletizing, due to a relatively high demand for quality control to minimize DM loss during processing (Rangnekar et al., 1982).

While these changes in digestibility with processing can be beneficial, there are more considerations when processed forages are included in TMR. For instance, as the amount of concentrate that is fed increases and replaces forages, the overall fiber digestibility may decrease, most likely due to a reduction in ruminal pH that suppresses cellulolytic microbe activity (Hoover, 1986). Bourquin et al. (1994) observed a 17.4 percentage change (reduction, when measured as the % of DMI) in the total tract digestibility of NDF and ADF when the forage inclusion level (%DM basis) was reduced from 96 to 60%. Furthermore, the amount of grain processing may also affect fiber digestibility. Kerley et al. (1985b) conducted 2 sheep experiments to determine the effects of particle size and dietary inclusion of ground corn cobs in pelleted diets on digestibility. The diets contained 45.5, 35.1, 25.1, or 15.1% ground corn cobs (DM basis) in their first experiment. The second experiment held the inclusion rate of ground corn cobs constant (21.5% DM basis), with the mean particle size of corn cobs ground to a fineness of 6.5, 5.4, 1.4, or 0.8 mm. Kerley et al. (1985b) determined that the overall mean particle size of diets fed decreased with decreasing inclusion of ground corn cobs in the diet from

Experiment 1. However, no differences were observed in mean fecal particle size among treatments in Experiment 2 with the same dietary inclusion of ground corn cobs among dietary treatments (21.5% DM basis) suggesting that reduction in particle size due to degradability in the gastrointestinal tract was greater for diets with the mean particle size of 6.5 and 5.4 mm. Thus, when considering processing for TMR, the whole ration should be considered, not just the forage.

Chemical Treatment of Forages

Another particular area of interest to enhance the use of poor quality forages has been chemical treatment. Chemically treating forages is often easier and more applicable to producers (Herrera-Saldana et al., 1983), and generally requires less equipment and machinery for treatment, than physical processing. Various chemical solutions that have been investigated for their effectiveness in delignification include sulfur dioxide (Ben-Ghedalia and Miron, 1984; Miron et al., 1990), ozone (Miron and Ben-Ghedalia, 1982; Bunting et al., 1984), and weak acids (Knappert et al., 1980; Silanikove and Levanon, 1987). These chemical compounds all increase the NDF digestibility of crop residues and other poor quality forages; however, results have been variable in the *magnitude* of improvement for forage species and chemical pretreatments. Due to availability and ease of application, ammonia (NH₃), urea (CO(NH₂)₂), sodium hydroxide (NaOH), hydrogen peroxide (H₂O₂), and calcium oxide (CaO) are often used as chemical pretreatments to increase the feeding value of poor quality forages.

As previously discussed, cellulose, hemicellulose, and lignin are the main structural polymers that consist of plant cell walls (Canale et al., 1990). The cellulose crystallinity of crop residues and other poor quality forages restricts microbial digestion due to a physical barrier caused by lignin binding to cellulose microfibrils and amorphous hemicellulose polymers

(Hartley and Jones, 1978; Mansfield et al., 1999). Because lignin inherently decreases cellulose digestibility (Jung, 1989), most of the previous research has been dedicated to developing a systematic process to chemically improve the digestibility of highly lignified cell wall fractions through a process known as delignification (Goering et al., 1972). Delignification is the process in which lignin is removed from lignin-containing substrates by the use of chemical compounds (Gierer, 1985). Delignification occurs by permitting swelling of cellulose microfibrils to increase the substrate's overall surface area and break down bonds between lignin and other cell wall components. The removal of the lignin bond increases microbial binding and allows rumen bacterial fibrolytic enzymes to more extensively break down cellulose by hydrolysis (Wang et al., 2004), which in turn increases the enzymatic activity (Lee, 1994). The delignification process frees water soluble hemicellulose and increases the overall DM digestibility (Moss et al., 1993). Thus, delignification may alleviate some of the negative impacts associated with feeding elevated levels of forages, such as poor utilization of fiber and energy and lengthy retention times in the gastrointestinal tract, as well it may increase DMI (Darcy and Belyea, 1980).

Due to ease of application and minimal equipment requirements, ammoniation has been a popular choice for chemical pretreatment among producers. Although there has been much variation reported concerning the effectiveness of ammoniation (Van Soest, 1983), it has continued to be the on-farm chemical treatment of choice for small-scale producers. For poor quality, mature forages that are deficient in protein, ammoniation may be a potential solution to increase nitrogen content (Gates et al., 1987). Numerous studies have shown that ammonia or urea treatment of poor quality forages and other crop residues increases CP content by up to 130%, depending on the concentration and quantity of solution applied (Jakhmola et al., 1993; Mgheni et al., 1993; Salem et al., 1994). Borhami et al. (1983) conducted several lamb

metabolism trials to investigate N utilization in sheep fed ammonia or sodium hydroxide treated straw. The researchers fed barley straw that had been treated with 3% (DM basis) ammonia or with 3% (DM basis) NaOH supplemented with 6 g/day of urea. In their observations, Borhami et al. (1983) saw no differences in intake or rumen fluid volume. Even with a lower N intake for lambs fed the ammoniated straw, they observed a 79% increase in rumen ammonia concentration for lambs fed the ammonia treated straw. They concluded that the lack of available energy in the poorly digested barley straw may have potentially reduced ammonia nitrogen utilization for the diets containing ammoniated straw. Even though they did not observe differences in DM or OM digestibility, a 19.6% reduction in total VFA concentration was noted in lambs fed ammoniated straw compared to lambs fed straw that was treated with NaOH and urea, suggesting that NaOH treatment may better improve ruminal digestion of straw. Minato et al. (1989) fed rice straw treated with 3.4% anhydrous ammonia to steers to investigate rumen microbial populations. They determined the viable counts of cellulolytic bacteria, predominantly *Ruminococcus albus* and *Fibrobacter succinogenes*, were 12.3% greater for ammoniated rice straw when compared to an untreated rice straw. Results from Minato et al. (1989) are in agreement with Cann et al. (1993). Cann et al. (1993) also suggested that the increase in cellulolytic bacteria in their study was due to the delignification process breaking down lignin bound carbohydrates, causing bacterial proliferation. Chemical processing may be used in combination with some of the physical processing methods, discussed in the previous section, to further improve the feeding value of poor quality forages. The combination of chemical and physical processing will be discussed further below.

Physical and Chemical Treatment of Forages

Commonly, chemical treatments are performed after a physical pretreatment, to reduce particle size, in an effort to achieve a more homogeneous incorporation. A considerable amount of research involved with chemically treating crop residues has incorporated physical processing into the methodology. However, the particular type of physical processing method coupled with the chemical treatment of forages appears to depend on the type of chemical processing being conducted as well as total quantity fed for individual experiments.

A combination of chemical and physical treatment that has gained recent popularity has been the on-farm treatment of ground forages with CaO. This is because CaO is a safer and less expensive chemical treatment when compared to NaOH and anhydrous ammonia. Chaudhry (1998) studied the effects of treating wheat straw with CaO or NaOH alone, or in combination with H₂O₂. Although Chaudhry (1998) observed an increase in the *in vitro* dry matter digestibility (**IVDMD**) for CaO treated straw, there was a 56.5% reduction in the overall IVDMD when H₂O₂ was used in combination with CaO. This research concluded that antimicrobial CaO₂ as a hydrate is potentially formed when the 2 chemical pretreatments are used, thus inhibiting microbial digestion. Chaudhry (1998) finally summarized that NaOH or NaOH in combination with H₂O₂ were the most effective at increasing the IVDMD of straw; however, these 2 treatments were more costly and hazardous in comparison to CaO.

An extensive project conducted by Sewell et al. (2009) investigated the effects of feeding thermochemically-treated crop residues that were extruded with 5% CaO (DM basis). For their experiments, after the designated crop residues (corn stover, corn fiber, wheat chaff, and wheat straw) were extruded, they manufactured corn replacement pellets (**CRP**) by pelleting 75% (DM basis) of the individually-extruded crop residues with 25% DDGS (DM basis). When corn stover, as CRP, was fed to lambs at 30% of the dietary DM, no differences were observed in the

apparent digestibility of NDF when compared to the control (60% corn grain, DM basis); however, a 25.1 percentage unit decrease was noted for the apparent digestibility of NDF when lambs were fed unprocessed CS (22% DM basis) when compared to lambs fed the CRP at 30% (DM basis). For their cattle feedlot performance trial, their pellets consisted of a 75%:25% (DM basis) blend of corn fiber:wheat chaff or wheat straw and replaced the corn grain in the control diet (50% corn; DM basis) with either the pellets or un-processed wheat straw. There was a 41% reduction in ADG for steers fed un-processed wheat straw when compared to all other diets and DMI increased by an average of 14.3% among the crop residue-containing diets when compared to cattle fed their control diet. Although Sewell et al. (2009) demonstrated that thermochemically-treated crop residues can partially replace corn in feedlot diets, industry and commercial adoption has not progressed because of the cost from equipment and labor associated with extrusion. Another possible explanation for the lack of acceptance of these dual processing techniques is that Hunt et al. (1984) reported that wheat straw could potentially be *over* processed if both chemically and physically treated. They suggested that this would negatively affect DM digestibility by decreasing ruminal retention time and shifting the site of fermentation to the lower gastrointestinal tract. However, Hunt et al. (1984) used NaOH to chemically process and it is a more caustic chemical than CaO.

Calcium oxide has been shown to increase the DM digestibility of crop residues and other poor quality forages (Gharib et al., 1975; Chaudhry, 2000; Granzin and Dryden, 2003). Because of this, cattle research has been conducted to determine the efficacy of replacing corn with CaO-treated forages in beef finishing diets. Russell et al. (2011) conducted a growing and feedlot finishing study in combination with a lamb metabolism study to determine profitability, feedlot performance, and ruminal metabolism for diets containing 20% corn stover that was either baled,

ensiled at 50% moisture, or hydrated to 50% moisture and treated with 5% CaO on a DMB. Russell et al. (2011) observed a 9.6% and 10.2% increase in DM digestibility for CaO-treated stover over baled and untreated, hydrated stover, respectively. Although they concluded that feeding CaO-treated stover when corn was priced at \$4.00 per bushel was not economical, when corn increased to \$5.00 or \$6.00 per bushel, CaO-treated stover fed at 20% throughout the growing and finishing phase produced the greatest net return. Shreck et al. (2013) indicated that CaO-treated corn stover can be fed in a 3:1 ratio in combination with MWDGS with as little as 25% corn grain to achieve similar gain to feed ratios (**G:F**) as diets containing 56% corn and 5% roughage.

The previous research investigating the effects of alkaline treatment of poor quality forages and crop residues has been focused on improvements in digestibility. Co-product availability in the Midwest and Great Plains, has piqued recent interest in “corn replacement rations” using, not only, chemically-treated crop residues, but also ethanol co-products. However, the combinations of chemical and physical processing methods to optimize potential feeding value of poor quality forages and crop residues in corn replacement systems are currently not known and require further investigation.

Pairing Distillers Gains with Forages

A potential co-product that has been suggested to pair with treated forages for a corn replacement ration is distillers grains with solubles (**DGS**). Protein, fat, and fiber are concentrated nearly 3 times in DGS after the ethanol fermentation process has removed most of the starch from corn grain (Stock et al., 2000). Thus, in comparison to corn grain, DGS have a greater NDF concentration and NDF serves as the primary energy source in DGS (Klopfenstein et al., 2008). In combination with an increase in fiber, the increase in fat content of DGS serves

as an additional source of energy. The NRC (1996) indicates that DGS contains 10.3% fat, versus 4.3% fat found in corn grain. Typically, when DGS are fed above 15% DM inclusion, they serve as a source of energy in feedlot rations (Erickson and Klopfenstein, 2002). Expansion of the ethanol industry has made ethanol co-products such as distillers grains (wet or dry, with or without solubles), condensed distillers grains solubles, and corn gluten feed more abundant and readily available. Because wet co-products are subject to spoilage and waste, drying has been implemented by the ethanol industry to prolong shelf life and stability to enable transportation. However, drying is an expensive process that requires substantial energy (Perrin et al., 2009) and may potentially reduce quality (Weiss et al., 1989). Dahlke (2013) indicated that even mild heat damage can cause a 56.5% reduction in 30 h NDF digestibility. Use of either wet or dry distillers grains by producers has been dependent on their proximity to ethanol plants and quantity fed (Dooley and Martens, 2008).

For cattle consuming poor quality forages, cereal grains have traditionally been used to increase energy density of the diet. However, there has been much research indicating that increasing the level of starch in forage-based diets can negatively affect forage digestibility (Rittenhouse et al., 1970; Bodine and Purvis II, 2003; Lardy et al., 2004). Distillers grains offer a good source of rumen undegradable intake protein (**UIP**) and NDF (NRC, 1996) that may make them a more complementary supplemental protein and energy source for cattle fed forages than cereal grains (Klopfenstein et al., 2008). In fact, supplementation with DGS has been shown to increase ADG in grazing stocker calves (Martínez-Pérez et al., 2013). Morris et al. (2005) supplemented growing heifers with 0, 0.68, 1.36, 2.04, or 2.72 kg DM of DDGS in diets consisting of either a good quality sorghum silage-alfalfa hay mix or a poor quality brome grass hay to determine economics of supplementation and predict intake of forages supplemented with

DDGS. Morris et al. (2005) determined that ADG for both forage diets increased linearly with increasing DDGS inclusion. Additionally, forage intakes were 32.6% greater for heifers consuming the sorghum-silage diet and forage intake decreased linearly as DDGS supplementation increased from 0 to 2.72 kg DM, regardless of forage source. When Morris et al. (2005) performed an economic analysis for heifers fed both poor and good quality forages, revenues were increased in both scenarios by DDGS supplementation. The results from Morris et al. (2005) are in agreement with MacDonald et al. (2007) and illustrate that for growing cattle consuming forage-based diets, DDGS supplementation improves ADG and reduces feed costs.

While supplementation on pastures has long proven effective as evidenced by the previous reports, the recent interest in treated forages fed in combination with DGS focuses more on the comparison to cattle fed corn-based diets. In this manner, treated forage and DGS combinations are being considered “corn replacements”. For example, Schreck et al. (2012a) fed 5% CaO-treated (DM basis) CS (20% of dietary DM) in combination with WDGS (40% DM basis), which replaced 10 percentage units of both corn grain and untreated crop residues (equal parts ground corn cobs, wheat straw, and CS). They observed no differences in ADG, DMI, G:F, or marbling score (**MS**) for the treated CS diet when compared to the corn-based control diet (46% corn grain, DM basis). In a similar trial conducted by Shreck et al. (2012b), there were no effects on ADG, DMI, or backfat thickness (**BF**) in steers fed 20% CaO-treated CS and 40% WDGS (DM basis) in comparison to their control diet (51% corn grain, 40% MWDGS; DM basis). The similar performance results for cattle fed treated CS diets vs. corn-based finishing diets observed by Shreck et al. (2012a) and Shreck et al. (2012b) may be explained by increased ruminal fermentation for treated CS diets. Duckworth et al. (2013) indicated that that treating CS with 5% CaO (DM basis) increased the in situ NDF digestibility of treated CS by 194%, 97%,

and 65% when compared to untreated CS over 24, 36, and 48 h of incubation. All of these previously discussed studies investigated the effects of CaO treatment alone and CaO treatment was not combined with other forms of chemical treatment. The optimum processing (chemical or physical) methods for forages included in combination with DGS as corn replacement feeds have not been reported.

Ethanol co-products have found their way into almost all sectors of the beef industry due to availability. Ethanol co-products have been determined to be excellent sources of UIP, which may be crucial in formulating beef finishing diets. Furthermore, co-products have the potential to increase the energy density of the diet, and may be beneficial in feedlot diets that use poor quality forages as a roughage source, particularly when they are fed at elevated concentrations.

Conclusion

Chemically and physically treated crop residues and other poor quality forages have been investigated extensively throughout the last century. Even though there are numerous chemical pretreatments that are effective at delignification, there have been limited publications that investigate the combinations of chemical and physical processing that may enable treated crop residues and ethanol coproducts to serve as corn replacements in beef finishing rations. Further investigation is necessary to understand the effects of replacing corn with treated forages and distillers grains to determine optimum chemical and physical processing methods and the effects of the combination on feedlot performance, carcass characteristics, and ruminal metabolism.

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CHAPTER 2

EFFECTS OF REPLACING CORN IN FEEDLOT CATTLE DIETS WITH TREATED CORN STOVER AND DISTILLERS GRAINS ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND ECONOMICS

ABSTRACT

The objectives of this study were to determine the effects of replacing corn in feedlot cattle diets with chemically treated or thermochemically treated (extruded) corn stover (**CS**) and modified wet distillers grain with solubles (**MWDGS**) on DMI, gain, carcass characteristics, and feedlot economics. Angus \times Simmental steers ($n = 128$, initial BW = 455 ± 47 kg) were allotted to 1 of 3 dietary treatments: (1) 55% corn, 35% MWDGS, 5% vitamin/mineral supplement, and 5% untreated, ground CS on a DM basis (**CON**), (2) CS treated with 5% CaO (DM basis) and stored in an Ag Bag (**BGCS**), or (3) CS treated with 5% CaO (DM basis) and extruded (**EXCS**). Both treated CS diets contained 20% CS, 40% MWDGS, 35% corn, and 5% vitamin/mineral supplement (DM basis). There were no differences ($P \geq 0.11$) in feedlot performance and carcass characteristics between BGCS and EXCS diets; therefore, data are presented as the contrast of CON versus BGCS and EXCS, combined. During the finishing phase, feeding CaO-treated CS reduced ($P \leq 0.03$) ADG, DMI, G:F, and final BW when compared to steers fed CON. Carcasses from steers fed BGCS or EXCS diets had decreased ($P \leq 0.05$) BF, YG, and HCW and tended ($P = 0.07$) to have decreased KPH when compared to carcasses from steers fed CON. There were no differences ($P \geq 0.16$) among dietary treatments for LM area or MS, regardless of dietary treatment. However, steers fed BGCS had lesser ($P < 0.01$) cost of gain when compared to steers fed EXCS. Feeding treated corn stover as a substitute for corn stover may not be a viable strategy for heavier weight cattle that are approaching finish weight. Replacement of corn with CaO-

treated CS and MWDGS in beef finishing rations reduced feedlot growth and carcass weight, regardless of whether CS was bagged or extruded.

Key Words: calcium oxide, corn stover, distillers grains, feedlot cattle

INTRODUCTION

Expansion of the corn ethanol industry has created competition for corn grain to be used as food, feed, and fuel. Although co-products of the ethanol industry may replace some of the corn grain used in beef finishing rations (Loza et al., 2010), the cost of corn grain and ethanol co-products can fluctuate due to season and demand.

Corn stover (**CS**) is an alternative feedstuff that is inexpensive and readily available. With the U.S. corn production of 10.8 billion bushels in 2012 and an estimated 13.8 billion bushels produced in 2013 (USDA, 2013), the estimated amount of harvestable CS is approximately 75 million metric tons (Acton, 2013). Corn stover, when fed in combination with modified wet distillers grains with solubles (**MWDGS**), can serve as a partial replacement for corn in feedlot diets (Lardy, 2007). However, due to the advanced stages in lignification from physiological maturity, CS is poorly digested (Klopfenstein, 1978).

Research has shown that physical or chemical pre-treatments of crop residues such as CS improve digestibility (Burdick et al., 1963; Kerley et al., 1985; Sewell et al., 2009). Shreck et al. (2013) showed that cattle fed diets that contained as little as 25% corn grain (DM basis), with the remainder of the diet containing co-products and treated crop residues, had similar G:F as cattle fed diets that consist of 5% roughage and 56% corn grain. There have been limited publications investigating the effects of *both* physical and chemical processing of CS to serve as a replacement for corn in beef feedlot diets.

Therefore, we hypothesized that steers fed diets containing CaO treated CS at 20% of the diet DM would perform similarly to or better than steers fed CON, a diet containing 55% corn and 5% untreated CS (DM basis), with steers fed the extruded, CaO-treated CS exhibiting the greatest growth performance. The objectives of this study were to determine the effects of

replacing corn in feedlot cattle diets with chemically treated or thermo-chemically treated (extruded) CS and MWDGS on DMI, gain, carcass characteristics, and feedlot economics.

MATERIALS AND METHODS

All animals in this trial were managed according to guidelines recommended in the Guide for the *Care and Use of Agriculture Animals in Agriculture Research and Teaching* (FASS, 2010). The University of Illinois Institutional Animal Care and Use Committee approved all experimental procedures prior to the initiation of this study.

Animals and Diets

Angus × Simmental crossbred steers (n = 128, initial BW = 455 ± 47.0 kg) were placed on trial at the University of Illinois Beef Cattle and Sheep Field Laboratory in Urbana, IL. Steers were housed in total confinement in 4.9 m × 4.9 m concrete slatted floor pens that are covered with high impact rubber matting. Steers were weighed on 2 consecutive d at the beginning of the trial to determine initial BW. Body weights from d 0 were used to randomly assign steers into pens on paper. Then, steers were implanted with Component TE-S® with Tylan (Elanco, Greenfield, IN) and allotted to their designated treatment pens on d 1.

Steers were randomly assigned to 1 of 3 dietary treatments (Table 2.1): (1) 55% corn and 5% untreated, ground CS on DM basis (**CON**), (2) CS treated with 5% CaO (DM basis) and stored in an Ag Bag (**BGCS**), or (3) CS treated with 5% CaO (DM basis) and extruded (**EXCS**). In the BGCS and EXCS diets, treated CS and MWDGS replaced corn grain and were 60% of the total diet DM (40% MWDGS and 20% CaO-treated CS, DM basis). Diets were mixed and delivered once daily and fed for ad libitum intakes. Samples of the TMR were collected weekly at the time of feeding from the feed bunks. Approximately 454 g were sampled from each bunk,

composited, and hand mixed. After mixing, 10% of the composited sample was retained and frozen at -20°C for later compositing. After the trial ended, the weekly composite samples were thawed, composited into 1 final sample, and mixed by hand. Then, 10% of the final composited TMR sample was retained for nutrient analysis.

Treatment of Corn Stover for BGCS and EXCS Diets

Round bales (approximately 544 kg) of CS were delivered to the University of Illinois Beef Cattle and Sheep Field Laboratory and stored under roof. Corn stover was baled in September 2010 and stored under roof until delivered to the University of Illinois in March 2011. After arrival, CS was ground through a 2.54 cm screen using a tub grinder (Haybuster Big Bite H-1000 series; Agricultural Products DuraTech Industries International, Inc., Jamestown, ND). Ground CS was stored in an open-fronted commodity bay for no more than 7 d prior to chemical treatment. Ground CS was then loaded into a mixing wagon (Knight Reel Auggie 3130; Kuhn Agricultural Machinery, Brodhead, WI) and hydrated to 50% moisture with tap water. Calcium oxide (Microcal OF 200, Mississippi Lime Company, St. Louis, MO) was added at a concentration of 5% (DM basis) to the hydrated CS and mixed for 15 min to ensure complete incorporation. The average pH of CaO-treated CS prior to ensiling was 10.9. Treated corn stover was then anaerobically stored in an Ag-Bag (A. Miller-St. Nazianz, Inc. Company, St. Nazianz, WI) for 21 d prior to feeding. For extruded CS, CS was loaded into a smaller, custom-built feed mixing wagon that was retro-fitted with a hydraulic-powered feed unloading conveyer belt (E Rissler Mfg. LLC, New Enterprise, PA) and hydrated to 34% moisture. The 34% hydrated CS was unloaded from the feed mixing wagon onto a conveyor belt and the 5% CaO (DM basis) and additional 16% water were added as a solution via calibrated pump prior to processing through a dual-shafted encased extruder (Readco Kurimoto Continuous Processor, York, PA). Quality

control for processed CS was monitored by regulating retention time (6 to 10 s) to achieve the desired exit temperature ($76.7 \pm 2.8^\circ \text{C}$). After processing, extruded CS was aerobically stored in a commodity bay for 8 ± 6 d prior to feeding. While the bagging and extrusion processing methods were targeted to apply identical concentrations of CaO chemical treatment, when diets were analyzed, the dietary concentration of calcium was different for the BGCS and EXCS diets.

Feedlot Performance and Carcass Data Collection

Body weight was recorded every 2 wk and individual feed intake was measured using the GrowSafe® (GrowSafe Systems Ltd., Airdrie, AB Canada) automated feed intake monitoring system. Performance data collection ceased 12 d before cattle were shipped due to restricted availability with GrowSafe® feed monitoring system. Two feedlot barns collapsed prior to the initiation of the trial, thus the use of the GrowSafe® feed monitoring system was limited (69 d) and intake data collection ended 12 d prior to harvest. However, BW was recorded on 2 consecutive d at the end of the intake data collection phase (d 69 and d 70). The average of the 2 d BW recorded after d 69 were used, with the 69 d of intake data collection, to calculate ADG and G:F. Steers remained on their dietary treatments for 12 d following the completion of intake data collection. Throughout the trial, 3 steers (1 from each treatment) were removed from the data set for reasons not related to the trial. Steers were weighed in a hydraulic squeeze chute (Flying W Livestock Equipment, Watonga, OK) with a Tru-Test XR 3000® (Tru-Test Inc., Mineral Wells, TX) weight recording system. Steers were deemed ready to ship after visual appraisal estimated that cattle had sufficient finish to grade Low Choice or higher.

Steers were shipped 301 km via commercial trucking and slaughtered at a commercial abattoir. The HCW were recorded on the day cattle were slaughtered. Carcasses were then chilled for 24 h at -4°C . After a 24 h chill, carcasses were ribbed between the 12th and 13th ribs

to determine 12th rib backfat thickness (**BF**) and LM area. Marbling score (**MS**) and KPH were then determined via USDA grading cameras. The YG was calculated using the USDA equation (USDA, 1997). Because intake data collection was terminated 12 d prior to harvest, a more accurate determination of final BW was calculated. Final BW was calculated as HCW divided by a common dressing percent (**DP**) of 63.0%. After steers were harvested, a total of: 20 marbling scores, 16 BF, LM area, KPH, YG measurements, and 15 HCW measurements were not recorded, and, thus, were removed from the carcass analysis. These measurements were not reported due to the occurrences of no roll and dark cutter carcasses as well as camera grading error, which were evenly distributed among treatments and not a result of dietary treatment.

Sample Analysis

Diet TMR samples were composited, freeze-dried (Labconco; FreeZone¹², Kansas City, MO), and ground with a Wiley mill (Arthur H. Thomas; Philadelphia, PA) to pass through a 1mm screen. Freeze-dried, composited TMR samples were analyzed to determine nutrient composition. Individual analyses included: DM (105° C) in a forced-air drying oven (Heratherm OMS100, Thermo Fischer Scientific Inc., Waltham, MA), ash and OM (500° C for 20 h, HotPack Muffle Oven, Model 770750, HotPack Corp., Philadelphia, PA), NDF (Ankom Technology, Method 6; Ankom200 Fiber Analyzer, Ankom Technology, Macedon, NY), ADF (Ankom Technology, Method 5; Ankom200 Fiber Analyzer, Ankom Technology, Macedon, NY), CP (Leco TruMac; LECO Corporation, St. Joseph, MI), fat (Ankom Technology, Method 2; Ankom^{XT10} Extraction System, Ankom Technology, Macedon, NY). Inductively coupled plasma electrophoresis was used to determine macrominerals after perchloric acid digestion (AOAC, 1998).

An economic analysis was performed using the actual feedstuff prices paid by the University of Illinois Beef Cattle and Sheep Field Laboratory during the duration of the trial (June 2011 through August 2011). Feedstuff prices per kg of DM were as follows: Corn \$0.201; CS \$0.076; BGCS \$0.096; EXCS \$0.142; MWDGS \$0.203; Supplement \$0.243. Bales of CS were priced at \$25/bale, were 85% DM, and weighed 544 kg on average. Grinding of CS was \$10/bale. Therefore, the total price per kg (DM basis) of untreated CS was calculated as: $[(\$35) / (544 \times 0.85)]$. Calcium oxide treatment (5% DM basis) of CS for BGCS included the total price of untreated CS plus the cost of CaO (\$0.407/kg) and was calculated as: $\{[(\$35) / (544 \times 0.85)] + (0.407 \times 0.05)\}$. Thermochemical treatment (extrusion) for EXCS included the total cost of untreated CS, cost of CaO, and an additional \$0.046/kg (DM basis) incorporated as the cost of labor for extrusion, rental, and trucking charges for the Readco® feed processor used in this trial. Thus, the price of EXCS was calculated as: $\{[(\$35) / (544 \times 0.85)] + (0.407 \times 0.05) + (0.046)\}$. Diet cost were calculated on a DM basis and presented as a cost per metric ton of DM. Cost of gain was calculated using the following equation: $[(\text{diet cost/kg}) \times G:F^{-1}]$. Total feed costs were calculated using the following equation: $[(\text{DMI} \times \text{days on feed}) \times \text{diet cost}]$. Because DMI remained constant for dietary treatments throughout the study, DMI was extrapolated for the following 12 d after individual feed intake was measured. Therefore 81 d were used in the calculation of total feed costs rather than 69 d in which individual DMI was measured. Therefore, the analysis conducted was strictly a reflection of feed intake, feed efficiency, and feedlot gain. All steers were managed identically during shipping and on the day of harvest. Other costs associated with feedlot profitability (e.g. shrink and gut fill) were not included in cost of gain equation. Carcass value was not included in this analysis.

Statistical Analysis

Feedlot growth performance, carcass characteristics, and economic data were analyzed in a completely randomized design. Steer served as the individual experimental unit. The MIXED procedure of SAS (SAS Institute; Cary, NC) was used to analyze all noncategorical feedlot performance, carcass characteristics, and economic data. Categorical carcass characteristics were analyzed using the GLIMMIX procedure of SAS (SAS Institute; Cary, NC). For feedlot performance, carcass traits, and economics, contrast statements were used to analyze CON versus BGCS and EXCS, and BGCS vs. EXCS. There were no difference ($P \geq 0.11$) between BGCS and EXCS for feedlot performance or carcass characteristics; therefore, only the contrast of CON vs. BGCS and EXCS will be reported and discussed. As for feedlot economics, both contrasts are presented. Differences were declared significant and $P \leq 0.05$. Trends were discussed at $0.05 < P < 0.10$.

RESULTS AND DISCUSSION

Although we had hypothesized that feeding cattle extruded CS would increase growth performance and improve carcass characteristics when compared to feeding cattle ensiled, or bagged, CaO-treated CS, this was not the case. There were no differences ($P \geq 0.12$) in growth performance or carcass characteristics between steers fed BGCS or EXCS; therefore, only the contrast of CON versus BGCS and EXCS will be discussed for feedlot performance and carcass traits. Both preplanned orthogonal contrasts (CON vs. BGCS and EXCS; BGCS vs. EXCS) for economics will be discussed.

During the finishing phase, steers fed CON, or the corn-based diet, had an 8% increase ($P < 0.01$) in DMI when compared to steers fed BGCS or EXCS, CaO-treated CS diets (Table 2.2). Because of this increase in DMI, or energy intake, steers fed CON had 18% greater ($P < 0.01$) ADG than steers fed treated CS. This increase in ADG increased ($P < 0.01$) efficiency of CON

steers, reported as G:F, as well. The reduced ADG and efficiency in steers fed 5% CaO-treated CS is contradictory to previous research (Russell et al., 2011; and Shreck et al., 2012a). Russell et al. (2011) reported a 5% improvement ($P < 0.05$) in feed efficiency that was primarily driven by a reduction ($P < 0.05$) in DMI with no change in ADG when steers were fed 20% (DM basis) CaO-treated CS (5%, DM basis) and 40% (DM basis) modified distillers grains with solubles when compared to cattle fed the control that contained 70% corn and 20% MWDGS (DM basis). Shreck et al. (2012a) reported no differences in ADG for steers fed 20% (DM basis) treated CS (5% CaO, DM basis) and 40% wet distillers grains with solubles (DM basis) when compared to steers fed their control diet that contained 46% corn and 10% of untreated crop residues (equal parts wheat straw, corn stover, and ground corn cobs; DM basis). Although ADG and DMI data from the current trial contradict Russell et al. (2011) and Shrek et al. (2012a), they are in agreement with Duckworth et al. (2013). In 2 studies, feeding 5% CaO-treated CS at 20% of the diet DM resulted in a 16% reduction ($P \leq 0.03$) in ADG for steers and heifers when compared to cattle fed untreated, hydrated (50% moisture) CS (20% DM basis; Duckworth et al., 2013). Duckworth et al. (2013) suggested that their reduction in ADG was caused from a 17% change (reduction) in DMI ($P < 0.01$) for cattle fed 5% CaO-treated CS when compared to the untreated CS diets. Results in growth performance and feed efficiency have been inconsistent among researchers. This may be caused by the variation in treatment methods for CS and the different controls they are being compared to (as discussed below). While all of the previously discussed studies treated CS with CaO at 5% (DM basis), storage methods were not consistent. In fact, the bagged CS used in this study was manufactured similarly to the treated CS fed by Russell et al. (2011) and Shreck et al. (2012a), while, Duckworth et al. (2013) aerobically stored their treated CS.

Even though the CS used for the BGCS diet CS was anaerobically stored, the addition of CaO and the inherent low water soluble carbohydrate content of CS may have prevented a faster, and more drastic, drop in pH that is more commonly seen in good quality, ensiled forages such as corn silage (pH = 7.2 after 3 mo of storage vs pH = 10.9 prior to bagging). Although there was not a notable amount of mold within the bag of BGCS in this study, we did notice CS used for the BGCS diet had large, dense masses throughout it that were difficult for the feed truck to break down. This may have affected the palatability of the diet and contributed to the reduced DMI in steers fed the BGCS diet. To the authors' knowledge, there have been no publications that describe the physical characteristics and palatability of CaO-treated CS, especially when it has been anaerobically stored. Schroeder (2013) noted that feeding cattle CaO at 1.2% of the diet DM decreased palatability of the feed. Cattle consumed smaller meals more frequently throughout the day, despite spending more time at the feed bunk when fed CaO compared to cattle that received no additional CaO in the diet; however, these authors fed CaO as an addition to the TMR and did not feed CS. This issue of storage, palatability, and physical characteristics of stored, treated CS warrants further research.

Because steers final BW was calculated from HCW, HCW was increased ($P = 0.03$) in steers fed CON by 17.5 kg on average (Table 2.3). In addition to heavier carcasses, feeding steers CON increased ($P < 0.01$) BF on the carcass by 39%, on average, compared to carcasses from steers fed either BGCS or EXCS. With no differences ($P = 0.48$) observed among dietary treatments for LM area and a tendency for cattle fed CON to deposit a greater ($P = 0.07$) percentage of kidney, pelvic, and heart fat, YG increased ($P < 0.01$) for steers fed CON. There was no effect ($P \geq 0.11$) on marbling score, percentage of choice, or percentage of average choice or better for steers fed CON compared to the combined effects of BGCS and EXCS. In a

similar study in which CaO-treated CS replaced corn grain in finishing feedlot diets conducted by Shreck et al. (2012b), no differences ($P \geq 0.05$) were observed for calculated YG or 12th rib BF thickness between their control diet (50% corn grain, DM basis) and 5% CaO-treated CS diet (36% corn grain, 20% CaO-treated CS; DM basis). Although our data for MS are in agreement with Shreck et al. (2012b), they conflict with other researchers that have fed CS treated with 5% CaO (DM basis). In another trial that reported feeding CaO-treated CS through the finishing phase, marbling score was decreased without affecting calculated YG, BF thickness, or KPH (Russell et al., 2011). Additionally, Duckworth et al. (2013) indicated that feeding treated CS (5% CaO, DM basis) resulted in a 13.2% reduction in MS for heifers when compared to cattle fed untreated CS (20% DM basis). The differences in MS in the present trial, as well as the aforementioned studies, may be attributed to the increase in corn inclusion rate in the control diet (70% DM basis) in the Russell et al. (2011) study compared to all the others. Researchers do agree that LM area is not affected by feeding CaO-treated CS (Russell et al., 2011; Shreck et al., 2012a; Shreck et al., 2012b; Duckworth et al., 2013). However, why it is not affected is unclear, especially because feedlot growth performance has been inconsistent among published reports when feeding CaO-treated CS.

There were no differences ($P = 0.11$) for cost of gain/kg of BW for cattle fed CON compared to the combined effects of BGCS and EXCS, and cattle fed EXCS had a greater ($P < 0.01$) cost of gain/kg of BW gain than cattle fed BGCS (Table 2.4). However, the largest driving factor of economics was the increase in DMI and ADG for cattle fed CON which resulted in the greatest ($P < 0.01$) total feed cost/hd. Russell et al. (2011) conducted an economic analysis evaluating the cost of production and net return per head when corn grain was priced at \$4, \$5, and \$6 per bushel and fed in combination with treated CS and modified distillers grains with

solubles. Russell et al. (2011) concluded that when corn was priced at \$5 or \$6 per bushel, treating CS with 5% CaO and feeding it at 20% (DM basis) throughout the entire feeding period offered the least total cost of gain and offered the greatest returns on a per head basis. In our study, cattle fed the BGCS diet had lower cost of gain and total feed costs/hd when compared to cattle fed EXCS. Due to the reductions in ADG and DMI observed for BGCS and EXCS, feeding treated CS did result in significant reductions in total feed costs when compared to steers fed our control diet.

IMPLICATIONS

Throughout this study, there were no feedlot performance or carcass differences between cattle fed diets containing either BGCS or EXCS. Including CaO-treated corn stover in the diet at 20% DM basis, regardless of processing and storage method, reduced ADG, DMI, G:F, BF, and YG with no effect on marbling score. However, cattle fed CS treated with 5% CaO had the lesser total feed costs compared to cattle fed CON.

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Table 2.1. Ingredient and analyzed nutrient composition of diets (% DM basis) fed to steers

Item, % DM basis	Dietary Treatments ¹		
	CON	BGCS	EXCS
MWDGS	35	40	40
Dry Rolled Corn	55	35	35
Corn Stover	5	20	20
Supplement ²	5	5	5
Analyzed Composition, % DM basis			
NDF	17.70	23.86	24.39
ADF	9.61	14.97	15.04
CP	14.20	14.65	15.09
Fat	5.14	4.56	4.86
Ca	0.69	1.35	1.69
P	0.42	0.43	0.43
S	0.27	0.32	0.32
Ash	5.31	8.38	9.05

¹CON = 55% corn and 5% untreated-ground corn stover on DM basis (corn control). BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO. EXCS = corn stover hydrated to 50%, treated with 5% CaO, and then extruded using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

²Supplement formulated to contain (DMB): Dry-Cracked Corn, 60.76%; Limestone, 34.19%; Swine Trace Mineral, 2.23% (85% Salt, 2.57% Fe, 2.86% Zn, 5,710 ppm Mn, 2,290 ppm Cu, 100 ppm I, 85.7 ppm Se); ADEK Vitamin Mix, 0.22% (680,400 IU Vit A/kg, 68,040 IU Vit D3/kg, 9,072 IU Vit E/kg, 453.5 IU Vit K/kg, 3.63 mg Vit B12/kg, 907.2 mg Riboflavin/kg, 2,494.8 mg d-Pantothenic Acid/kg, 3,402 mg Niacin/kg, 29,461 mg Choline/kg); Tylan 40, 0.25% (88 g tylosin/kg of DM, Elanco Animal Health, Greenfield, IN); Rumensin 80, 0.34% (176 g monensin/kg of DM, Elanco Animal Health); Thiamine 40, 0.21% (88,000 mg thiamine mononitrate/kg of DM, ADM Alliance Nutrition, Inc., Quincy, IL); Copper Sulfate, 0.11%; Fat, 1.69%.

Table 2.2. Effects of feeding CaO treated or thermochemically-treated corn stover on feedlot growth performance of finishing steers

Item	Dietary Treatments ¹			SEM	P-value ²
	CON	BGCS	EXCS		
n	43	41	41		
Initial BW, kg	453	452	461	7.32	0.72
Final BW ³ , kg	585	557	559	10	0.03
ADG, kg	1.67	1.43	1.34	0.05	<0.01
DMI, kg	9.50	8.63	8.88	0.18	<0.01
G:F	0.176	0.166	0.155	0.005	<0.01

¹CON = 55% corn and 5% untreated-ground corn stover on DM basis (corn control). BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO. EXCS = corn stover hydrated to 50%, treated with 5% CaO, and then extruded using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

²Probability for preplanned orthogonal contrast between CON vs. BGCS + EXCS.

³Final BW calculated as HCW/0.63 (Common DP).

Table 2.3. Effects of feeding CaO treated or thermochemically-treated corn stover on carcass characteristics of finishing steers

Item	Dietary Treatments ¹			SEM	<i>P</i> -value ²
	CON	BGCS	EXCS		
n	43	41	41		
HCW, kg	369	351	352	6	0.03
Backfat, cm	1.39	0.98	1.03	0.06	<0.01
LM area, cm ²	81.11	83.38	81.43	1.52	0.48
KPH, %	2.00	1.89	1.92	0.04	0.07
Yield Grade ³	3.38	2.71	2.83	0.10	<0.01
Marbling Score ⁴	456	423	436	15	0.16
Quality Grade					
≥Choice, %	62.2	60.0	61.1	-	0.87
≥Average Choice, %	35.1	14.3	27.8	-	0.11

¹CON = 55% corn and 5% untreated-ground corn stover on DM basis (corn control). BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO. EXCS = corn stover hydrated to 50%, treated with 5% CaO, and then extruded using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

²Probability for preplanned orthogonal contrasts between CON vs. BGCS + EXCS.

³Yield Grade calculated using USDA equation (USDA, 1997).

⁴Marbling Score: 400 = Low Choice, 500 = Average Choice, 600 = High Choice.

Table 2.4. Effects of feeding CaO treated or thermochemically-treated corn stover on economics of finishing steers

Item	Dietary Treatments ¹			SEM	P-value ²	
	CON	BGCS	EXCS		CON vs. all	BGCS vs. EXCS
Diet ³ , \$/metric ton of DM	\$197.55	\$182.90	\$192.10	-	-	-
Cost of gain, \$/kg of BW gain	\$1.15	\$1.14	\$1.32	0.04	0.11	<0.01
Total feed cost/hd ⁴	\$151.96	\$127.89	\$138.10	2.87	<0.01	0.01

¹CON = 55% corn and 5% untreated-ground corn stover on DM basis (corn control). BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO. EXCS = corn stover hydrated to 50%, treated with 5% CaO, and then extruded using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

²Probability for preplanned orthogonal contrasts between CON vs. BGCS + EXCS and BGCS vs. EXCS.

³Feedstuff prices per kg of DM: Corn, \$0.201; CS, \$0.076; BGCS, \$0.096; EXCS, \$0.142; MWDGS, \$0.203; Supplement \$0.243

⁴Calculated using 81 days on feed.

CHAPTER 3

EFFECTS OF TREATMENT METHOD OF CORN STOVER ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, DIGESTIBILITY, AND RUMINAL METABOLISM WHEN FED TO CATTLE

ABSTRACT

The objectives were to evaluate the effects of replacing corn in feedlot finishing diets with corn stover (**CS**) treated by various methods, chemical (CaO and NaOH) and physical (anaerobic or extruding), and included in diets containing modified wet distillers grain with solubles (**MWDGS**) on growth performance, carcass characteristics, digestibility, and ruminal metabolism of cattle. *Exp. 1*: Steers (n = 18, initial BW 385 ± 32 kg) and heifers (n = 41, initial BW 381 ± 27 kg) were allotted to 1 of 5 dietary treatments: (1) 55% corn, 35% MWDGS, 5% vitamin/mineral supplement, and 5% untreated, ground CS (**CON**), (2) CS treated with 5% CaO (DM Basis) and stored in an ag-bag (**BGCS**) CS, (3) CS treated with 5% CaO (DM Basis) and extruded (**5 EXCS**), (4) CS treated with 4% CaO and 1% NaOH (DM Basis) and extruded (**4,1 EXCS**), or (5) CS treated with 3% CaO and 2% NaOH (DM Basis) and extruded (**3,2 EXCS**). All treated CS diets contained 20% CS, 40% MWDGS, 35% corn, and 5% vitamin/mineral supplement (DM basis). There were no treatment differences ($P \geq 0.20$) ADG, G:F, BF, MS, LM, or YG. However, cattle fed CON had increased ($P = 0.02$) DMI compared to cattle fed the treated CS diets. *Exp. 2*: Using Exp. 1 diets, steers (n = 5; initial BW = 417 ± 21 kg) were fed for 90% of ad libitum intake in a 5×5 Latin square design. Apparent digestibility of NDF and ADF increased ($P < 0.01$) for cattle fed treated CS diets compared to cattle fed the control diet, regardless of the treatment applied. Ruminal pH was lowest in cattle fed BGCS from 0 to 6 h

post-feeding compared to cattle fed all other diets. Cattle fed the BGCS and EXCS diets had the greatest ($P < 0.01$) mean acetate concentrations, which increased ($P = 0.01$) total VFA concentrations. Replacing a portion of the corn with treated CS in feedlot diets containing MWDGS increased fiber digestibility without affecting feedlot cattle gain, feed efficiency, marbling score, or LM area.

Key Words: calcium oxide, corn stover, digestibility, distillers grains

INTRODUCTION

Ethanol co-products may be able to partially replace corn grain in beef finishing diets (Loza et al., 2010). Corn stover (**CS**) is an alternative feedstuff that is inexpensive and readily available. In combination with modified wet distillers grains with solubles (**MWDGS**), CS has been used to replace corn in beef finishing diets (Lardy, 2007); however, CS is poorly digested (Klopfenstein, 1978).

Physical and chemical treatments have been shown to improve digestibility of CS (Burdick et al., 1963; Kerley et al., 1985; Sewell et al., 2009). Due to availability, ease of application, and cost, CaO has become an attractive chemical pre-treatment for CS (Russell et al., 2011; Shreck et al., 2012a). Additionally, Sewell et al. (2009) demonstrated that extruding CS with CaO can improve NDF digestibility when compared to unprocessed CS. However, NaOH increases fiber digestibility of crop residues to a greater extent than CaO alone (Chaudhry, 2000). Shreck et al. (2013a) showed that cattle fed diets containing co-products and treated crop residues, have similar feed efficiencies as cattle fed corn-based diets.

The specific combinations of physical and chemical processing methods to maximize the digestibility of crop residues such as CS are currently not known. We hypothesized that cattle fed diets containing CaO-treated CS at 20% of the diet DM would perform similarly to cattle fed a corn-based control diet during the finishing phase. Additionally, we predict that chemically and thermochemically treating CS will improve digestibility due to neutralizing rumen pH from the inherent basic nature of CaO and NaOH. Therefore, the objectives of these 2 studies were to evaluate the effects of replacing corn in feedlot finishing diets with treated CS treated by various methods, chemical (CaO and NaOH) and physical (anaerobic or extruding), and included in diets

containing MWDGS on growth performance, carcass characteristics, digestibility, and ruminal metabolism of cattle.

MATERIALS AND METHODS

All animals in this trial were managed according to guidelines recommended in the Guide for the *Care and Use of Agriculture Animals in Agriculture Research and Teaching* (FASS, 2010). All experimental procedures were approved prior to the initiation of this trial by the University of Illinois Institutional Animal Care and Use Committee.

Experiment 1

Animals and Diets. Angus × Simmental crossbred steers (n = 18, initial BW 385 ± 32 kg) and heifers (n = 41, initial BW 381 ± 27 kg) were placed on trial at the University of Illinois Beef and Sheep Field Laboratory in Urbana, IL. Steers were housed in total confinement in 4.9 m × 4.9 m pens on concrete, slatted floors that are covered with rubber matting.

Steers and heifers were randomly assigned to 1 of 5 diets (Table 3.1): (1) 55% corn, 35% MWDGS, 5% vitamin/mineral supplement, and 5% untreated, ground CS (**CON**), (2) CS treated with 5% CaO (DM Basis) and stored in an Ag-Bag (**BGCS**) CS, (3) CS treated with 5% CaO (DM Basis) and extruded (**5 EXCS**), (4) CS treated with 4% CaO and 1% NaOH (DM Basis) and extruded (**4,1 EXCS**), or (5) CS treated with 3% CaO and 2% NaOH (DM Basis) and extruded (**3,2 EXCS**). All treated CS diets contained 35% corn, and 5% vitamin/mineral supplement (DM basis). Treated CS and MWDGS replaced corn grain. Corn replacement diets contained 20 and 40% (DM basis) of CS and MWDGS, respectively. Diets were mixed and delivered once daily and cattle were fed for ad libitum intake. The TMR samples were collected weekly at the time of feeding from the feed bunks. At the time of collection, approximately 454 g were sampled from each bunk, composited, and mixed by hand. After mixing, 10% of the composited sample was

retained and frozen for later compositing. After the trial ended, the 11 weekly samples were thawed, composited into 1 final sample, and mixed by hand. Then, 10% of the final composited TMR sample was retained for nutrient analysis.

Treatment of Corn Stover for Treated Corn Stover Diets. Round bales (approximately 544 kg) of CS were delivered to the University of Illinois Beef and Sheep Field Laboratory and stored under roof for no more than 14 d prior to processing. Corn stover was baled in September 2010 and stored under roof until delivered to the University of Illinois in March 2011. Bales of CS were ground using a tub grinder (Haybuster Big Bite H-1000 series; Agricultural Products DuraTech Industries International, Inc., Jamestown, ND) through a 2.54 cm screen and stored in a commodity bay for no more than 7 d prior to chemical processing. Corn stover was then loaded into a mixing wagon (Knight Reel Auggie 3130; Kuhn Agricultural Machinery, Brodhead, WI) and hydrated to 50% moisture with tap water. Calcium oxide (Microcal OF 200, Mississippi Lime Company, St. Louis, MO) was added at a concentration of 5% (DM basis) to the hydrated CS and mixed for 15 minutes to ensure complete incorporation. The average pH of CaO-treated CS prior to bagging was 10.9. Treated corn stover was then bagged in an Ag-Bag (A. Miller-St. Nazianz, Inc. Company, St. Nazianz, WI) and anaerobically stored for no less than 21 d prior to feeding. For extruded CS, CS was loaded into a smaller, custom built, retro-fitted feed mixing wagon with a hydraulic-powered conveyer belt (E Rissler Mfg. LLC, New Enterprise, PA) and hydrated to 34% moisture. The 34% hydrated CS was unloaded from the mixing wagon onto a conveyor belt and the 5% CaO, 4% CaO:1% NaOH, or 3% CaO:2% NaOH (5% DM basis) and additional 16% water were added as a solution via calibrated pump prior to processing through a dual-shafted encased extruder (Readco Kurimoto Continuous Processor, York, PA). Two individual pumps were used to transfer the CaO and NaOH solutions from separate storage

tanks, in which both solutions were mixed fresh daily. Quality control of processed CS was monitored by regulating the retention time (6 to 10 s) to achieve the desired exiting temperature ($76.7 \pm 2.8^\circ\text{C}$). Output of the processor was 270 kg/h. After processing, extruded corn stover was aerobically stored in a commodity bay for 8 ± 6 d prior to feeding.

Feedlot Performance and Carcass Data Collection. Steers and heifers were weighed on 2 consecutive d at the beginning of the trial to determine initial BW. On d 1, steers and heifers were implanted with Component TE-S® and TE-H®, respectively, with Tylan (Elanco, Greenfield, IN) and weights from d 0 were used to randomly assign steers and heifers to their designated mixed-gender treatment pens. Body weight was recorded on d 0, 1, 14, 28, 42, 56, and 70. Cattle were weighed in a hydraulic squeeze chute (Flying W Livestock Equipment, Watonga, OK) with a Tru-Test XR 3000® (Tru-Test Inc., Mineral Wells, TX) weight recording system. Individual feed intake was measured for 75 d using the GrowSafe® (GrowSafe Systems Ltd., Airdrie, AB Canada) automated feed intake monitoring system. Steers and heifers were deemed ready to ship after visual appraisal estimated that cattle had sufficient finish to grade Low Choice or better.

All cattle were shipped 301 km and slaughtered at a commercial abattoir. Hot carcass weights (**HCW**) were recorded on the day cattle were slaughtered. Carcasses were then chilled for 24 h at -4°C . After a 24 h chill, carcasses were ribbed between the 12th and 13th ribs to determine 12th rib backfat thickness (**BF**), LM area, marbling score (**MS**), and kidney pelvic and heart fat (**KPH**) via USDA grading cameras. Yield Grade (**YG**) was calculated using the USDA equation (USDA, 1997). Final BW was calculated by adjusting HCW to a common dressing percentage (**DP**) of 62.0. This final BW was then used to calculate ADG, and G:F.

Sample Analysis. Compositated TMR diet samples were freeze-dried (Labconco; FreeZone¹², Kansas City, MO), and ground with a Wiley mill (Arthur H. Thomas; Philadelphia, PA) to pass through a 1mm screen. Compositated, freeze-dried TMR samples were analyzed to determine nutrient composition. Analyses included: DM (105° C) via forced-air drying oven (Heratherm OMS100, Thermo Fischer Scientific Inc., Waltham, MA), ash and OM (500° C for 20 h, HotPack Muffle Oven, Model 770750, HotPack Corp., Philadelphia, PA), NDF (Ankom Technology, Method 6; Ankom200 Fiber Analyzer, Ankom Technology, Macedon, NY), ADF (Ankom Technology, Method 5; Ankom200 Fiber Analyzer, Ankom Technology, Macedon, NY), CP (Leco TruMac; LECO Corporation, St. Joseph, MI), fat (Ankom Technology Method 2; Ankom^{XT10} Extraction System, Ankom Technology, Macedon, NY). Inductively coupled plasma electrophoresis was used to determine macro minerals after perchloric acid digestion (AOAC, 1988).

Statistical Analysis. Feedlot performance and carcass characteristics data were analyzed in a completely randomized design. Animal served as the experimental unit. The MIXED procedure of SAS (SAS Institute; Cary, NC) was used to analyze all performance and carcass characteristics. The initial BW of cattle fed the 3,2 EXCS diet was greater ($P < 0.05$) than cattle fed 4,1 EXCS and BGCS. Therefore, initial BW was used as a covariate to analyze all feedlot performance and carcass characteristics. Differences were declared significant at $P \leq 0.05$.

Experiment 2

Animals and Diets. Angus × Simmental steers ($n = 5$; initial BW = 417 ± 21 kg) were surgically fitted with rumen cannulae 4 mo prior to the initiation of this study. Steers were gradually adapted over 3 wk from forage to a concentrate diet. Steers were randomly assigned to 1 of the 5 treatment diets from Exp. 1 (Table 3.2). Steers were fed in a 5×5 Latin square design

for 90% of ad libitum intake. Diets were individually mixed in a paddle mixer (Model SPC-2436, Marion Mixers, Inc., Marion, IA) daily prior to feeding at 0900.

Steers were housed in a climate controlled barn located at the University of Illinois Beef and Sheep Field Laboratory in individual metabolism stalls. Stalls measure 1.5 m × 2.4 m and are constructed of stainless steel tubing with dense rubber flooring. Stall floors were scraped and washed at least twice daily, before the morning feeding and once in the afternoon.

Sampling and Analysis. To determine apparent digestibility, VFA concentration, and ruminal pH, 14 d feeding periods were used. The first 9 d of each period allowed for dietary adaptation. Following the adaptation phase, 5 d of fecal collection were performed to determine total tract apparent digestibility. On the last day of the fecal collection period, rumen fluid was sampled and analyzed for VFA concentration and pH. At the conclusion of each period, partial rumen evacuations were conducted by transferring approximately 8 L of rumen fluid from the steer on the current diet to the next steer within the 5 × 5 Latin square rotation of diets.

Individual ad libitum feed intakes were determined and recorded during the adaptation phase. During the 5 d apparent digestibility collection phase, feed intakes were determined for 90% of the average ad libitum intakes during the adaptation phase. During the 5 d apparent digestibility collection phase, 100 g of the daily rations for each diet were sampled and frozen at -20°C. At the conclusion of the study, frozen feed samples were composited to be analyzed for nutrient composition. To measure fecal output for total tract apparent digestibility, five stainless steel pans with known empty weights were placed behind the metabolism stalls. Pans were immediately placed after feeding on d 10 for 120 h of fecal collection. Every 24 h, pans were weighed back and 10% of the total fecal weight was sub-sampled and frozen. At the conclusion of the study, frozen fecal sub-samples were thawed and composited for nutrient analysis to

determine nutrient digestibility. Compositated feed and fecal samples were freeze-dried (Labconco; FreeZone¹² Kansas City, MO) and ground with a Wiley mill (Arthur H. Thomas; Philadelphia, PA) to pass through a 1mm screen. Procedures of proximate analysis were as described in Exp. 1.

To determine the effects of diets on pH over time, ruminal fluid was sampled at 0, 1.5, 3, 6, 9, 12, and 18 h post-feeding. Immediately after collection, ruminal fluid was filtered through 2 layers of cheese cloth and pH was recorded (Metler Toledo FE20; Metler Toledo Inc., Columbus, OH). To determine VFA concentration, a subsample of strained ruminal contents was saved at 0, 3, and 6 h post-feeding. Approximately 75 ml of filtered rumen fluid was then acidified with 75 mL of 2N HCl, mixed, and refrigerated for 12 h at 2° C. After 12 h of refrigeration, 4 mL of rumen fluid and 1 mL of 25% H₃PO₃ were pipetted into centrifuge tubes and allowed to stand for 30 m. Samples were then centrifuged (Model J2-21; Beckman Instruments, Inc., Brea, CA) for 20 m at 20,000 × g and the supernatant was filtered through 0.45 μ filters and transferred into 1.5 mL microfuge tubes. Samples were then frozen overnight at 2° C and thawed the next morning to be centrifuged in a microfuge (Model 5418, Eppendorf North America, Hauppauge, NY) for 10 m. The supernatant was then pipetted to GC vials. The GC vials were stored at 2° C until gas chromatography (Model 5890 Series II GC with FID detector, Agilent GC; Santa Clara, CA) was performed to determine VFA concentration. The column used was custom packed (1.83 m × 4 mm, 10% SP-1200/1% H₃PO₄ on 80/100 Chromosorb W AW support; oven temperature was 125° C, inlet temperature was 175° C, and outlet temperature was 180° C) to ensure peaks were defined within the analysis.

Statistical Analysis. The experimental design was a 5 × 5 Latin square. Steer served as the experimental unit. Data were analyzed using the MIXED procedure of SAS (SAS Institute;

Cary, NC) with repeated measures to test the effects of time and time \times treatment interactions on pH and VFA concentration. If a significant time \times treatment interaction was observed, the SLICE procedure in SAS (SAS Institute; Cary, NC) was used to separate treatment effects within h. Significance was declared at $P \leq 0.05$. Trends were discussed at $0.05 < P < 0.10$.

RESULTS AND DISCUSSION

Experiment 1

There were no treatment differences ($P \geq 0.49$) on final BW, ADG, or G:F (Table 3.3). An average 16.7% increase ($P = 0.02$) in DMI was observed for cattle fed CON when compared to cattle fed all other diets. Similar to our results, previous research conducted by Russell et al. (2011) indicated that there was a 6.5% increase ($P < 0.05$) in DMI for cattle consuming a control diet containing 70% corn grain and 20% MWDGS (DM basis) when compared to cattle consuming a treated CS diet (5% CaO, DM basis) that was fed at 20% (DM basis). Surprisingly, the increased energy intake associated with increased DMI observed for steers and heifers fed CON did not result in differences ($P \geq 0.49$) in ADG or G:F among dietary treatments. These findings are contradictory to previous reports. Russell et al. (2011) found that cattle fed 20% CaO-treated CS (5%, DM basis) and 40% MDGS (DM basis) had a 5% improvement ($P < 0.05$) in G:F when compared to cattle fed the control diet (70% corn grain, 20% MDGS; DM basis). They attributed this G:F increase to a 5% reduction ($P < 0.05$) in DMI and no differences in ADG for cattle fed CaO-treated CS compared to those fed the control diet. While the lack of change in final BW for treated CaO-treated CS diets noted in this trial does agree with the findings from Shreck et al. (2012a; 2012b), it contradicts the observations from Russell et al. (2011) and Duckworth et al. (2013). Russell et al. (2011) and Duckworth et al. (2013) reported decreased final BW (by 1.2 and 2.9%, respectively) in steers fed CaO-treated CS fed at 20%

(DM basis) when compared to those fed non-treated CS at the same inclusion. The reduction in BW reported by Duckworth et al. (2013) is of particular interest. Unlike the previously discussed study by Russell et al. (2011), Duckworth et al. (2013) fed the same amount (40% DM basis) of MWDGS and CS among dietary treatments during the finishing phase, but the control diet contained 20% CS (DM basis) that was untreated, but hydrated to 50% moisture, and anaerobically stored. The reduction in final BW in that study was attributed to the decrease in both DMI and ADG ($P \leq 0.03$) for steers fed 5% CaO-treated CS when compared to the untreated CS diet (Duckworth et al.; 2013). The conflicting results for final BW, ADG, and DMI among trials testing 5% CaO-treated CS requires further research. The current trials to date have all used variable control diets which makes comparison across studies challenging.

There were no treatment effects ($P \geq 0.20$) for BF, LM area, KPH, YG, or MS (Table 3.4). In agreement with the current study, Shreck et al. (2012a) indicated that there were no differences ($P > 0.05$) in MS, YG, BF, or LM area for steers fed 20% treated-CS (5% CaO, DM basis), 40% WDGS, and 36% dry-rolled corn (DM basis) when compared to cattle fed 46% dry-rolled corn, 40% WDGS, and 10% of untreated crop residues (equal parts wheat straw, corn stover, and ground corn cobs; DM basis). Furthermore, Shreck et al. (2012b) reported no MS, YG, BF, or LM area differences ($P > 0.05$) in cattle fed 36% corn grain, 20% treated CS (5% CaO, DM basis), and 40% MDGS (DM basis) when compared to cattle fed 50% corn grain, 5% untreated CS, and 40% MDGS (DM basis). Although these 2 studies investigated particle size and crop residue source effects in corn and co-product-fed finishing cattle, treated CS was treated in a similar manner to BGCS in the current study. However, carcass data from the current study conflicts with the findings of Duckworth et al. (2013). In 2 experiments in that trial, authors reported at least a tendency ($P \leq 0.08$) for cattle fed 5% CaO-treated CS to have reduced

MS when compared to cattle fed unprocessed CS at the same inclusion. Furthermore, Duckworth et al. (2013) reported a 13.4% reduction in finishing steers and an 18.6% reduction in YG for heifers fed CaO-treated CS (20% DM basis) when compared to diets that contained 20% untreated and hydrated CS, 40% MWDGS, and 30% corn (DM basis). The differences in YG between our data and that of Duckworth et al. (2013) were mainly driven by the reduction in BF for steers and heifers observed by Duckworth et al. (2013). An explanation for our reported lack of carcass differences that conflicts with the findings of Duckworth et al. (2013) may be due to the overall poor growth performance of the cattle fed 5% CaO-treated CS in that trial, as discussed above. Of the previously mentioned studies, Russell et al. (2011) was the only study that reported KPH, which is in agreement to our data comparing 5% CaO-treated CS to the control. However, it appears to be consistent among researchers that LM area is unaffected by feeding CaO-treated CS (Russell et al., 2011; Shreck et al., 2012a; Shreck et al., 2012b; Duckworth et al., 2013). This effect is unclear, particularly since growth performance has been variable among researchers when feeding CaO-treated CS

There was no effect of dietary treatment ($P = 0.84$) on HCW (Table 3.4). This finding is consistent with Russell et al. (2011) and Shreck et al. (2012a; 2012b). They also noted HCW remained unchanged for cattle fed diets that contained 20% treated CS (DM basis) with 5% CaO (DM basis) when compared to their individual control diets. However, Duckworth et al. (2013) reported a 3.25% reduction for steers and a 5.19% reduction for heifers that were fed 20% CaO-treated CS with 5% CaO (DM basis) when compared to cattle fed the untreated, hydrated, and anaerobically stored CS diet (20% DM basis). This effect was explained by the decrease in final BW for steers and heifers that were fed treated-CS, as previously discussed.

Even though there were significant reductions in DMI for cattle fed treated CS diets, this reduction in DMI did not result in decreased feed efficiency. But, treated CS did successfully replace corn in beef finishing rations when fed in combination with MWDGS without altering ADG and G:F. Interpretation of these results may be warranted due to few animals on test for dietary treatments and variation in ADG and G:F for treated CS diets. Nonetheless, MS, BF, LM area, and YG were unaffected by dietary treatment.

Experiment 2

There were no differences ($P = 0.58$) in apparent DM digestibility, regardless of treatment fed. However, apparent digestibility of NDF and ADF increased ($P < 0.01$) when cattle were fed diets containing treated CS compared to cattle fed CON (Table 3.5). Duckworth et al. (2013) reported an 11.8% increase ($P \leq 0.05$) in apparent DM digestibility when feeding diets that contained 20% CS, treated with 5% CaO (DM basis) when compared to a diet that contained 20% (DM basis) untreated, ground CS. However, they reported no differences ($P > 0.05$) in apparent ADF digestibility between the treated CS diet and their control diet consisting of 50% dry rolled corn and 15% corn silage (DM basis). Shreck et al. (2013b) reported increased NDF digestibility when feeding treated CS compared to their corn control, but no change in DM digestibility was indicated. The conflicting results in previous literature are unclear, but may be related to the changes in dietary fiber concentrations between treated CS diets in relation to control diets in the various studies.

It does appear, however, that much of the change in digestibility may be caused by increasing ruminal fermentation. Duckworth et al. (2013) found that treating CS with 5% CaO (DM basis) resulted in a 67% reduction in hemicellulose concentration when compared to untreated CS. Duckworth et al. (2013) also evaluated the in situ NDF digestibility of CS that was

treated with 5% CaO (DM basis) and CS that had been hydrated to 50% moisture and anaerobically stored (untreated). Over 24, 36, and 48 h of incubation, they reported that chemical treatment of CS with CaO (5% DM basis) increased the NDF digestibility of treated CS by 194%, 97%, and 65% when compared to untreated CS. Although Duckworth et al. (2013) did not anaerobically preserve their treated CS diet, their results help illustrate why chemical treatment of CS improved the apparent total tract NDF digestibility in the current study.

There was a time \times treatment interaction ($P < 0.01$) for ruminal pH (Figure 3.1). Ruminal pH was most acidic for cattle fed the BGCS diet from 0 to 6 h after feeding. These findings are contrary to our original hypothesis. We had hypothesized that CaO would increase ruminal pH because of its alkaline nature; however, mean ruminal pH decreased ($P < 0.01$) when cattle were fed 5% CaO treated CS diets, regardless of the physical processing method. These data conflict with the report of Shreck et al. (2013b) that found no differences ($P > 0.10$) in the mean ruminal pH for cattle fed diets containing CS treated with 5% CaO (% DM basis) when compared to cattle fed the control diet containing 46% dry rolled corn and 40% wet distillers grains with solubles (% DM basis). However, more similar to the current study, Duckworth et al. (2013) reported a trend ($P = 0.06$) for decreased ruminal pH in steers fed 5% CaO-treated CS at 20% (DM basis) when compared to those fed untreated CS diet (20% CS, DM basis). Studies reporting the effects of feeding CaO-treated CS on ruminal pH have been limited and results are variable among researchers. This may be primarily attributed to the variance in proportions of VFA as discussed below.

In the current study, there were no time \times treatment interactions ($P \geq 0.24$) for VFA concentrations (Table 3.6). Mean acetate concentration increased ($P < 0.01$) when cattle were fed treated CS, regardless of treatment, compared to acetate concentrations from cattle fed CON.

This increase in acetate was likely the result of the aforementioned increase in NDF and ADF digestibility. This effect of improved fiber digestibility is unclear, as this may have been caused by the increased dietary fiber concentration. Our reported increase in acetate concentration may be a function of improved fiber digestibility or an artifact of the increased dietary fiber concentration.

There was a significant effect of treatment ($P = 0.01$) for total VFA concentration. Furthermore, there was a time \times treatment interaction ($P < 0.01$) for acetate: propionate (A:P) ratio. Steers fed CON had the lowest A:P ratio when compared to cattle fed the treated CS diets. At 0 h, A:P ratio for cattle fed all treated CS diets greater when compared to A:P ratio of cattle fed CON, but by 3 and 6 h post-feeding, A:P ratio for cattle fed treated CS diets had decreased and did not differ from A:P ratio for cattle fed the CON diet. All of these VFA effects were driven by the shift in acetate, as there was no effect ($P = 0.31$) of treatment on propionate concentrations. While a previous report (Shreck et al. 2013b) also noted no changes in propionate concentrations when feeding CaO-treated CS, they also did not find any differences in mean acetate concentrations between their CaO-treated CS diet and their control diet (60.3 versus 57.7 mM); however, they did note that VFA concentrations were reduced in cattle fed the treated CS diet when compared to those fed the control diet. In their study, VFA samples were measured every 3 h and composited from 3 to 15 h post-feeding, which may explain the lower total concentrations of VFA compared to our study that only measured VFA concentration from 0 to 6 h post-feeding. Again, the increase in total VFA concentrations among steers fed treated CS diets may be the cause of the reduced ruminal pH observed in the present trial.

Even though there were significant improvements in NDF and ADF digestibility in treated CS diets and increased concentrations of VFA in the present experiment, these did not

translate to increases in cattle performance, as noted in Exp. 1. It is possible that the increased fiber in the rumen of cattle fed CS diets affected rate of passage and rumen volume which in turn increased digestibility and VFA concentrations. This may be why the reduction in DMI, noted in Exp. 1, when cattle were fed treated CS diets, regardless of the treatment, did not ultimately reduce ADG. Cattle fed CaO-treated CS diets may have been deriving more energy from the available feedstuffs. Furthermore, because there is currently a lack of information regarding the effects of feeding treated CS to cattle in peer-reviewed literature, the discussion generated here is based predominantly on reports (Russell et al., 2011; Shreck et al., 2012a; Shreck et al., 2012b; Shreck et al., 2013a; Shreck et al., 2013b) . This is an area in critical need of research.

CONCLUSIONS

Even though chemically and thermochemically treating CS decreased DMI, these changes did not result in reduced gains or improved efficiency. But, treated CS did successfully replace corn in beef finishing rations when fed in combination with MWDGS without altering BF, LM area, KPH, YG, or MS. Furthermore, treating CS improved apparent total tract NDF and ADF digestibility and increased ruminal acetate concentrations, regardless of chemical treatment or processing method. Further research is warranted to examine the effects of treated CS on rumen volume and rate of passage of treated CS through the gastro intestinal tract in relation to other ingredients.

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Table 3.1. Ingredient and analyzed nutrient composition (% DM basis) of diets fed to cattle in Experiment 1

Item, % DM basis	Dietary Treatments ¹				
	CON	BGCS	5 EXCS	4,1 EXCS	3,2 EXCS
MWDGS	35	40	40	40	40
Dry Cracked Corn	55	35	35	35	35
Corn Stover	5	20	20	20	20
Supplement ²	5	5	5	5	5
Analyzed Composition, % DM basis					
NDF	17.78	22.34	22.78	26.53	23.59
ADF	8.87	14.79	14.03	16.50	13.32
CP	14.00	14.51	14.29	14.21	14.51
Fat	5.01	4.83	4.57	4.52	5.00
Ca	0.90	1.67	1.73	1.23	1.13
P	0.41	0.42	0.40	0.42	0.42
S	0.28	0.31	0.32	0.31	0.32
Ash	5.33	8.66	9.20	8.87	8.27

¹CON = 55% corn and 5% untreated-ground corn stover on DM basis (corn control). BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO. 5 EXCS = corn stover hydrated to 50% moisture, treated with 5% CaO, and then extruded. 4,1 EXCS = corn stover hydrated to 50% moisture, treated with 4% CaO and 1% NaOH, and then extruded. 3,2 EXCS = corn stover hydrated to 50% moisture, treated with 3% CaO and 2% NaOH, and then extruded. All extruded corn stover blends were processed using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

²Supplement formulated to contain (DMB): Dry-Cracked Corn, 60.76%; Limestone, 34.19%; Swine Trace Mineral, 2.23% (85% Salt, 2.57% Fe, 2.86% Zn, 5,710 ppm Mn, 2,290 ppm Cu, 100 ppm I, 85.7 ppm Se); ADEK Vitamin Mix, 0.22% (680,400 IU Vit A/kg, 68,040 IU Vit D3/kg, 9,072 IU Vit E/kg, 453.5 IU Vit K/kg, 3.63 mg Vit B12/kg, 907.2 mg Riboflavin/kg, 2,494.8 mg d-Pantothenic Acid/kg, 3,402 mg Niacin /kg, 29,461 mg Choline/kg); Tylan 40, 0.25% (88 g tylosin/kg of DM, Elanco Animal Health, Greenfield, IN); Rumensin 80, 0.34% (176 g monensin/kg of DM, Elanco Animal Health); Thiamine 40, 0.21% (88,000 mg thiamine mononitrate/kg of DM, ADM Alliance Nutrition, Inc., Quincy, IL); Copper Sulfate, 0.11%; Fat 1.69%.

Table 3.2. Ingredient and analyzed nutrient composition of diets (% DM basis) fed to steers in Experiment 2

Item, % DM Basis	Dietary Treatments ¹				
	CON	BGCS	5 EXCS	4,1 EXCS	3,2 EXCS
MWDGS	35	40	40	40	40
Dry Cracked Corn	55	35	35	35	35
Corn Stover	5	20	20	20	20
Supplement ²	5	5	5	5	5
Analyzed Composition, % DM basis					
NDF	22.20	25.13	26.44	26.12	27.01
ADF	10.55	15.75	16.38	16.29	14.82
CP	14.68	14.71	14.62	14.74	14.78
Fat	4.90	4.37	4.47	4.69	4.86
Ca	0.56	1.64	1.68	1.25	1.13
P	0.43	0.41	0.42	0.44	0.43
S	0.28	0.32	0.33	0.33	0.31
Ash	4.66	7.88	8.43	8.09	7.77

¹CON = 55% corn and 5% untreated-ground corn stover on DM basis (corn control). BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO. 5 EXCS = corn stover hydrated to 50% moisture, treated with 5% CaO, and then extruded. 4,1 EXCS = corn stover hydrated to 50% moisture, treated with 4% CaO and 1% NaOH, and then extruded. 3,2 EXCS = corn stover hydrated to 50% moisture, treated with 3% CaO and 2% NaOH, and then extruded. All extruded corn stover blends were processed using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

²Supplement formulated to contain (DMB): Dry-Cracked Corn, 60.76%; Limestone, 34.19%; Swine Trace Mineral, 2.23% (85% Salt, 2.57% Fe, 2.86% Zn, 5,710 ppm Mn, 2,290 ppm Cu, 100 ppm I, 85.7 ppm Se); ADEK Vitamin Mix, 0.22% (680,400 IU Vit A/kg, 68,040 IU Vit D3/kg, 9,072 IU Vit E/kg, 453.5 IU Vit K/kg, 3.63 mg Vit B12/kg, 907.2 mg Riboflavin/kg, 2,494.8 mg d-Pantothenic Acid/kg, 3,402 mg Niacin /kg, 29,461 mg Choline/kg); Tylan 40, 0.25% (88 g tylosin/kg of DM, Elanco Animal Health, Greenfield, IN); Rumensin 80, 0.34% (176 g monensin/kg of DM, Elanco Animal Health); Thiamine 40, 0.21% (88,000 mg thiamine mononitrate/kg of DM, ADM Alliance Nutrition, Inc., Quincy, IL); Copper Sulfate, 0.11%; Fat 1.69%.

Table 3.3. Effects of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on growth performance of cattle in Experiment 1

Item	Dietary Treatments ¹					SEM	<i>P</i> -value ²
	CON	BGCS	5 EXCS	4,1 EXCS	3,2 EXCS		
n	12	12	11	12	12	-	
Initial BW, kg	386 ^{ab}	377 ^b	385 ^{ab}	364 ^b	401 ^a	8.13	0.03
Final BW ^{3,4} , kg	478	472	473	468	479	7.44	0.84
ADG ³ , kg	1.27	1.19	1.21	1.15	1.29	0.10	0.84
DMI ³ , kg	8.08 ^a	6.86 ^b	6.85 ^b	6.87 ^b	7.11 ^b	0.32	0.02
G:F ³	0.157	0.171	0.178	0.165	0.180	0.010	0.49

¹CON = 55% corn and 5% untreated-ground corn stover on DM basis (corn control). BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO. 5 EXCS = corn stover hydrated to 50% moisture, treated with 5% CaO, and then extruded. 4,1 EXCS = corn stover hydrated to 50% moisture, treated with 4% CaO and 1% NaOH, and then extruded. 3,2 EXCS = corn stover hydrated to 50% moisture, treated with 3% CaO and 2% NaOH, and then extruded. All extruded corn stover blends were processed using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

²Means within the same row without common superscripts differ ($P \leq 0.05$).

³Final BW calculated as HCW/0.62 (Common DP).

⁴Initial BW was used as a covariate.

Table 3.4. Effects of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on carcass characteristics of cattle in Experiment 1

Item	Dietary Treatments ¹					SEM	<i>P</i> -value ²
	CON	BGCS	5 EXCS	4,1 EXCS	3,2 EXCS		
n	12	12	11	12	12	-	
HCW ³ , kg	297	293	294	290	297	4.61	0.84
Backfat ³ , cm	1.11	0.92	0.80	0.99	0.86	0.10	0.20
LM area ³ , cm ²	77.69	79.98	79.88	78.14	75.10	2.46	0.62
KPH ³ , %	2.2	2.1	2.0	2.1	2.0	0.1	0.42
Yield Grade ^{3,4}	2.7	2.3	2.2	2.5	2.4	0.2	0.26
Marbling Score ^{3,5}	497	459	459	424	463	29	0.53

¹CON = 55% corn and 5% untreated-ground corn stover on DM basis (corn control). BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO. 5 EXCS = corn stover hydrated to 50% moisture, treated with 5% CaO, and then extruded. 4,1 EXCS = corn stover hydrated to 50% moisture, treated with 4% CaO and 1% NaOH, and then extruded. 3,2 EXCS = corn stover hydrated to 50% moisture, treated with 3% CaO and 2% NaOH, and then extruded. All extruded corn stover blends were processed using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

²Means within the same row without common superscripts differ ($P \leq 0.05$).

³Initial BW was used as a covariate.

⁴Yield Grade calculated using USDA equation (USDA, 1997).

⁵Marbling Score: 400 = Small⁰⁰, 500 = Modest⁰⁰, 600 = Moderate⁰⁰.

Table 3.5. Effect of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on total tract apparent digestibility in Experiment 2

Item	Dietary Treatments ¹					SEM	<i>P</i> -value ²
	CON	BGCS	5 EXCS	4,1 EXCS	3,2 EXCS		
n	5	5	5	5	5	-	-
Apparent Digestibility, % DM basis							
DM	72.3	72.4	71.1	70.8	73.6	1.31	0.58
NDF	49.3 ^b	67.4 ^a	65.7 ^a	64.7 ^a	72.1 ^a	3.02	<0.01
ADF	52.6 ^b	64.6 ^a	66.8 ^a	66.3 ^a	66.0 ^a	2.30	<0.01

¹CON = 55% corn and 5% untreated-ground CS on DM basis (corn control). BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO. 5 EXCS = corn stover hydrated to 50% moisture, treated with 5% CaO, and then extruded. 4,1 EXCS = corn stover hydrated to 50% moisture, treated with 4% CaO and 1% NaOH, and then extruded. 3,2 EXCS = corn stover hydrated to 50% moisture, treated with 3% CaO and 2% NaOH, and then extruded. All extruded corn stover blends were processed using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

²Means within the same row without common superscripts differ ($P \leq 0.05$).

Table 3.6. Effect of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on ruminal VFA concentrations over time in Experiment 2

Item	Dietary Treatments ¹					SEM	<i>P</i> -values ²	
	CON	BGCS	5 EXCS	4,1 EXCS	3,2 EXCS		T	T × H
n	5	5	5	5	5			
Acetate, mM						5.17	<0.01	0.41
0 ³	44.5	74.6	67.2	61.7	62.6			
3	57.5	83.0	84.2	75.3	79.4			
6	59.4	83.8	90.7	84.1	86.7			
Propionate, mM						2.81	0.31	0.32
0	18.8	23.7	20.3	16.4	17.0			
3	36.2	40.2	43.8	33.9	40.3			
6	37.9	39.0	40.3	34.1	35.1			
Butyrate, mM						1.50	0.05	0.24
0	5.70	13.70	10.0	10.4	10.7			
3	11.4	16.7	14.3	16.1	14.9			
6	10.4	15.2	13.8	16.4	14.3			
total VFA, mM						8.10	0.01	0.55
0	72.9	116.6	101.4	92.3	94.0			
3	110.2	144.6	146.2	129.2	138.5			
6	112.2	143.3	148.7	138.7	140.8			
A:P ⁴						0.25	0.06	0.01
0	2.36	3.33	3.46	3.89	3.70		<0.01	
3	1.66	2.17	1.92	2.28	1.97		0.47	
6	1.68	2.22	2.28	2.50	2.49		0.16	

¹CON = 55% corn and 5% untreated-ground corn stover on DM basis (corn control). BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO. 5 EXCS = corn stover hydrated to 50% moisture, treated with 5% CaO, and then extruded. 4,1 EXCS = corn stover hydrated to 50% moisture, treated with 4% CaO and 1% NaOH, and then extruded. 3,2 EXCS = corn stover hydrated to 50% moisture, treated with 3% CaO and 2% NaOH, and then extruded. All extruded corn stover blends were processed using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

²T = Main effect of dietary treatment, T × H = interaction of dietary treatment × hour.

³Time post-feeding (h).

⁴A:P = ratio of Acetate to Propionate.

Figure 3.1.

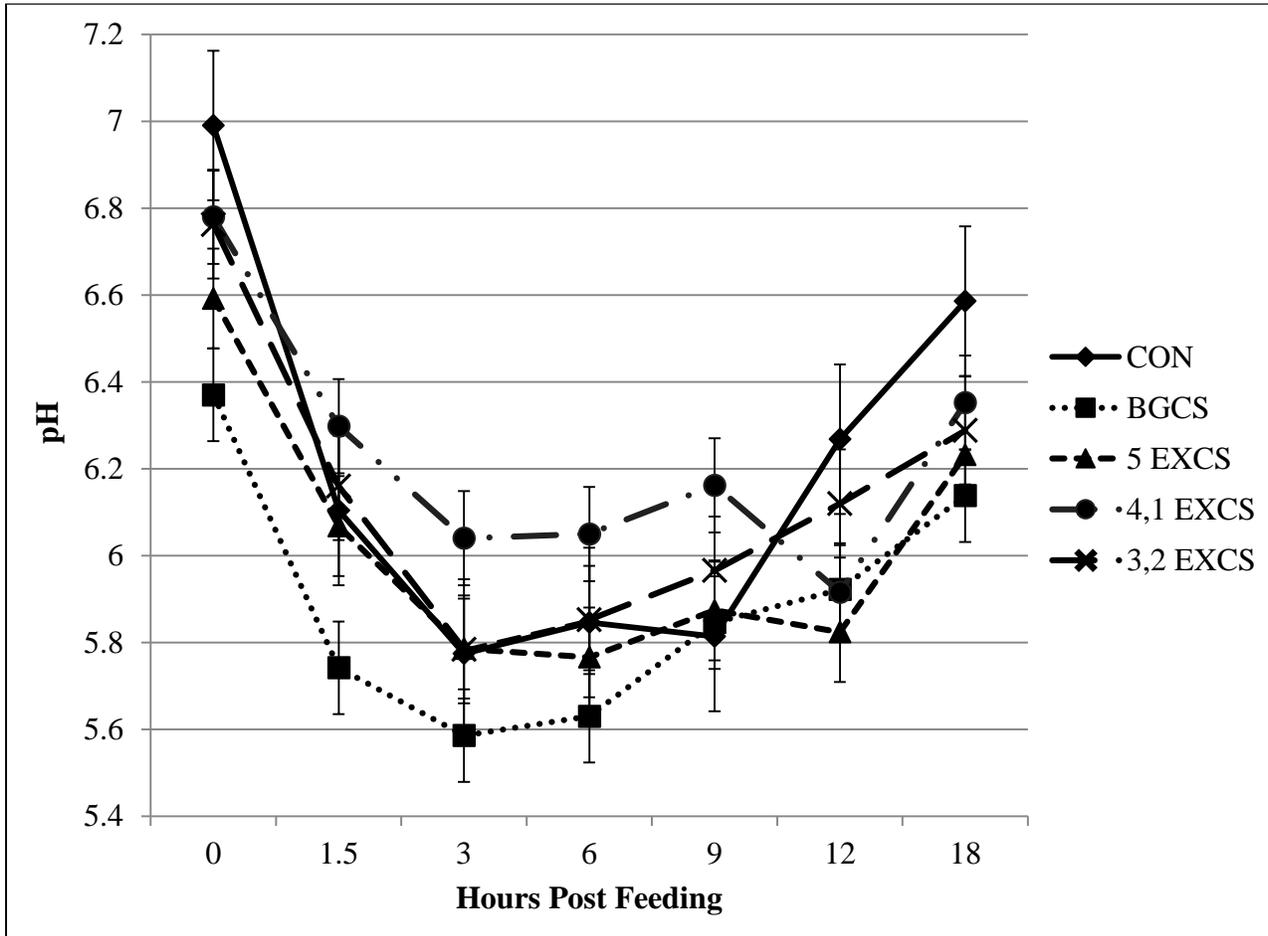


Figure 3.1. (Continued) Effect of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on ruminal pH change over time in Experiment 2. Steers were fed 1 of 5 dietary treatments: (1) 55% corn and 5% untreated, ground CS (**CON**, **◆**), (2) CS treated with 5% CaO (DM Basis) and stored in an Ag-Bag (**BGCS**, **■**) CS, (3) CS treated with 5% CaO (DM Basis) and extruded (**5 EXCS**, **▲**), (4) CS treated with 4% CaO and 1% NaOH (DM Basis) and extruded (**4,1 EXCS**, **●**), or (5) CS treated with 3% CaO and 2% NaOH (DM Basis) and extruded (**3,2 EXCS**, **×**). There was a time × treatment interaction ($P < 0.01$) on ruminal pH. There was a main effect treatment ($P = 0.02$) on ruminal pH. The error bars reflect the SEM associated with the interaction of treatment × time (SEM = 0.10).

CHAPTER 4

CONCLUSIONS

Chemical and physical treatments of crop residues and other poor quality forages have been investigated in the last 50 years. Even though there are numerous chemical pretreatments that increase digestibility of forages, there are few publications that report the effects of combinations of chemical and physical processing methods. Furthermore, there is little information for how treated crop residues may serve as a replacement for corn grain in beef finishing rations when fed in combination with distillers grains. A particular crop residue gaining a presence as a potential feedstuff is corn stover (**CS**). Therefore, 3 studies were conducted to determine optimum chemical and physical processing methods of CS and to evaluate the effects of replacing corn with treated CS and distillers grains on feedlot growth performance, carcass characteristics, economics, and ruminal metabolism.

The objectives of the first experiment, presented in Chapter 2, were to determine the effects of replacing corn in feedlot cattle diets with chemically (calcium oxide; **CaO**) treated or thermochemically treated (extruded with CaO) CS and modified wet distillers grains with solubles (**MWDGS**) on dry matter intake (**DMI**), gain, carcass characteristics, and feedlot economics. We hypothesized that steers fed diets containing CaO treated CS would perform similarly to or better than steers fed a corn and MWDGS-based control. There were no differences between chemically-treated and thermochemical-treated CS on finishing phase growth performance or carcass traits. Feeding treated CS reduced average daily gain (**ADG**), dry matter intake (**DMI**), and feed efficiency, and final body weight (**BW**) when compared to steers fed the control. Additionally, steers fed treated CS diets had reduced backfat (**BF**), yield grade (**YG**), and hot carcass weight (**HCW**), and tended to deposit less kidney, pelvic, and heart fat

(**KPH**) when compared to carcasses from steers fed the control. However, neither longissimus muscle (**LM**) area nor marbling score (**MS**) were affected by dietary treatment. Steers fed 20% CaO-treated CS had reduced total feed costs when compared to steers fed the control diet, but this was primarily attributed to the reduced DMI and ADG for cattle fed treated CS.

Secondly, we wanted to test different chemical treatments and the effects of the treated-CS on metabolism; therefore, in Chapter 3, we conducted 2 experiments. The objectives were to evaluate the effects of replacing corn in feedlot finishing diets with CS treated by various methods, chemical (CaO and/or sodium hydroxide; **NaOH**) and physical (anaerobic or extruding), and included in diets containing MWDGS on growth performance, carcass characteristics, diet digestibility, and ruminal metabolism. For this experiment, we hypothesized that cattle fed diets containing CaO-treated CS would perform similarly to cattle fed a corn-based control diet during the finishing phase. Furthermore, we hypothesized that feeding cattle treated CS would improve digestibility, due to neutralizing rumen pH from the basic nature of CaO and NaOH alkaline compounds, such that digestibility would be similar to cattle fed a corn-based control diet. There were no differences in ADG, feed efficiency, MS, or LM area by treatment. However, cattle fed the control diet had increased DMI compared to cattle fed the treated CS diets. Unlike in Chapter 2, feeding treated CS showed the potential to replace corn in beef feedlot finishing diets, when fed in combination with MWDGS, without sacrificing feedlot gain, feed efficiency, or MS. Apparent digestibility of NDF and ADF increased when cattle were fed treated CS diets compared to cattle fed the control diet, regardless of the treatment applied. Mean ruminal pH was lowest in cattle fed CaO-treated CS that had been stored in an Ag Bag, from 0 to 6 hours post-feeding compared to cattle fed all other diets. Furthermore, cattle fed diets treated with 5% CaO (on a DM basis) diets had the greatest mean acetate concentrations, resulting in

increased total VFA concentrations. The observed increase in acetate concentration may have been due to improved fiber digestibility from physical and chemical treatment for cattle fed the treated CS diets.

In conclusion, the chemical and physical treatment of crop residues and other poor quality forages may offer improved fiber digestibility and help substitute corn in beef finishing diets. For small-scale producers, feeding treated CS during the finishing phase may not be economically feasible due to additional expense from machinery costs that were not accounted for in the present economics. However, for producers with more equipment and labor resources, bagging CS could potentially be a viable practice to reduce total feed costs in beef finishing diets. While feeding bagged CS reduced the cost of gain and overall feed costs in Chapter 2, the potential reductions in feedlot gain and intake need to be considered. Carcass value was not analyzed in this study. Further research would be needed to determine break even cost from the potential decreases in gain and intake. Although growth performance has been variable in our results, it appears that LM area is unaffected, which is consistent with previous reports. Finally, it is uncertain if replacement of corn in feedlot diets with treated CS truly improves the fiber digestibility, as this may have been due to an increase in fiber concentration in our treated CS diets.

**APPENDIX A: CHARACTERISTICS OF CORN STOVER AND EQUIPMENT USED
FOR CORN STOVER TREATMENT**

Item	Untreated Corn Stover	BGCS	5 EXCS	4,1 EXCS	3,2 EXCS
% Moisture	14.3	49.7	41.8	40.3	42.9
% DM	85.7	50.3	58.2	59.7	57.1
pH	5.6	10.9	11.5	11.6	11.9

Equipment Used

- John Deere 6140 (Deere & Company, Moline, IL)
- John Deere 2955 (Deere & Company, Moline, IL)
- John Deere 7400 (Deere & Company, Moline, IL)
- Haybuster Big Bite H-1000 series (Agricultural Products DuraTech Industries International, Inc., Jamestown, ND).
- Knight Reel Auggie 3130 (Kuhn Agricultural Machinery, Brodhead, WI)
- G6060 Ag-Bagger (A. Miller-St. Nazianz, Inc. Company, St. Nazianz, WI)
- Rissler Feed Mixing Wagon (E Rissler Mfg. LLC, New Enterprise, PA)
- Readco Kurimoto Continuous Processor (Readco Kurimoto, LLC, York, PA)
- Metler Toledo FE20 pH meter (Metler Toledo Inc., Columbus, OH)