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The Utilization of Brown Midrib Corn Silage Hybrids and Kernel Processing to Improve Corn Silage Value and the Use of High Protein Distillers Grains to Evaluate Starch Digestion

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THE UTILIZATION OF BROWN MIDRIB CORN SILAGE HYBRIDS AND KERNEL PROCESSING TO IMPROVE CORN SILAGE VALUE AND THE USE OF HIGH PROTEIN DISTILLERS GRAINS TO EVALUATE STARCH DIGESTION

by

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THE UTILIZATION OF BROWN MIDRIB CORN SILAGE HYBRIDS AND KERNEL PROCESSING TO IMPROVE CORN SILAGE VALUE AND THE USE OF HIGH PROTEIN DISTILLERS GRAINS TO EVALUATE STARCH DIGESTION

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Three studies evaluated the effects of corn silage hybrid, inclusion level and kernel processing in growing and finishing diets. Two more studies were conducted on high protein dried distillers grains and its effect in finishing diets. Experiment 1 and 2 evaluated three corn silage hybrids; standard (CON; hybrid-TMF2H708), brown midrib (*bm3;* hybrid-F15579S2) and Unified™ brown midrib with SilaSoft™ kernel technology with a floury endosperm (*bm3*-soft; hybrid-F15578XT) harvested with or without kernel processing on growth and metabolism. Experiment 3 evaluated a brown midrib hybrid (*bm3*; hybrid-F27F627; Mycogen® Seeds) or a control (CON; hybrid-TMF2H708) in the diet at 15%, 45% or 75% and dropping to 15% DM for the second half of the trial and fed to a common backfat thickness. Experiment 4 and 5 evaluated high protein dried distillers grains plus solubles (HiPro) or traditional DDGS to a control diet with no DGS, using steam flaked corn (SFC) or dry rolled corn (DRC) as a grain source. In Exp. 1 and 2, the inclusion of *bm3* and *bm3*-soft increased ($P<0.01$) fiber digestibility, average daily gain (ADG) and gain:feed (G:F), with no effect ($P=0.47$) on starch digestibility. Kernel processing decreased ($P=0.02$) dry matter intake (DMI), which tended to reduce G:F 2.9%. In Exp. 3, cattle consuming 15% silage had greater ($P<0.01$) ADG and G:F and smaller HCW because they were fed 28 days less. The 45 and 75/15% did not differ

($P \geq 0.10$) in G:F and were more profitable ($P < 0.01$) than CON. In Exp. 4 and 5, DDGS and HiPro increased ($P < 0.01$) DMI, G:F, and ADG. Cattle consuming DDGS and HiPro had lower ($P < 0.01$) DM, OM, and starch digestibility. Including *bm3* improved performance in the first two studies, and increasing inclusion of silage increased profitability. Using HiPro did not result in improvements in feed efficiency in DRC-based diets beyond DDGS.

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Table of Contents

List of Tables

List of Figures

Introduction

As the global population grows from 7.6 billion towards 9.8 billion by 2050 (United Nations, 2017), growth of the middle class that can afford protein sources such as beef is likely to expand as well. With an increasing demand for a safe and nutritious beef supply by a growing human population, it is imperative beef producers maximize feed efficiency of cattle without being hindered economically. Currently, as key improvements have been made due to implants, ionophores and beta agonists, researchers, nutritionists and producers are left evaluating current and novel feed ingredients and trying to maximize their potential for energy utilization. Specifically, for ruminants, starch digestibility in both the rumen and small intestine needs to be reevaluated in relation to protein supply, specifically in dry rolled corn-based diets, where apparent total tract starch digestibility is only approximately 92% (Theurer, 1986) Additionally, it has left researchers evaluating the role corn silage plays in the beef finishing diet, no longer as just a primary roughage source. Corn silage is considered an energy dense roughage source at 75% TDN (NASEM, 2016) because it contains 50% grain. However, it is still primarily utilized in beef and dairy diets as a roughage source, with less consideration for the availability of energy from the grain (Goodrich et al., 1974).

As corn silage is increased in the diet, it has been well documented that G:F is decreased through a reduction in energy intake (Goodrich et al., 1974; Erickson, 2001). Through recent research evaluating the use of increased corn silage in the diet with ethanol byproduct distillers grains plus solubles (DGS); the value of corn silage as an energy and grain source in beef finishing diets has been increased (Burken et al., 2017a). Despite becoming more economical, corn silage has a high lignin content and low fiber

digestibility, which leaves much of the fibrous energy unavailable to rumen microbes. As a result, researchers have been evaluating hybrids of corn silage with a brown midrib mutation that has a lower lignin content leading to improved fiber digestibility, thus increasing energy available for cattle. In addition to revisiting fiber digestibility in the diet, starch digestibility in the kernel of corn silage has also been reevaluated, primarily in dairy diets, through the use of kernel processing. Therefore, the objectives of the following studies were to evaluate corn silage hybrid, kernel processing and level of inclusion in the diet and its effect on animal performance and carcass characteristics in finishing diets.

The use of DGS has provided a major advantage for beef producers in regions such as Nebraska, where dry rolled corn-based diets are primarily used. The high protein content of DDGS (30% CP, DM basis) and high RUP (63%; Castillo-Lopez et al., 2013) potentially encourages greater α-amylase secretion from the pancreas allowing for greater starch digestion post-ruminally (Blom et al., 2016). Post-ruminal starch digestion is approximately 40% more energetically efficient than starch digestion in the rumen (Owens et al., 1986), increasing the value of corn in the diet if starch digestion occurs there. The use of DGS in the diet has allowed Nebraskan producers to have a competitive advantage over other areas utilizing steam flaked corn as a primary grain source, which has more readily available and fermentable starch as compared to dry rolled corn. Now, as ethanol plants look to produce more ethanol per bushel of corn, the corn has been fractionated further during the process, removing germ and bran from the final DGS product, resulting in a product known as high protein dried distillers grains plus solubles.

How this greater protein content affects nutrient digestibility in ruminants needs to be evaluated in beef finishing diets as compared to traditionally produced DGS.

CHAPTER I. Review of the Literature

Corn Silage Background, Production, and Value

Corn silage is beneficial for beef and dairy producers because of its large yield, grain production and the preservation of an ingredient for year-round use (Heguy et al., 2016). It is ideal for producers who live in regions where access to fresh crops throughout every season is not viable (Pahlow et al., 2003). While silage has been primarily utilized as a roughage source, it can also provide energy in the diet, as it has a 75% TDN value primarily because it is 50% corn grain (NASEM, 2016). As a result, and through increased economic incentive, the production and use of corn silage increased to 113 million acres in 2012, up from 104 million acres in 2007 (USDA Census, 2012).

Dry matter yields of corn silage are larger than other forage crops typically ensiled for use in beef production despite being harvested before physiological maturity. As Allen et al. (2003) observed, corn silage has greater yields than small cereal grains and legumes, requiring fewer acres needed for the same amount of feed to be produced. Corn silage can also provide some flexibility for producers to produce either a forage or grain, dependent upon the economic indicators available for grain production and use in a feedlot setting. Unfortunately, there are some drawbacks involved with corn silage production (Allen et al,. 2003). It requires high levels of N and P from the soil and leaves little cover after the crop has been harvested. Additionally, corn silage requires traffic and labor on the field increasing compaction of the soil post-harvest.

The objective for optimal corn silage quality is to have an average dry matter content of 35% to discourage dry matter losses through seepage, while maximizing a large quantity of grain within the corn plant, and allowing for excellent quality of forage for optimal fiber digestibility (Miller et al., 1983). Optimal corn silage harvest is typically achieved when corn is two-thirds to three quarter milkline, when both tonnage and forage quality are ideal for beef cattle performance (Bal et al., 1997). Maximum yield and silage quality are dissimilar to other crops in that they are optimized at a similar time in the growing cycle of the corn silage (Allen et al., 2003). Corn silage maturity is achieved prior to black layer formation in corn plants, which indicates maturity of the kernel and the time at which nutrients such as starch are no longer being stored in the grain (Hilscher, 2018). Achieving 35% DM is difficult to evaluate when corn is standing in the field, so the adoption of kernel milk line as an analysis for corn silage maturity has been prevalent (Afuakwa and Crookston, 1984). Milkline occurs as the corn matures and after the dent appears in the top of the kernel and the starch solidifies towards the cob of the plant, creating a milkline. In research by Hilscher (2018), optimal DM of corn silage can be brought up to 43% but can hinder growth performance of cattle when included in growing diets with high silage inclusions (80%) rather than finishing diets with low silage inclusions (~15%). As corn silage maturity increases, NDF decreases as part of the whole plant and increases in the corn grain, at the expense of NDF becoming less digestible. Allowing corn silage to mature heavily results in poor fermentation of the silage and decreases silage quality. As the silage becomes drier, digestible NDF decreases approximately 13% as DM decreases from 30 to 40%, but starch digestibility increases 40% (Owens, 2008). According to many research trials evaluating corn silage DM at

harvest, optimal DM levels to maximize yield and nutrient quality can be anywhere from 28% DM to approximately 40% DM without adverse effects on livestock performance (Hilscher, 2018, Buchanan-Smith, 1982, Burken, 2014).

The silage must then be stored for at least 21 d to ensure proper fermentation and stabilization by anaerobic microbes. Although corn silage is beneficial in beef feedlot diets, it requires careful and precise production to create a high-quality product, specifically during the ensiling process. Corn silage harvest should be done as quickly as possible, as quality can change dramatically throughout the harvesting period and across environments, soils, corn hybrid, maturity, grain quantity and stover quality (Allen et al., 2003, Andrae et al., 2001, Hunt et al., 1992). Effectively preserving whole plant corn is difficult because respiration, oxidation and effluent losses can occur due to the fermentative and microbial changes that occur (Darby et al., 2002, Barnett, 1954). These negative factors can be exacerbated when the corn silage is ensiled under suboptimal conditions, such as too wet or too dry. When produced properly, corn silage is a valuable energy and roughage source for cattle feeders to utilize, and recent research suggests it could be more economical when included in the diet above 15% inclusion (DM basis) in beef finishing diets (Burken et al., 2017a).

As with all plants, corn silage increases in yield with advancing maturity; however, maturity results in decreased fiber digestibility as lignin cross-links with cell wall polysaccharides within the plant during secondary wall thickening of the plant. Hemicellulose and cellulose cross-linked with lignin are unavailable for attachment by rumen microbes thus decreasing digestibility (Jung and Allen, 1995; Van Soest, 1964). During the thickening of the secondary cell wall, pectin, a more digestible portion of the

plant cell wall, is no longer deposited, causing decreasing fiber digestibility further with increasing maturity (Jung and Allen, 1995). As a result, increasing silage inclusion in the diet may limit the growth performance of the animal due to gut fill from the highly lignified material (Tjardes et al., 2000). Brown midrib hybrid corn silage addresses this issue because it has a reduced lignin content, increasing fiber digestibility and energy available for rumen microbes to convert to VFA (Tjardes et al., 2000). Improving fiber digestibility of corn silage can increase the energy available for cattle to utilize, but it is important that improving fiber digestibility should not happen at the expense of starch digestibility or DM yield of the corn silage (Andrae et al., 2001), which will be discussed further below.

Silage Fermentation and Nutritional Changes

The process of ensiling corn silage takes approximately 2 to 6 weeks, allowing for the respiration processes of microbes to cease if oxygen is prevented from penetrating the ensiled corn (Der Bedrosian et al., 2012). During this period, epiphytic lactic acid bacteria (LAB), found on the surfaces of the plant prior to harvest metabolize water-soluble sugars from the plant, decreasing silage pH through the production of acids (Der Bedrosian et al., 2012, Pahlow et al., 2003). Fiber is also slightly degraded with ensiling time, as NDF digestibility is increased by approximately 1.2 percentage units a month when silage is stored for up to 6 months prior to feedout (Hallada et al., 2008). Some minor dry matter losses are expected during silage fermentation, through sugars within the corn being respired by microbes in the silage during fermentation (Darby et al., 2002).

There are four primary stages of ensiling: an initial aerobic phase, the fermentation phase, the stable phase, and the feed-out period (Pahlow et al., 2003). The primary aerobic phase time length should be minimized because an aerobic environment allows for molds and harmful yeasts to multiply. The oxygen that was within the packed silage allows the plants to respire until the oxygen is consumed, creating an anaerobic environment for anaerobic microbes to be active during the fermentation phase (Pahlow et al., 2003). Silage pH decreases from 7 to 4 during this initial stage through lactic acid production by anaerobic microbes, preserving the corn (Merry et al., 1997, Pahlow et al., 2003). Upon harvest and ensiling of the crop, silage microflora change significantly as oxygen is removed from the environment. One of the most essential micro-organisms for successful silage fermentation is epiphytic lactic acid bacteria (LAB) which increase following harvest and during ensiling (Pahlow et al., 2003). Lactic acid bacteria numbers are hypothesized to increase because of availability of superoxide dismutase and magnesium from the chopped plant, which are intended to alleviate peroxide stress the plant experienced during the harvest process (Pahlow et al., 2003). The aerobic phase ends after approximately 24-48 hours and the fermentative anaerobic phase begins.

The second phase of silage formation is fermentation, which occurs once all oxygen has been removed from the silage (Pahlow et al., 2003). During this phase, some molds, yeasts and facultative and obligate anaerobes compete with LAB for nutrients that are available in the corn (Pahlow et al., 2003). However, because LAB is prevalent, it outcompetes harmful bacteria. In the fermentation phase, ideally 4 to 6% of the total DM will be converted to lactic acid to assist in stabilization of the fermented material (NASEM, 2016). Lactic acid bacteria increase in number and release lactic acid, rapidly

dropping pH of the silage, stabilizing and preserving the corn. Enterobacteria are another form of epiphytic bacteria that produce acetic acid, which reduces nitrates to nitrites and nitrogen oxide (Pahlow et al., 2003), further depressing pH, acidifying the ensiled material, slowing both aerobic and anaerobic microbial activity. During this second period, effluent and gas are released, and some shrinkage occurs as readily available nutrients are consumed by anaerobic microbes (Pahlow et al., 2003). Ideal silage will have a final lactic to acetic acid ratio of at least 3:1.

The third phase of ensiling occurs when the metabolic processes of the silage cease. Due to the acidic environment, only acid tolerant enzymes are active, degrading structural carbohydrates (Pahlow et al., 2003). Some proteases can still convert complex N compounds from the plant into NH_3 during extended periods of storage reducing RUP content (Pahlow et al., 2003). During this time, LAB numbers decrease significantly, while some yeasts and spores survive in a nearly inactive state, which are only activated when the environment becomes more favorable for their growth (Pahlow et al., 2003). During this time, acid tolerant enzymes continue to degrade hemicellulose, increasing NDF digestibility over time (Der Bedrosian et al., 2012). The pH remains stable during this phase at approximately 4.

The final phase is the feedout period, during which oxygen seeps into the silage at a depth of up to 1 m beyond the face of the surface (Honig, 1991). Particularly in corn silage, acetic acid bacteria will rapidly multiply during this phase, heating the silage, reducing lactic acid concentration, and increasing pH, thus causing nutritional value to decline as harmful bacteria multiply (Pahlow et al., 2003). Oxidation losses occur as aerobic microbes consume the ensiled material when exposed to oxygen upon opening of

the silo, damaging the most digestible portion of the feed, the water-soluble carbohydrates (Darby et al., 2002). In order to reduce losses and control quality during the feedout phase, it is recommended to remove 0.15 to 0.30 m per day from the silage face (Charley, 2016)

Consistency and care in silage production are major concerns, as issues can arise due to improper ensiling, long harvesting periods, and slow removal of oxygen from the silo. Some of these problems occur during fermentation and cause issues such as the pH does not get low enough due to a lack of easily digestible carbohydrates (Pahlow et al., 2003). This can cause a secondary fermentation phase, during which harmful bacteria multiply and degrade the silage (Pahlow et al., 2003). These issues are more commonly observed when ensiling grass and legume-based forages that do not have a lot of readily available water-soluble carbohydrates. Other issues that can occur are when the silage has not been sealed properly are allowing yeasts and aerobic bacteria to reproduce, consuming readily available carbohydrates in the silage and reducing silage quality (Pahlow et al., 2003). This occurs more often when sealing of the silage pit is delayed or silage production occurs over a period longer than a few days (Pahlow et al., 2013). When yeasts multiply, they degrade the nutritional value of the silage more quickly once exposed to oxygen because they utilize available nutrients in the corn (Pahlow et al., 2003). Many of the challenges facing silage production are oxygen, temperature of the silage, dry matter content, the pH value and the concentration of organic acids within the silage (Pitt and Muck, 1993). Corn silage is a valuable feed ingredient in feedlots and can be used more effectively by cattle if production is carefully handled.

Effect of Kernel Processing

Beef and dairy producers are continually researching ways to improve the energetic value of corn silage in the beef finishing diets. This has been accomplished using different hybrids, changing DM, theoretical length of cut (TLC) and kernel processing. Kernel processing is done at corn harvest to crack the kernels of grain to increase surface area and increase starch availability for rumen microbes. However, kernel processing can add a cost to the corn silage through extra engine and fuel requirements (Johnson et al., 2003). The results of research on kernel processed corn silage impact on both digestibility and performance have been conflicting results and focused on lactating dairy cows (Johnson et al., 2003, Bal et al., 2000, Rojas-Bourrillon et al., 1987), with little emphasis in feedlot finishing diets. According to Ebling and Kung (2004), processing corn silage decreases the amount of intact corn kernels found in 250 g of silage, from an average of 39 unbroken kernels to less than 10. To improve silage quality, some research has indicated kernel processing the silage during cutting may improve corn silage starch digestibility (Rojas-Bourrillon et al., 1987) by decreasing kernel particle size 15 to 30% and increasing surface area for rumen microbes to degrade starch (Schurig and Rodel, 1993). As a result, kernel processing may increase corn silage feed value because it cracks the kernel, making the starch within more available without negatively affecting the fibrous physically effective NDF stover portion of the plant. In addition to cracking the kernel, the entire plant is crushed through the kernel processor, disrupting the stover and cob portion of the plant, likely affecting some of the fiber particle availability of the plant as well.

The nutrient composition of kernel processed silage can be altered slightly (Weiss and Wyatt, 2000) by increasing the NDF concentration. This change was attributed to

increased losses of water-soluble carbohydrates during fermentation because of increased availability of starch in kernel processed silages for microbes to utilize (Weiss and Wyatt, 2000). The increased fermentation of water-soluble carbohydrates in kernel processing improves silage quality, as Rojas-Bourrillon et al. (1987) observed because it increased lactic acid concentration. Zimmer (1976) attributed increased lactic acid concentration to greater wet packing density of the silage and increased carbohydrate availability of the cracked kernels, reducing silage pH more quickly during the fermentation phase (Rojas-Bourrillon et al., 1987). Kernel processing appeared to influence silage quality but should be revisited with modern equipment and in beef feedlot finishing diets.

In a study by Cooke and Bernard (2005), the effects of kernel processed corn silage included in the diet at 38% DM were evaluated with lactating dairy cows. Starch digestibility increased from 75.6% to 85.4% when the kernels were processed to 2 mm as compared to 8 mm ($P < 0.01$). Additionally, kernel processing to either 2 or 8 mm increased NDF and ADF digestibility ($P < 0.01$) by 32.4% (20.1 to 29.7%) and 50.5% (14.6% to 29.5%), respectively, with no effect on DMI between the treatments ($P > 0.05$) at a theoretical length of cut of either 1.95 or 2.54 cm. Because of smaller kernel particle size, Johnson et al. (2003) recommended increasing chop length to 1.90 cm to maintain the physically effective fiber content of the silages and to counteract the effect of increased passage rate from the smaller particle size of kernel processed silage. Cooke and Bernard (2005) observed increasing the TLC of the corn silage from 1.95 cm to 2.54 cm did not affect fiber digestibility of the corn silage that had been processed to 2 mm. Kernel processing is hypothesized to increased fiber digestibility because the crushed stover not only allows for greater surface available for ruminal fibrolytic microbial

populations, but it also breaks down the cob, thereby reducing sorting of the diet (Cooke and Bernard, 2005). Much of the research on kernel processing has involved dairy cattle, and it needs to be further evaluated in the feedlot to determine if results are similar in cattle who consume less daily.

Ruminal Fermentation and pH

The ruminal fermentation profile of cattle has been altered due to the use of kernel processing in corn silage. In a study by Rojas-Bourrillon et al. (1987), the fermentation profile was altered in the rumen when a 90% kernel processed corn silage diet (DM basis) was fed to growing steers. With greater availability of starch from kernel processed silage researchers observed a reduction in ruminal pH ($P < 0.05$) without an increase in total measured VFA concentration (Rojas-Bourrillon et al., 1987). However, average ruminal pH was above 6.2 throughout the collection period, and fiber digestion is hindered if it drops below 6.2 (Mould et al., 1983) suggesting even though starch digestion may be increased, fiber digestibility tended to be lower than in a non-processed diet with no effect on starch digestibility (Rojas-Bourrillon et al., 1987). They did observe reduced propionic acid and an increased acetate: propionate ratio compared to control silages suggesting starch digestion at a pH of 6.2 was not enhanced as no difference in starch digestibility was observed (Rojas-Bourrillon et al., 1987). A reduction in propionate concentration suggests some of the starch may have bypassed the rumen through an observed numerical reduction in ruminal retention time (Rojas-Bourrillon et al., 1987). In a study by ZoBell et al. (2002), where processed corn silage was included in the diet at 55% DM, no difference ($P = 0.44$) in ruminal pH was observed compared to an isogenic control corn silage. However, the total VFA's in

mmol/L were greater (115 mmol/L) for unprocessed versus processed (108 mmol/L) corn silage included in the diet ($P = 0.04$; ZoBell et al., 2002). Dhiman et al. (2000) observed an increase in starch digestibility and a decrease ($P < 0.01$) in ruminal pH from 5.85 to 5.73 when kernel processed silage was included in the diet at 34%. Kernel processing may play a role in increasing passage rate through the rumen, but fiber still needs to be degraded to pass through the omasal orifice to the lower digestive tract, which can be inhibited in even high starch diets.

Nutrient Digestibility

The smaller particle size of kernel processed silage should make it pass through the rumen more quickly, reducing fiber digestibility, negating positive effects observed due to increased starch digestibility in the rumen (Miller et al., 1969). Site of nutrient digestion, specifically starch and fiber, is why kernel processing silage has been difficult to evaluate in corn silage-based diets. Kernel processing to 2 mm can improve starch and fiber digestibility specifically when increasing the length of cut of silage from 1.95 to 2.54 cm allowing fibrolytic microbes to attach to cell walls and degrade due to a slower passage rate (Cooke and Bernard, 2005). In a study by Wilkinson et al. (1978), kernel processing increased ($P < 0.01$) dry matter digestibility of the diet by 1.8 percentage units when corn silage was fed ad libitum in the diet. A negative associative effect between fiber and starch occur, because as increased starch is digested from the diet, VFA production by ruminal microbes is increased, reducing ruminal pH, creating a less hospitable environment for fibrolytic bacteria, reducing fiber digestibility. When studies evaluate the effects of kernel processing, fiber and starch digestibility both need to be evaluated to determine the overall effect of kernel processing.

Apparent total tract nutrient digestibility can help researchers determine how ingredients are utilized by cattle and assist in understanding how this may affect performance. In a study by ZoBell et al. (2002), kernel processing improved NDF digestibility in 55% silage DM diets, but this did not translate into improved ADG (P = 0.39) or a change in daily DMI (P = 0.33), suggesting a change in rumen fermentation may not translate to improved growth performance. Kernel processing is dependent on TLC and the width of the kernel processing rollers. No other nutrient digestibility was affected by processed corn silage (ZoBell et al, 2002). As in other studies, ZoBell et al. (2002) suggested the improvement of NDF digestibility was likely due to the changes in surface area of stover and cell wall available for ruminal microbes to attach and degrade fibrolytic material. However, because increased NDF digestibility has not always been observed, the improvement ZoBell et al. (2002) observed may not have warranted a great enough increase in energy available for a growth response (Johnson et al., 2003).

In a study by Johnson et al. (2003) kernel processing silage to 1 mm to feed to dairy cattle improved (P < 0.01) starch digestibility but was negated by a tendency for decreased (P = 0.10) NDF digestibility when included in the diet at 26.8% (DM basis) resulting in no change in DM digestibility (P > 0.11). This agrees with the common reaction of negative associative effects between starch and fiber. Rojas-Bourrrillon et al. (1987) agreed processing whole corn silage did not affect (P > 0.05) DM digestibility or steer growth performance when included in the diet at 90% DM. Even as silage was increased in the diet up to 90% DM, kernel processing appeared to provide no benefit over traditionally produced corn silage. However, as corn silage harvesters have improved in efficiency and cutting technology, kernel processing is worth reevaluating,

especially as producers are encouraged to harvest drier silage that have a harder endosperm on the corn kernels (Hilscher, 2018).

In a series of studies by Dhiman et al. (2000), the effect of processed corn silage included in the diet at 30% to 37% DM inclusion in lactating dairy cow diets on total tract digestibility, ruminal fluid parameters and milk composition were evaluated. Total tract OM digestibility decreased ($P < 0.01$) by 6.1%, NDF digestibility was decreased ($P < 0.01$) by 12.8%, and starch digestibility tended to increase 3.5% ($P = 0.09$) when the corn silage was kernel processed and included in the diet at 34 % DM. Similar results were obtained by Johnson et al. (2003), who hypothesized starch digestibility increased in the rumen because of kernel processed corn silage have more readily available starch for rumen microbes to digest. As a result, NDF digestibility was likely decreased because of increased passage rate through the rumen, inhibiting attachment by fibrolytic microbes. Some of the improvement in starch digestibility has been attributed to a reduction in sorting, because cattle could not sort off poorly processed corn cobs in the feed which decrease indigestible fiber intake (Dhiman et al., 2000). In addition to an increase in starch digestion of 3.5%, Dhiman et al. (2000) observed there were fewer kernels in the feces of cattle fed kernel processed corn silage, suggesting kernel processing increased corn digestion (14 vs 53 kernels per kg of feces, DM). Despite the fact there were improvements in starch digestibility and a reduction in NDF digestibility, no changes ($P > 0.35$) were observed in the lactation performance of the dairy cattle (Dhiman et al., 2000). Through increased levels of corn silage in the diet, kernel processing appears to play a role in manipulating digestibility of nutrients throughout the digestive tract, with little biological effect on performance.

In a study by Andrae et al. (2001), researchers determined the effect of kernel processing, hybrid and maturity on apparent total tract nutrient digestibility of a high roughage diet that included 60% corn silage and 40% alfalfa hay (DM basis). When analyzing kernel processing, they observed increased starch ($P < 0.01$) digestibility with a simultaneous reduction in NDF and ADF digestibility ($P < 0.01$), resulting in no net effect on DM digestibility (Andrae et al., 2001) agreeing with research by Johnson et al. (2003) and Dhiman et al. (2000). Increasing starch digestibility may have inhibited fiber digestion because of an altered ruminal environment (Andrae et al., 2001) as observed in other studies. Another reason for decreased fiber digestibility may have been due to increased passage rate through the rumen, decreasing time available for rumen microbes to break down fiber in the silage particles before they leave the rumen (Andrae et al., 2001). Kernel processing appears to affect more than just starch digestibility within the rumen, causing an increase in starch digestion that decreases fiber digestibility, either through a reduction in adherence by ruminal microbes and/or a reduction in rumen retention time.

Performance

Very few studies have researched the use of kernel processed corn silage in the diet and its effect on growth performance in beef cattle finishing diets. In a study feeding kernel processed silages at 65, 90 and 60% DM with alfalfa hay or corn grain used to change the energy content, growing steers did not have different ADG ($P > 0.05$) at any inclusion of corn silage in the diet (Rojas-Bourrillon et al., 1987). In a similar study by ZoBell et al. (2002), the growth of replacement heifers fed kernel processed corn silage included in the diet at 55% (DM basis) cut to 13.3- or 10.6-mm TLC did not have any

effect on ADG ($P > 0.39$). In a lactating dairy cow study by Bal et al. (2000), they observed an increase in DMI, milk production and milk fat yields for cattle fed processed corn silage when diets included 67% corn silage DM. Dry matter intake increased from 25.3 to 25.9 kg/day ($P < 0.01$) when cattle were fed processed corn silage in their diet helping with increased milk production (Bal et al., 2000). Including processed silage in the diet of lactating dairy cattle increased body weight by 8 kg measured over 28 d periods (Bal et al., 2000). In a trial by Dhiman et al. (2000), kernel processed silages on lactating dairy cattle included in the diet at 30% DM, DMI was increased in multiparous Holstein cattle by 1.2 kg/day. Additionally, kernel processed corn silage included in the diet at 30-37% also increased milk fat by 0.35 percentage units in multiparous dairy cattle (Dhiman et al., 2000). While it has been extensively studied in dairy cattle diets, changing the availability of starch in the diet of cattle consuming high concentrate diets in the feedlot should be evaluated, especially when increasing corn silage inclusion in the diet.

Fiber Digestion in Ruminants

Ruminants have the unique ability to digest fiber because of the fibrolytic enzymes of rumen microbes. Fibrolytic bacteria are present in the rumen, and their primary purpose is to degrade cellulose and hemicellulose and release primarily acetate and some butyrate as an energy source for the ruminant (Blummel et al., 1996). Fiber digestibility is initiated when microbes penetrate cell wall material through damaged areas, which were incurred either through chewing or processing of the forage. Once adhered to the fiber particle, microbes release cellulolytic enzymes to degrade the cell wall and utilize the carbohydrates for their fermentative processes (Varga and Kolver,

1997). More digestible portions such as pectin are degraded first, followed by the degradation of the less digestible hemicellulose and cellulose. This leaves the framework of an empty cell wall, which is primarily indigestible lignin, to be passed through the rest of the gastrointestinal tract.

Fiber is a broad term to describe a set of complex polysaccharides that make up the cell wall, including cell wall proteins, structural polysaccharides and lignin, which is only partially digestible by ruminants and indigestible in monogastrics (Moore and Jung, 2001). Neutral detergent fiber (NDF) is made of cellulose, hemicellulose and lignin, of which lignin is indigestible by even microbial enzymes in the rumen. Microbial enzymes have the ability in the rumen and large intestine to degrade a β-1,4 linkage of cellulose and hemicellulose polysaccharide linkages. Cellulose is made of linear chains of D-glucopyranose and alternate glucose linked by β -1-4 bonds and is stabilized by hydrogen bonds (NASEM, 2016). Cellulose is then bound to hemicellulose via hydrogen bonds, which consists of a heterogeneous group of polysaccharides, rather than just glucose residues (NASEM, 2016). Hemicellulose is bound to lignin via ester and ether bonds, making it less digestible because of the indigestibility of lignin (NASEM, 2016).

Lignin is useful for providing physically effective fiber, which increases chewing through rumination by the animal, thus increasing time spent in the rumen. However, lignin essentially does not provide any nutrients to cattle (Andrae et al., 2001). Reducing lignin in brown midrib corn hybrids can be very beneficial. This is because lignin is essentially a term to describe indigestible polymers in the cell wall providing structure and rigidity to the plant (Vanholme et al., 2010). Lignin is increased as the plant matures, decreasing digestibility as it creates cross linkages with hemicellulose. Lignin consists of

highly condensed phenylpropanoid cell walls which are resistant to microbial degradation in the rumen (NASEM, 2016). These molecules are attached to one another either through carbon-carbon bonds or ether cross linkages (NASEM, 2016).

Lignification causes a barrier between cell wall carbohydrates and rumen microbes, reducing digestibility of the hemicellulose bound to the lignin (Moore and Jung, 2001). Lignin can also limit fiber digestibility through a few other factors. Phenolic compounds found in non-core lignin are likely toxic to fiber digesting bacteria, disenabling them from degrading cell wall attached to lignin. Additionally, lignin creates a hydrophobic environment, in which enzymes from microbes that are hydrophilic cannot attach and degrade (Buxton and Redfearn, 1997). Reducing lignin is important for beef cattle producers because of a potential for an increase in fiber digestibility and growth performance. As a result, lignin is the biggest reason anaerobic digestion of forages is limited within the rumen and reducing lignin would increase digestibility by ruminal microbes.

Effect of Corn Hybrid

The brown midrib mutant gene, *bm1*, was discovered in 1924 in dent corn (Emerson et al., 1935). Other brown midrib mutants have been discovered, and they all have a common characteristic of reddish-brown pigmentation of the leaves. The *bm3* mutant, discovered later in the 1930's by Emerson et al. (1935), is the brown midrib of most interest because it has greater potential for ruminal digestible NDF and up to 35% less lignin concentration as compared to traditional isogenic hybrids (Miller et al., 1983; Oba and Allen, 2000). The concentration of an enzyme known as O-methyltransferase is decreased in brown midrib corn silage (Barriere and Argillier, 1993) resulting in less

lignification production as the corn plant matures. This causes a reduction in the rate at which 5-hydroxyferulic acid is converted to sinapinic acid, increasing hydroxyguaiacyl lignin as compared to syringyl lignin (Moore and Jung, 2001).

The difference in lignin concentration of brown midrib corn silage results in agronomic differences between corn hybrids. According to Ballard et al. (2001), isogenic TMF corn silage hybrids are tall and leafy and have thinner stalks than brown midrib hybrids. These isogenic TMF corn silage hybrids have a softer starch in the kernel, which may improve starch digestibility (Ballard et al., 2001). Brown midrib corn silages have approximately 10% lower grain yields as compared to typical corn hybrids (Miller et al., 1983), as well as higher lodging potential compared to conventional corn silage (Cherney et al., 1991), because of lower structural integrity. According to Miller et al. (1983), brown midrib corn silage grain yield was 77% of conventional, while stover was 90% of conventional corn hybrids. Additionally, brown midrib corn silage has had more barren plants within the field than the conventional, resulting in fewer average ears per stalk (Miller et al., 1983). Stalk breakage occurs at a greater rate for brown midrib corn silage hybrids during the corn grain harvest as compared to conventional corn silage hybrids further reducing yields (Miller et al., 1983). According to Tu and Bauman (1977), during the initial research phase of *bm3* hybrids for corn silage, a reduction in yield by 10% was made up for with improved NDF digestibility of the plant. However, despite improved fiber digestibility, some research indicates reduced yields of *bm3* silages and increased lodging risk detracts producers utilizing *bm3* hybrids (Ballard et al., 2001). However, more recent research by Young et al. (2016), a comparison of brown midrib silage to an

isogenic control resulted in no differences in yield, suggesting that brown midrib silage hybrids are becoming a more viable option for producers with improved technology.

Increasing fiber digestibility leads to an increase in energy available from the plant for the animal. Researchers have observed an increase in DMI of cattle fed brown midrib corn silage because the increased fiber digestibility reduced gut fill, allowing animals to increase energy intake (Tine et al., 2001). Ruminal fill is affected by fibrous fractions that are more slowly fermented than nonfiber fractions, affecting gut fill, and decreasing DMI, thereby hindering growth performance or milk production through a limitation in energy intake (Oba and Allen, 1999). Changing the quality of the fiber in plants can change both digestibility and gut fill, leading to changes in digestibility and energy intake of the diet.

With a reduction in lignin content in brown midrib corn silage, content of other nutrients is also changed because of the modified cell wall structure of the plant. In a study by Tjardes et al. (2000), brown midrib corn silage had 6.3% more starch than a conventional corn silage in addition to a lower NDF and ADF fraction. Contrary to Tjardes et al. (2000), Oba and Allen (1999) observed no difference in starch content of the brown midrib corn silage as compared to conventional corn silages at approximately 33% DM starch of measured samples. Other than some discrepancies in starch and a slightly lower NDF content, other nutrients have been found to be similar between brown midrib and isogenic traditional corn silage hybrids (Cherney et al., 1991, Oba and Allen, 2000).

Flinty or floury endosperm hybrids and dual-purpose leafy hybrids have been evaluated for corn silage production. When comparing floury and flinty corn silage

hybrids (Johnson et al., 20002), floury endosperm corn silage had greater starch digestibility, but as the plant matured both hybrids had decreasing starch digestibility. The zein protein in corn grain attaches to starch molecules making it less available for digestion in ruminants, while floury endosperm hybrids have reduced zein, increasing starch digestibility potential (Lopes et al., 2009). Very little research has been done in brown midrib corn silage with floury endosperm, suggesting there needs to be more extensive research to determine its value in beef finishing diets. Grant et al. (2017) reviewed the use of brown midrib with a floury endosperm in dairy diets included at 49% DM compared to a traditional control corn silage and a brown midrib corn silage. Microbial biomass production was greatest for the brown midrib with floury endosperm corn silage (147 mg/g) as compared to brown midrib (138 mg/g), suggesting increased microbial crude protein synthesis and more starch digestibility within the rumen (Grant et al., 2017). However, total milk yield and 3.5% FCM were not different ($P > 0.05$) between brown midrib hybrids, but efficiency of FCM production for DMI was greatest for the brown midrib with floury endosperm (Grant et al., 2017). In this study, no difference in digestibility of nutrients was observed, suggesting an increased passage rate for brown midrib corn silage hybrids through the gastrointestinal tract. Some research needs to be done in beef finishing diets to determine if brown midrib corn silage with a floury endosperm and improves silage quality to improve growth performance as compared to regular brown midrib corn silage.

Rumen Fermentation Characteristics

Physical gut fill limits DMI in ruminants on forage diets, which is a function of both digestion rate and rate of passage through the rumen (Greenfield et al., 2001).

Effective fiber from the corn silage slows ruminal passage rate because ruminal microbes need to attach to and degrade fiber slowly, which includes breaking down the fiber, releasing gases and decreasing particle size to flow through the omasal orifice (Lascano and Heinrichs, 2011). Fermentation of fiber is a slower process than the degradation of starch, which results in an increase in ruminal pH through lower VFA production and an increase of mastication, releasing more salivary buffer to the rumen (Galyean and Defoor, 2003). Feeding *bm3* corn silage in the diet at 35 or 55% DM can reduce ruminal pH, because of its' lower lignin content and potential for greater fiber digestibility than isogenic corn silage (Oba and Allen, 2000). Increasing the fiber digestibility and passage rate results in a postruminal flow of NDF from *bm3* silages which averages 0.9 kg/d less than control corn silages when fed diets of 60% corn silage (DM basis; Greenfield et al. 2001).

Nutrient Digestibility

Altering the physical components of the fiber portion of corn silage has the potential to improve fiber digestibility in beef cattle diets (Tjardes et al., 2000). This is likely more apparent when silage is included in the diet at inclusions greater than average feedlot finishing diets, which is typically 10-15% DM. Neutral detergent fiber is the primary nutrient affected when using *bm3* corn silage hybrids in beef cattle diets because lignin binds primarily to hemicellulose. In a trial by Ebling and Kung, (2004), 30 h in vitro NDF digestion of brown midrib silage hybrids (53%) were greater ($P < 0.01$) than conventional control silage hybrids (40%). The brown midrib hybrids also have greater in vitro digestion rates of other nutrients of silage including DM (Muller et al., 1972). In a study by Tjardes et al. (2000), diets including 86% brown midrib corn silage (DM basis)

had greater overall DM, OM, NDF, and ADF digestibility as compared to an isogenic control. Neutral detergent fiber digestibility improved ($P < 0.01$) by 10.5 percentage units over the control when fed an ad libitum diet, and 15.8 percentage units when fed a diet restricted to 80% of ad libitum intake (Tjardes et al., 2000) due to a slower passage rate at lower DMI. When this diet was fed to growing steers, the brown midrib corn silage resulted in a tendency to increase DMI by 0.28 kg/day ($P = 0.06$) with no change in ADG ($P = 0.23$; Tjardes et al., 2000). Once animals were finished on a high concentrate diet, no differences in performance due to the previous grower diet of primarily corn silage were observed ($P > 0.10$).

According to Greenfield et al. (2001), there was greater rumen DM and OM digestibility by 7.1 and 4.7 percentage units, respectively, when brown midrib corn silage was included in the diet at 60% DM. This translated to greater DMI but a lower total tract starch digestibility (Greenfield et al., 2001). Hassanat et al. (2016) observed ruminal degradability of NDF was greater for brown midrib silages included in the diet compared to a conventional corn silage, at 64% versus 60.4% degradability, respectively. According to Lim et al. (2015), the 30-h in vitro NDF digestibility of the brown midrib corn silage in dairy cattle diets including 35 or 50% corn silage (DM basis), was on average 11 percentage units greater than conventional corn silage. Both NDF and ADF digestibility are affected by *bm3* corn silage, but this does not always translate to improved growth performance. Additionally, there is little research on the effect of brown midrib corn silage on performance in beef finishing diets.

Performance

Much of the research evaluating brown midrib corn silage in the diet has been focused primarily in the dairy industry with little emphasis in beef finishing diets. In early trials utilizing brown midrib hybrid corn, the brown midrib trait had a growth performance advantage over traditional corn silage hybrids when no additional corn grain was fed in the diet as a supplement (Keith et al., 1981). Additionally, Keith et al. (1981), fed diets that compared ad libitum access to corn silage and corn grain diets fed at 2% of the bodyweight at approximately 50% corn grain and 50% corn silage, resulting in inclusions of 88%, 60% or 27% DM. When fed 88% corn silage diet ad libitum with only a supplement, *bm3* corn silage improved ADG ($P < 0.10$) from 0.82 to 0.90 kg/d. Adding concentrate and reducing corn silage to 27% in the diet resulted in no differences in growth performance between corn silage hybrid treatments when diet was approximately 50% grain ($P > 0.10$). As silage was decreased in the diet, fiber digestion was likely reduced in a lower pH ruminal environment because of the rapidly fermenting grain replacing the corn silage. Tjardes et al. (2000) fed a diet consisting of 86% *bm3* corn silage (DM basis) and observed daily DMI increase by 0.62 kg/day when fed to growing steers. While NDF digestibility was increased, an improvement in ADG was not observed ($P = 0.33$) during the growing portion but was greater during the finishing phase ($P = 0.06$), but not throughout the entirety of the study ($P = 0.23$; Tjardes et al., 2000). When utilizing brown midrib corn silages in dairy diets at 37% in the diet, researchers observed improved milk yield (Barlow et al., 2012). Hassanat et al. (2016) observed feeding brown midrib silage at 58% in the diet increased DMI by as much as 1.6 kg/d in dairy cattle diets. When comparing 35 and 50% corn silage inclusion in the diet, Lim et al. (2015) observed brown midrib corn silage had an improvement in milk yield over conventional

corn silage-based diets by 2.7 kg/d. An increase in intake through improved fiber digestion and greater passage rate through the gastrointestinal tract of cattle has been well documented across many research trials, but it is necessary to revisit this effect on growth performance in beef feedlot finishing diets. Improving NDF and ADF digestibility is of interest in the feedlot industry, specifically if greater corn silage inclusions are more economical.

Corn Silage Inclusion in Beef Cattle Diets

Recent research done at the University of Nebraska-Lincoln evaluating increasing corn silage in the diet has been shown to be economical when included with DGS in the diet (Burken et al., 2017b). Producers and researchers have been evaluating the use of increasing corn silage in the diet during times of expensive corn for many years (Goodrich et al., 1974). Corn production had increased to 89.1 million acres in 2018, with much of the growth largely due to the use of alcohol fuel as an energy source (USDA, 2018). By increasing corn production, more acres are available for corn silage production, an alternative to when corn grain is expensive. However, because corn silage has 50% corn grain and 50% roughage source, it has had limited adoption at higher inclusions in the feedlot finishing diet. The primary issue with increasing corn silage in the diet is that it typically results in a decreased G:F and ADG during the feedlot finishing phase (Goodrich et al., 1974, Erickson, 2001). However, this was prior to the expansion of the ethanol industry, and research evaluating increased silage in the diet with the inclusion of DGS has only recently been evaluated. In a study by Burken et al. (2017a) including modified distillers grains plus solubles (MDGS, 47% DM, 31% CP; NASEM 2016) in the diet at 20 or 40% and either 15 or 45% corn silage, MDGS resulted

in ADG being poorer at lower concentrations at 20% MDGS by 13.6% as silage increased from 15 to 45%, but at 40% MDGS ADG was only reduced by 5.0%. Dry matter intake decreased by 14.6% when the diet included 20% MDGS and silage went from 15 to 45%, with no difference in DMI between diets including 40% MDGS (Burken et al., 2017a).

The use of high forage diets in the finishing diets allows producers to increase days on feed and increase size to increase hot carcass weight at the same backfat thickness. These marketing tactics also allow producers to take advantage of excess forage and less expensive sources of energy for their animals. Growing the frame of cattle for yearling fed programs creates larger framed cattle and increases pounds of beef marketed from the carcass. Other calves are brought through a calf-fed system, where they are fed high concentrate diets in the feedlot upon weaning, where they reach slaughter weight at a younger age and smaller size less efficiently than yearlings.

Corn silage is unique within the beef industry because it represents a forage source that is roughly 50% grain and 50% roughage, making it a high energy feedstuff that can be used in both backgrounding and finishing systems. To harness the effects of the compensatory gain period from backgrounded cattle, producers will feed high roughage diets during the first few months of the feedlot to reduce gain and increase frame size before stepping cattle up to high concentrate diets. Compensatory gain is a period of rapid growth following a period of nutrient restriction in feedlot diets. During the time of restricted nutrient intake, producers will feed high roughage or limited energy intake diets to decrease growth. Once fed an adequate nutrient intake, cattle will experience increased ADG and DMI and lower energetic requirements for growth

(Carstens et al., 1991). Nutrients can be limited to cattle through one of two ways, either through high forage intake to limit nutrient intake through gut fill or by limiting the daily DMI while feeding a high energy diet, keeping cattle hungry.

High concentrate diets are typically utilized by the beef industry because they minimize days spent on feed and maximize ADG (Vasconcelos and Galyean, 2007). While this has been a benefit, it does not necessarily consider the cost of feed ingredients. Corn silage as a proportion of the diet can be economical, especially during times of highly priced corn, because corn silage provides both energy and roughage. While maximum growth performance is a goal by feedlots, maximum profitability and lower cost rations utilizing less concentrated feeds may be more beneficial. Large feedlots are limited by the amount of corn silage that can be fed in the diet because of limitations in space and land on which to grow corn for silage. For smaller producers who have access to land, this may provide an economical alternative to finish smaller lots of cattle.

Corn Silage in Finishing Diets

Corn silage has been increased in the diets of finishing beef cattle to partially replace corn grain when corn grain is expensive (Goodrich et al., 1974, DiCostanzo et al., 1998). When corn silage is elevated in finishing beef diets, we observe a classical decrease in ADG and a poorer feed efficiency due to decreases in energy available for gain in the diet (Preston, 1975, DiCostanzo et al., 1997). In a review by Goodrich et al. (1974), researchers evaluated the effects of high inclusion of corn silage in finishing beef diets and its economic impact on the industry, summarizing 17 trials using 878 steers. From these 17 studies, corn silage concentration of the diet was increased from 10 to 80% (DM basis), where ADG ranged from as low as 0.86 kg/d with the 80% corn silage diet to

1.14 kg/d at a diet with 10% silage inclusion. Cattle had a greater reduction in ADG as silage levels increased from 70 to 80% inclusion (DM basis) decreasing 0.06 kg/d as compared to 10 to 20% DM inclusion when ADG decreased only 0.013 kg/d (Goodrich et al., 1974). As expected, researchers observed those cattle growing slower also reached mature size at heavier weights, resulting in more days on feed (DOF) needed, increasing from an average of 283 DOF for 10% inclusion of silage to 314 DOF for cattle finished on 80% corn silage. As researchers evaluated DMI as silage in the diet increased, they observed a reduction in DMI when diets were fed 40-50% DM corn silage, suggesting cattle were reducing intake because they were limited by gut fill (Goodrich et al., 1974). In a study by McEwen et al. (2007), Angus steers fed 50% corn silage (DM basis) diets, still had greater ($P < 0.01$) DMI compared to cattle fed 15% corn silage (DM basis) diets, suggesting that chemostatic endpoint may still be playing a role at that 50% inclusion rate; however, but DMI is also likely dependent on silage quality, hybrid and other agronomic factors. Research by McEwen et al. (2007) observed feed efficiency tended to increase from 6.11 kg of feed/kg of gain to 6.38 kg of feed/kg of diet as silage increased from 15 to 50% in the diet. Despite poorer feed efficiency, Angus cattle fed 50% corn silage (DM basis) had similar ($P = 0.13$) ADG and greater DMI ($P < 0.01$), which authors suggested the lower DMI in 15% silage diets was potentially due to metabolic regulation of intake (McEwen et al., 2007). In a second study with Charolais cattle, fed either 50 or 15% corn silage-based diets, ADG, DMI and feed efficiency remained unaffected by silage inclusion in the diet ($P > 0.14$; McEwen et al., 2007), but may have been confounded by other ingredients included in the diet such as grain source (barley or corn) and final shrunk bodyweight endpoint (550 or 600 kg). Increasing corn

silage in the diet has not been adopted because of negative associative effects between fiber and starch, resulting in a reduction in feed efficiency. Additionally, increasing corn silage inclusion in the diet requires a lot more bunker space, which is a challenge, especially for larger feedlots feeding large amounts of cattle year-round.

Corn Silage and Distillers Grains

Prior to the expansion of the ethanol industry, corn silage inclusion in the diet was researched heavily, and feed efficiency typically was decreased approximately 10% when corn silage in the diet increased from 15 to 45% inclusion in the diet (Burken et al., 2017a). As the ethanol industry has expanded and the use of DGS has become more common, reevaluating increasing corn silage in the diet with coproducts has become necessary. Folmer et al. (2002) researched differing corn silage hybrids fed to growing steers for a period of 110d in the diet at 90% (DM basis) and a 10% SBM and urea supplement and reported 1.34 kg/d ADG. Additionally, in a study by Tjardes et al., (2000), cattle gained 1.02 kg/d when fed diets of 86% corn silage without the inclusion of coproducts over a period of 112 days. In a study by Weber et al., (2010), steers gained 1.64 kg/d when fed 80% corn silage with 15% WDGS (DM basis) for a period of 86 days gained approximately 1.64 kg/d, which is much greater than either study by Folmer et al. (2002) and Tjardes et al. (2000). While direct comparisons across experiments cannot be made, there appears to be some performance benefit of adding WDGS to the diet. Bremer et al. (2010) evaluated increasing levels of DDGS in the diet and observed a linear increase in ADG and G:F. This response has been attributed to the protein content of the DGS, especially in diets for growing calves, this can meet the MP requirements, as well as provide energy from the deamination of protein post ruminally.

In a study by Felix et al. (2014), the effects of differing protein sources in high corn silage diets (79% DM) were evaluated on growth performance of growing cattle. The three protein sources were urea, SBM or DDGS. As expected, cattle fed diets including either SBM or DDGS had greater ($P < 0.01$) ADG and G:F than those cattle supplemented with just urea as their protein source due to greater RUP availability. When evaluated economically, cattle fed DDGS had the lowest ($P < 0.01$) cost per gain (Felix et al., 2014). Urea is typically a protein source that is considered 100% RDP, which likely meant the cattle fed the urea supplement diet were short on MP supply. Average daily gain increased by approximately 19% as the diet was switched from a urea-based supplement to DDGS, gaining 1.57 kg/d. Providing RUP to meet growing MP requirements at an affordable rate greatly increases the value of corn silage in the diet, as observed by Burken et al. (2013). Felix et al. (2014) reported that increasing CP content of the diet with urea from 11 to 13% caused a reduction in ADG and G:F in growing cattle, suggesting MP requirements cannot be met with urea, and growing calves specifically need RUP to maximize growth performance in high corn silage-based diets.

In high corn silage-based diets, supplying enough MP for growing cattle appears to provide a growth performance benefit. In recent research performed at the University of Nebraska-Lincoln, Hilscher (2018) evaluated the effects of increasing RUP in corn silage-based diets (88% diet DM) at 0.5, 1.4, 2.4, 3.3 or 4.2% RUP in the diet DM. As the MP requirements of growing calves were met with increasing RUP in silage growing diets, cattle supplemented with 4.2% had heaviest ending body weight at the end of an 88-d trial. Additionally, a linear increase ($P < 0.01$) in ADG was observed, increasing G:F ($P < 0.01$) as RUP increased in the diet (Hilscher, 2018). The approximate RUP

content in corn silage is 13%, and digestibility of that RUP is approximately 50% (Oney et al., 2019). Supplying supplemental protein in growing calf diets to meet MP requirements at 9 to 13% CP with soybean meal improved DMI, ADG and G:F in growing calves (Perry et al, 1983). In a trial feeding 85% corn silage (DM basis) supplementing RUP in the diet at 0, 3.25, 6.5, 9.75 and 13% of the diet increased ending body weight and ADG linearly (Oney et al., 2017D). Once cattle weighed approximately 331 kg, RUP supplementation only further increased F:G 11% as compared to 30% when cattle weighed 272 to 331 kg, suggesting the lower requirement of RUP by larger calves played a role (Oney et al., 2017). Rumen undegradable protein in growing calves is important, as supplementing calves with just a urea supplement did not result in the same improvement in performance as compared to the RUP supplemented studies. Rumen undegradable protein supplementation in corn silage-based diets appears to provide a benefit, as observed in the previous trials, which is why the use of MDGS in the diet may have provided the benefit in research by Burken et al. (2017a) when corn silage was increased in the diet. This review suggests, especially early in the growing period when cattle are smaller, meeting MP requirements in corn silage diets with RUP improves ADG and G:F, because RUP requirements are not met with corn silage alone.

Negative Associative Effects between Fiber and Starch

Associative effects occur when ingredients in the diet act together and do not result in the predicted effects when comparing the individual ingredients separately. Negative associative effects are observed when individual ingredients work together and result in less than the predicted performance than the individual ingredients themselves. Ruminants have a unique ability to digest both concentrates and fibrous substances.

Negative associative effects occur when grains are a large portion of the diet in forage diets, causing a lower efficiency (Dixon and Stockdale, 1999). This occurs when microbial digestion of fibrous components of forages is negatively affected by low pH created by microbial digestion of starch (Dixon and Stockdale, 1999). Due to readily fermentable carbohydrates available in the diets from processed grain, digestibility of the fibrous components of the diet is decreased as a result (Dixon and Stockdale, 1999).

Joanning et al. (1981) evaluated the associative effects on diet digestibility and cattle response between corn grain and corn silage by feeding diets containing 90% corn silage with no grain, 30% corn silage with 60% grain, or 90% corn grain with no silage in the diet. Researchers observed negative associative effects due to the 30:60 diets, where diet dry matter digestibility was approximately 11% lower than individually fed corn silage or corn grain (Joanning et al., 1981). According to Joanning et al. (1981), an increase in DMI in mixed forage and corn diets increased passage rate through the rumen and small intestine, decreasing the ability for rumen microbes to degrade both starch and fiber effectively. This resulted in a reduced ability of the animal to utilize the nutrients in the diet.

Corn Silage Effects

As the diet was shifted from corn grain to corn silage, Vance et al. (1972) observed that maintenance energy values of the ingredients remained unchanged, but that net energy of gain values were decreased for corn grain and increased for corn silage as corn was reduced from 83 to 46% of the diet (DM basis). Peterson et al. (1973) observed a similar issue when researchers fed diets that included either 86% corn grain, 57% corn grain and 29% corn silage, 29% corn grain and 57% corn silage, or diets that included

just 86% corn silage between the mid-levels of both corn grain and silage in the diet (Peterson et al., 1973). This study evaluated the diets using net energy values derived from Lofgreen and Garrett (1968), and it was observed that a negative associative effect between the grain and silage may have occurred, as cattle fed either corn silage or corn grain only had gains 123 and 135% above the expected calculated values, while mixed diets only observed increased gains 110 and 113% above expected calculated values (Peterson et al., 1973). Increasing the energy content of the diet increased ($P < 0.01$) feed efficiency from 0.135 to 0.198 as cattle were transitioned from 86% corn silage to 86% corn grain in the diet (Peterson et al., 1973). However, when gain was calculated based on concentrate in the diet, the high corn silage diets at 86% DM inclusion had the lowest amount of concentrate required per kg of gain at 4.24 kg of concentrate/kg of gain, as compared to the high corn diet (86% DM inclusion) of 5.08 kg. The negative associative effects of corn silage and corn grain are further observed in this as a diet that included 57% corn and 29% corn silage needed 5.38 kg of concentrate/kg of gain (Peterson et al., 1973).

In a study by Gill et al. (1976), where corn silage replaced high moisture corn in the diet and was included in the diet at 14, 30 or 75% (DM basis), 28 more DOF were required for cattle fed 75% corn silage to allow cattle to reach a similar final gross weight. As observed in other trials with increasing corn silage, the 75% treatment resulted in a reduced ADG of 1.13 kg/d as compared to 1.50 and 1.41 kg/d for the 30 and 14% inclusion, respectively. Unlike what was observed with Joanning et al. (1981), where a reduction in DM digestibility was observed due to negative associative effects between corn grain and corn silage, in the study by Gill et al. (1976), the diet with 30%

corn silage and 60% grain had a similar feed efficiency to cattle fed 14% corn silage and 77% corn grain, at 5.58 and 5.33 kg of feed/kg of gain, respectively. A reduction in DMI was observed in the 14% corn silage cattle, suggesting an energetic response limiting intake as compared to 30%, resulting in no change on overall feed efficiency in the trial. The cattle consuming 75% corn silage had a lower dressing percentage than 30 or 14% inclusion of corn silage (Gill et a., 1976), which was observed in a study by Peterson et al. (1973), where increasing corn silage to 86% (DM basis) in the diet resulted in a dressing percentage of 62.6% as compared to 64.4% for a high moisture-corn based diet. This suggests greater corn silage inclusion in the diet results in increased gastrointestinal weight due to fill and organ size as compared to lower corn silage inclusions in the diet.

Gill et al. (1976) observed feeding cattle 75% DM corn silage diets had greater backfat thickness than 30 and 14% inclusion (1.87 cm versus 1.35 and 1.42 cm, respectively; Gill et al., 1976) when cattle were brought to similar final shrunk body weights. Due to differences in dressing percentage, the similar final body weights resulted in lower HCW for cattle fed 75% corn silage, despite being fed 28 more DOF. This may have been because cattle were finished smaller during the time of this study, and may have met their physiological endpoint earlier, resulting in the 28 DOF not providing much benefit as compared to the 14 and 30% treatments (Gill et al., 1976). Peterson et al. (1973) also observed cattle on a high silage diet (86% inclusion, DM basis) needed an additional 55 DOF to finish to a similar carcass weight endpoint as cattle fed high corn grain diets (86% DM inclusion), due to lower ADG.

More recent research on increasing corn silage in the diet was done by Erickson (2001), evaluating increasing corn silage in the diet at 15, 30 or 45% (DM basis) in both

yearling and calf-fed experiments. In experiments with yearling cattle, DMI was unaffected ($P > 0.25$) by corn silage level in the diet (Erickson, 2001), suggesting gut fill may have been hindered at 45% inclusion as those cattle did not consume as much energy as those animals on a high concentrate diet (15% corn silage). In these experiments, corn silage was replaced by dry rolled corn as silage was decreased in the diet, unlike what has been presented earlier where high moisture corn had been used. In yearlings fed for 147 days, feed efficiency was lowest ($P = 0.02$) for cattle fed 30% silage, suggesting there was still some negative associative effects between corn and corn silage; however, this was not observed in the second yearling trial or calf-fed trial that were set up similarly.

In the third study by Erickson, (2001) using calf fed steers, results were as expected. As corn silage in the diet increased from 15 to 30 to 45%, ADG decreased 3.1% and 7.8%, respectively, dropping 10.7% from 15 to 45% inclusion. Feed efficiency followed this same downward trend ($P < 0.01$) as corn silage increased in the diet. In this calf-fed study, DMI increased from 15 to 30 and 45% inclusion in the diet, as those animals tried to get to a similar chemostatic endpoint. Animals did not have a greater intake ($P > 0.07$; 9.7 kg/d vs. 9.8 kg/d) for the 30 and 45%, respectively, suggesting gut fill remains around the 50% silage inclusion, as observed previously. Fat depth decreased ($P < 0.01$) with increasing corn silage, suggesting the cattle fed 45% silage in their diet could have been fed longer and to a larger mature size over cattle fed 15 and 30% silage inclusion in calf-fed diets (Erickson, 2001).

Most of the experiments evaluated corn silage inclusion in the diet before the ethanol industry expansion, meaning no DGS byproducts were included in the diet at that time. Many of these diets may have been short on protein and a negative associative

effect between corn silage and corn grain were observed, as cattle did not perform as well as expected. Many of these studies that evaluated corn silage in the diet did not allow cattle to finish at a common endpoint such as backfat thickness, but rather were fed to common day on feed. Specifically, regarding growing and finishing cattle in the feedlot, feeding to a common backfat thickness or physiological endpoint must be evaluated to economically evaluate the value of corn silage in the diet and how it affects the profitability of cattle as they go through the entire finishing period.

Corn Silage Pricing

Few research articles have evaluated the price of corn silage due to its complexity and all the factors that play a role when pricing corn silage in the field. Pricing corn silage is difficult because corn silage varies considerably from year to year as nutrient content, yield, grain concentration, lignin concentration and thus fiber digestibility, and even moisture content can be affected by the environment, harvest methods and storage methods. Once corn silage has been fed, one must account for DM shrink, which has not been documented well, as well as harvest costs, storage costs, and the value of the manure upon reapplication to the corn silage field. Goodrich et al. (1974) evaluated the economics of using corn silage in the diet when corn was priced at $3.50/24.05 kg (bu) and $26.45/0.91 t (ton; 32% DM) and found it was favorable to feed high concentrations of silage, even though yardage costs increased due to longer days on feed. Burken et al. (2013) also evaluated elevated corn silage in the diet when corn was at $3.00, $5.00 or $6.50/24.05 kg (bu) with corn silage priced relative to it to the price of corn grain at 8, 8.5 or 9 times the bushel price to determine value per as-fed ton of corn silage. It was observed in that study that as corn silage increased in diets containing 40% MDGS,

profitability linearly ($P < 0.01$) increased from 15% corn silage in the diet to 55% corn silage in the diet when priced at 8 and 8.5 times the price of corn, regardless of initial bushel corn price. When diets included 45% corn silage without the addition of MDGS at 40% DM basis, corn silage was not a profitable option for producers to consider (Burken et al., 2013). In this study, however, cattle had been fed to a common day on feed rather than to a common endpoint, which may have played a role in how much profitability was realized over 15% inclusion in the diet of corn silage (Burken et al., 2013).

In order to determine the price of corn silage, researchers from Iowa State and the University of Wisconsin have developed spread sheets to allow producers to determine the value of their corn silage standing in the field or stored in a bunker, including accounting for shrink, the opportunity cost of not leaving the corn for grain production, the value of the stover, and the value of the fertilizer needed to producer the crop, based on the anticipated grain yield. Finding a fair price for corn silage can be difficult because of the factors that are involved with corn silage, including handling and harvesting costs for making corn silage, stover value, forage quality, grain content of the silage, and production costs that are involved on a year to year basis (Lauer and Undersander, 2004). Even the way the corn silage is stored in a bunker or upright silo affects corn silage price, as DM losses differ between storage conditions (DiCostanzo et al., 1998). In the past, producers have been willing to price corn silage based on the price of corn grain by converting the price per bushel to get dollars per wet ton based on the average dry matter by values of 6 to 10 (Lauer and Undersander, 2004). As the field becomes wetter, the value per wet ton and the conversion factor decreases to account for the water in the corn silage (Lauer and Undersander, 2004). Unfortunately, this method is arbitrary and should

be revisited to determine truly the value of corn silage as it is used and recycled within the producers' system, including the value of the manure being placed back on the land.

For producers to determine whether corn silage will be used in their feedlot diets, the price of corn, the price of feeder cattle and the potential yield of corn in the area need to be considered (DiCostanzo et al., 1998). Additionally, corn silage is harvested when corn grain harvest is going to be limited due to adverse weather conditions (DiCostanzo et al., 1998). In a study by Row et al. (2016), corn grain as a percentage of corn silage increased with maturity of the plant, improving starch content and the total digestible DM yield per acre, which affects the price of corn as the yields of grain and stover change. In previous research by Goodrich et al. (1974), pricing corn silage lower than its' feed value relative to corn results in greater profits as corn silage was increased in the diet. Furthermore, DiCostanzo et al. (1998) evaluated increasing corn silage in the diet for producers feeding one lot of cattle per year and observed that higher inclusions of corn silage, particularly when corn prices were high, provided more profitability and diet flexibility to producers than lower inclusions. This research concluded returns per acre were greatest when corn silage was included in the finishing diet at 36% DM rather than 12 and 24% DM, when corn was priced at $3.00/24.05 kg (bu) and corn silage at $21.50/0.91 t (ton). As corn silage price increased and corn grain price remained the same, DiCostanzo et al. (1998) reported feeding lower levels of corn silage at 12% was the most economical. This suggests, depending on the value which a producer places on corn silage results in wide ranges of returns per acre and per animal. Research by Burken, (2014) observed that as corn silage price increased as a factor of corn grain price, it became more economical to feed more corn silage in the diet as corn grain price

increased. Pricing corn silage has a direct impact on returns of cattle, and producers need to be aware that all considerations are taken into account when pricing corn silage appropriately before increasing or decreasing corn silage inclusion in the diet.

Distillers Grains Plus Solubles in Beef Cattle Finishing Diets

Distillers grains plus solubles (DGS) are a byproduct of the ethanol industry, which experienced massive expansion during the early 2000s. They have become a valuable feed source for feedlots providing both protein and energy for growing cattle. Distillers grains plus solubles are produced as a byproduct of the dry milling process, which involves dry grinding grains such as corn, sorghum, wheat, and barley (Stock et al., 2000). Once grain is received at an ethanol plant, kernels are processed through a hammer mill to increase surface area of the kernel and increase starch availability. The cracked corn is then mixed with water and α-amylase in a cooker to make slurry. The α-amylase acts to break down starch molecules into oligosaccharides to create a product known as mash. Sulfuric acid is then added to decrease the pH of the mash to enhance productivity of the α-amylase (OSHA, 2015). Yeast is then added to the mash where fermentation occurs to convert glucose to ethanol and carbon dioxide. The fermentation process occurs for a period of approximately 40 to 60 hours, to ensure maximum ethanol production (OSHA, 2015). The ethanol is distilled off, and the whole stillage, which includes the germ, fiber and protein, is centrifuged down to remove water and create wet distillers grains (31% DM, Berger and Singh, 2010). Thin stillage is left over, which is further evaporated to condensed distillers solubles, which is either added back to the wet distillers grains or sold as a separate feed ingredient. The wet distillers grains plus solubles can be further dried down to create modified distillers grains plus solubles

(MDGS, 48% DM) or dried distillers grains plus solubles (DDGS, 89% DM, NASEM, 2016).

The corn kernel is approximately 72% starch, 8.8% CP, 9.7% NDF, and 3.8% fat (NASEM, 2016). Once the starch is removed, which is approximately 2/3 of the kernel, the remaining components of the corn are multiplied approximately by a factor of 3 (Klopfenstein et al., 2008). This increases the average CP of WDGS, MDGS and DDGS to approximately 30%, NDF to 31%, and fat to 10% (NASEM, 2016). The CP content of DGS is considered approximately 63% RUP, which is considered highly digestible post ruminally (Castillo-Lopez et al., 2013). The fate of dietary protein in ruminants is divided into rumen degradable protein (RDP) and rumen undegradable protein (RUP). Understanding RUP and its digestibility is important because it acts as a source of protein for the animal rather than microbes in the rumen and can supply essential amino acids cattle require for growth and maintenance purposes. As the ethanol industry has expanded and the quality of DGS from ethanol plants has become more consistent, producers have realized a valuable feed source for the beef feeding industry. Over the years, researchers have evaluated the effect of DGS in the diet, the optimal inclusion levels, roughage inclusion levels, ruminal acidosis, and its' effect on differing corn processing methods and site of starch digestion.

As ethanol production technology has progressed, ethanol plants are continually evaluating ways to further improve the efficiency of the process and get more ethanol from each bushel of grain. While ethanol production has been consistent for many years, ethanol plants are researching how to get even more energy out of the corn kernel for ethanol production. This has resulted in the removal of oil from the corn reducing fat

from approximately 12% to 8% (Jolly, 2013). Currently, further fractionation of the cellulose present through cellulosic fermentation creates a lower fiber and higher protein DGS product. As more ethanol plants consider this type of ethanol production, producers are left with a novel DGS again, and need to know how it can be utilized in beef cattle production. Beef producers and nutritionists alike must be prepared for a constantly changing DGS product and the value it may have in beef feedlot diets in the future.

Ethanol production has been modified to allow for the recovery of some of the byproducts currently being left in DGS production. This process occurs through the modification of the dry grind processes, which results in the reduction of the amount of DGS produced and increases the amount of ethanol produced (Berger and Singh, 2010). This process, known as corn and DDGS fractionation, further removes germ and fiber from the corn to recover more for ethanol production (Berger and Singh, 2010). The germ and fiber removal occur at the initiation of the ethanol process, during the initial milling process (Berger and Singh, 2010). The fractionation can occur through wet or dry fractionation (Berger and Singh, 2010). Wet fractionation occurs through a short soak of the corn and removal of the germ, pericarp and endosperm fiber before the fermentation process through milling (Berger and Singh, 2010). During the dry fractionation process, a series of steps known as degerm and defibering are used to remove germ and pericarp fiber prior to fermentation. During further fractionation, corn oil is removed from the syrup produced from the thin stillage (Berger and Singh, 2010). Finally, during the drying process, oil and fiber can be further removed from the DDGS that have been produced (Berger and Singh, 2010). These processes result in a DGS product that is higher in protein and lower in fiber than regularly produced DGS (Berger and Singh, 2010).

Through this newer fractionation process, this new high protein DGS product is typically about 45% CP and 3.7% fat (Kim et al., 2009). As this product becomes more readily available in the marketplace for beef producers, its' value needs to be evaluated within feedlot finishing diets.

Production and Use

Initially, DGS were to be utilized as a protein source because they were included in the diet at less than 20% (DM basis) to meet the MP requirements of growing cattle. However, because they are priced relative to corn, they have become a valuable energy source for beef cattle when included at more than 20% of the diet (DM basis; Klopfenstein et al., 2008). The excess protein is deaminated and the carbon skeleton used for energy the urea is excreted (Klopfenstein et al., 2008). Bremer et al. (2011), reviewed 20 studies including WDGS in the diet, 4 studies evaluating MDGS and 4 evaluating DDGS in the diet at inclusions of 0 to 40% in the diet (DM basis). Based on pen performance, WDGS was valued at 145 to 131% the feeding value of corn when included at 20 to 40% of the diet, MDGS was 124 to 117% at 20 to 40% inclusion in the diet, and DDGS was 112 to 110% the value of corn at 20 to 40% inclusion in the diet. According to Stock et al. (2000), the greater energy values of DGS products over corn are not related to increased digestibility as compared to corn, but rather a variety of factors including reducing acidosis risk, improving energy utilization and using the fat and protein for energy for growth. Regarding digestibility, diets containing DGS compared to corn controls have experienced lower digestibility than corn (Corrigan et al., 2009; Vander Pol et al., 2009; Hamilton, 2016; May et al., 2010). In a direct comparison of WDGS, MDGS, and DDGS at 20, 30 or 40% in the diet, Nuttelman et al. (2011) observed the

feeding values of WDGS, MDGS, and DDGS were 46, 27 and 9% greater than corn, respectively, across the three levels of inclusion. As the ethanol industry has progressed and the dry milling process has been updated to increase ethanol yields, these values may change as the components of distillers are modified, such as greater CP or lower fat content.

While steam flaked corn has a feeding value that is 10 to 15% greater than conventional dry rolled corn, researchers have not observed an improvement in performance when DGS have been included in the diet of steam flaked corn-based diets (Klopfenstein et al., 2008). When DGS are included in the diet of dry rolled corn-based diets and high moisture corn-based diets, feed efficiency and growth performance are optimized when included at approximately 30% (DM basis; Vander Pol et al., 2005). This value can be changed according to the goals of the feeding operation. As Watson et al. (2015) observed, increasing WDGS inclusion in the diet to 30% DM maximized ADG, while including either WDGS or MDGS at 40% of DM maximized feed efficiency. According to Corrigan et al. (2009), when increasing levels of WDGS are included in the diet, there is a linear improvement in feed efficiency up to 40% inclusion with DRC-based diets from 0.163 to 0.185 ($P < 0.01$). The same comparison was made with steam flaked corn-based diets. Feed efficiency remained stagnant (0.182 to 0.183, $P = 0.52$) and dry rolled corn had similar results to steam flaked corn with WDGS suggesting DRC is affected more than SFC (Corrigan et al., 2009). Further, Luebbe et al. (2012) observed steers fed SFC-based diets were negatively affected ($P < 0.01$) by WDGS inclusion in the diet as it increased from 15 to 60% WDGS (DM basis), decreasing from 0.174 to 0.162. This likely occurred due to energy dilution of the diet (Luebbe et al., 2012). In further

research evaluating the inclusion of both sorghum and corn DGS in the diet, May et al. (2010) observed the optimal inclusion of WDGS in SFC-based diets was approximately 15% (DM basis). As WDGS was increased in the diet to 30%, there was a reduction in G:F. Total tract apparent starch digestibility was not changed in SFC-based diets when DGS from either corn or sorghum were included in the diet at 15%. Contrary to this, Luebbe et al. (2012) observed including WDGS in SFC-based diets at 15, 30, 45 or 60% (DM basis) resulted in increased ($P < 0.01$) ruminal starch digestion as WDGS inclusion increased. However, this was affected by a reduction in starch intake with increasing WDGS inclusion, but total tract starch digestibility had a quadratic response in total tract starch digestibility, with maximum starch digestion through the gastrointestinal tract at 15 or 30% (DM basis; Luebbe et al., 2012). The use of DGS in the diet is affected by supplemental energy intake, moisture content of DGS and corn processing method (Luebbe et al., 2012).

High Protein Dried Distillers Grains plus Solubles

High protein distillers dried grains plus solubles are produced because of a new biorefining ethanol technology, corn fractionation, that dehulls and degerms the corn before fermentation (Widmer et al., 2008). Prefractionation occurs when germ and pericarp fiber are screened out prior to fermentation (Berger and Singh, 2010). During this process, protein content can be increased, fat content is decreased and ADG can be decreased as well (Berger and Singh; 2010, Hubbard et al., 2009). The value of the increased protein in HiPro DDGS was evaluated by Hubbard et al. (2009), who used the *in-situ* bag technique to determine the degradability of the protein in the rumen of dairy cattle. As time in the rumen progressed from 16 to 48 hours, RUP was estimated to be

62% at 16 hours and decreased to 31% after 48 hours, which is approximately what current research suggests traditional DDGS are considered.

According to Hubbard et al. (2009), HiPro DDGS included in lactating dairy cow diets had greater energy concentration over traditional DGS (1.65 vs 1.56 Mcal/kg), which should allow for more energy available for lactation. Hubbard et al. (2009) speculated that HiPro DDGS increased fiber digestibility because DGS fiber replaced forage fiber, which is more digestible. High protein dried distillers grains plus solubles have a greater energy and crude protein content compared to traditional DGS due to the corn being dehulled and degermed prior to fermentation for ethanol production (Widmer et al., 2007). In a study by Widmer et al. (2008) evaluating the inclusion of HiPro DDGS in swine diets, the inclusion of HiPro DDGS did not result ($P > 0.10$) in an improvement in growth performance as compared to traditionally produced DGS. According to Hubbard et al. (2009), using HiPro DDGS in the diet in place of traditionally produced DDGS, milk urea N was measured to be greater ($P < 0.01$) than cattle fed traditionally produced DDGS. This lead to speculation the digestible RUP available in HiPro DDGS may be more available for utilization by cattle for their productive purposes.

When Depenbusch et al. (2008) evaluated the inclusion of fractionated DDGS in SFC based diets as compared to a negative control and traditional DDGS at 13% of the diet (DM basis) there were no statistical differences between control and DDGS treatment in DMI, ADG and feed efficiency ($P \geq 0.48$). When comparing the two DGS treatments, Depenbusch et al. (2008), observed cattle consuming traditionally produced DDGS had greater ($P < 0.01$) DMI, than cattle consuming the fractionated DDGS, with no improvement ($P \geq 0.07$) in ADG or feed efficiency.

High protein DDGS produced through fractionation technology is likely being produced in anticipation of providing protein for the swine and poultry industry. The effect of feeding HiPro DGS in beef cattle finishing diets has not been extensively, specifically regarding each novel product that has been produced by ethanol plants within the various regions of the United States. Depending on the fractionation process used and the efficiency of ethanol production, the energetic value of coproducts will change for producers in the future.

Corn Processing

Starch Digestion

Starch is the primary energy source in feedlot diets. As a result, maximizing starch digestion has been a primary objective for beef finishing diets. One of the primary ways starch digestion is manipulated is through processing of the grain source. Corn is primarily processed one of three ways, dry rolling, which accounts for approximately 12.5% of corn processing in the Unites States, high-moisture corn (HMC; 16.7% of corn processed) or steam-flaking (70.8% of corn processed; Samuelson et al., 2016). These numbers were calculated through a nutritionist survey and did not account for geographical location or volume of corn being processed. These three methods are the primary processing methods in the United States and their use is dependent on region and access to corn, mills, and access to price of energy. Steam flaking is more popular in Texas; whereas DRC and HMC are more common in Nebraska, where corn has a lower basis and is more readily available. Corn is processed to increase the surface area of the starch particles, increasing starch digestibility in both the rumen and postruminally. High-moisture corn is corn that has been harvested at a higher moisture than regularly

harvested corn, typically at 25-30% moisture (Buchanan-Smith et al., 2003). This is stored like silage in an anaerobic environment to allow for proper fermentation and degradation of the zein starch matrix, further making the starch available for the rumen microbes. Steam flaked corn is corn that has been steamed at a temperature of approximately 102°C for at least 30 minutes before being rolled, resulting in gelatinization of the starch molecules (Zinn et al., 2002). During this steaming period, moisture content of the corn increases approximately 5% (Zinn et al., 2002). Flakes are then rolled through two corrugated rolls with a final dry matter content of 76 to 81% (NASEM, 2016), with optimal flake weights at approximately 0.31 kg/L (24 lb/bu; Zinn et al., 2002). Steam flaking increases the NEm and NEg of corn by 14.2% and 17.3%, respectively. Starch digestibility is improved because the protein matrix is disrupted during steaming due to shear forces from the rollers during flaking, increasing starch digestion (Zinn et al., 2002).

Each processing method affects site of starch digestion and how much is digested by the ruminant. According to Theurer, (1986), ruminal starch digestibility of DRC, HMC, and SFC are 76.2, 89.9, and 84.8%, respectively. When measuring post ruminal starch digestibility, DRC, HMC, and SFC, had digestibility of 68.9, 67.8 and 92.6%, respectively. When considering apparent total tract starch digestibility, Theurer (1986) observed 92.2, 95.3 and 98.6% for DRC, HMC, and SFC, respectively. When similar research was performed by Cooper et al. (2002), a similar trend was observed. Cattle were fed diets consisting of 82% corn (DM basis) and apparent total tract starch digestibility was determined. Ruminal digestibility of starch was greater ($P < 0.05$) for HMC and SFC over DRC by approximately 19% (Cooper et al., 2002). Both SFC and

HMC had similar total tract starch digestibility but were approximately 3% greater compared to DRC increasing from 96.1% for DRC to 98.7 and 99.8% for HMC and SFC, respectively (Cooper et al., 2002). Ruminal starch digestion typically ranges from 75 to 80% and is largely unchanged if ranges of starch intake do not fall outside of 1 to 5 kg of starch in a day (Huntington et al., 2006). As starch entering the small intestine increases, digestibility can be decreased from 80% to as little as 34% when as much as 2 kg/d of starch makes it past the rumen. Maximizing starch digestion in the rumen and postruminally is a challenge for producers to ensure energy is not being passed through the animal, but more starch will be digested in the small intestine, despite being at a reduced feed efficiency (Huntington et al., 2006). Processing corn to improve starch digestion in the rumen and post ruminally is the goal to reduce glucose being lost as CO_2.

When DGS are included in the diet, a variety of responses can be expected, depending on the distillers grain inclusion, the processing method of the grain source, moisture content of the DGS, and the type of grain used in the diet (Vander Pol et al., 2008; Corrigan et al., 2009, May et al., 2010). The method in which corn is processed prior to feeding plays a role in how DGS interacts with the corn. Steam flaked corn requires a large upfront cost but provides a performance benefit to cattle by about 10% over cattle fed dry rolled corn-based finishing diets (Owens et al., 1997). That being said, when evaluated with an inclusion of wet distillers grains plus solubles (WDGS) in the diet, steam-flaked corn loses its competitive advantage, specifically when included in the diet at 30% (Vander Pol et al., 2008). The inclusion of WDGS in the diet improved G:F of cattle fed both HMC and DRC based finishing diets, while performance of cattle fed a SFC based finishing diet remained stagnant with increasing levels of WDGS in the diet

(Vander Pol et al., 2008). According to Klopfenstein et al. (2008), WDGS in SFC based diets did not improve SFC further above DRC, over the original 12% improvement in feeding value. When included with DRC at 40%, G:F of the animals became similar to those fed SFC-based diets (Vander Pol et al., 2005).

Mechanism of Action

Starch fermentation is initiated in the rumen primarily by amylolytic bacteria once it has been consumed by the ruminant. These bacteria loosely attach to feed particles through an electrical charge or via receptors and secrete amylase for the breakdown of the starch molecules (Huntington, 1997). At this point, some digestion of starch also occurs via the work of both protozoa and fungi populations present within the rumen. According to Kotarski et al. (1992), there are eight primary strains of bacteria that produce enzymes to attack and hydrolyze the α-1-4 and α-1-6 bonds present in starch. These bacteria do not produce all the necessary enzymes required for total starch breakdown to glucose, thus, an additive effect is observed across many bacterial species to completely degrade and utilize starch by microbes (Huntington, 1997). Amylolytic bacteria hydrolyze starch by secreting surface-associated amylase and binding proteins to break down the surface of the starch particles and their cellular membranes (Kotarski et al., 1992). There are approximately 15 strains of amylolytic bacteria, which produce at least 8 differing endo- and exo- amylolytic enzymes to degrade starch. Protozoa and fungi present in the rumen can affect starch digestion as well. Protozoa can decrease starch digestion through the engulfment of starch particles, which makes them unavailable for bacterial populations. In defaunated sheep fed HMC-based diets, the extent of starch digestion in the rumen was enhanced as compared to faunated sheep (Mendoza et al., 1993). Fungi may play a

contrary role to protozoa, as they may aid in breaking the cell surface of feed particles, increasing the surface area available for microbes (McAllister et al., 1994).

Starch digestion and absorption have been manipulated for many years through three main factors: feed consumption by the animal, the amount of grain processing the energy source has received and any feed additives that are available to affect dry matter intake (Huntington, 1997). Once bacteria have broken down and consumed starch through microbial fermentation, their primary end products they release are volatile fatty acids (VFA), primarily as acetate, propionate and butyrate. These VFA are absorbed across the rumen wall and used as the primary energy source for the ruminant. Propionate, the most energetically efficient VFA, is gluconeogenic and provides 27 to 54% of the glucose produced and utilized by the animal (Lindsay, 1970). The rest of the glucose in the animal is provided from starch reaching the small intestine and being digested and absorbed in the small intestine. Acetate is absorbed and transported to the liver, where it is converted to Acetyl-CoA or ketones to be utilized by tissues, and butyrate is absorbed by the rumen epithelium to be converted to ketone bodies for energy use by the gastrointestinal tissues (NASEM, 2016).

Starch not digested in the rumen is transported to the small intestine for further starch digestion and utilization by the animal. Once the starch reaches the duodenum, pancreatic amylase is released breaking down the starch to maltose and limit dextrins, which are branched-chain starch products (Huntington et al., 2006). In addition to providing pancreatic α-amylase, the pancreas also provides bicarbonate to neutralize the acidic contents coming from the abomasum (Huntington et al., 2006). Once broken down into maltose and limit dextrins, brush border enzymes release carbohydrases to further

breakdown starch molecules (Huntington et al., 2006). Glucose is finally absorbed from the intestinal lumen into portal circulation via one primary transporter known as sodium-dependent glucose transporter (SGLT1; Harmon and McLeod, 2001). Increasing starch passing through the small intestine does not appear to create an adaptive response in cattle with increased α-amylase being released from the pancreas, suggesting the response between starch and protein digestion is linked (Kreikemeier et al., 1991; Zinn et al., 2002, Huntington, 1997, Huntington et al., 2006, Owens, 1986). Starch digestion in the small intestine has been observed to be more energetically efficient than in the rumen (McLeod et al., 2001), going from approximately 80% in the rumen to 97% in the small intestine (Harmon and McLeod, 2001). Manipulating the site of starch digestion and its extent in the small intestine would be beneficial for beef producers to maximize energy retention by the animal. This can be accomplished through researching alternative ingredients and processing methods to maximize starch digestion.

Small intestinal starch digestion in ruminants is limited due to the small amounts of α-amylase being released from the pancreas. In non-ruminant species, the presence of protein entering the duodenum results in a positive feedback to allow for an increased release of α-amylase and other digestion enzymes from the pancreas. Limited starch digestion post-ruminally is thought to have occurred because cattle evolved primarily as cellulose fermenters (Harmon, 2009). According to Swanson et al. (2002), infusing carbohydrates post-ruminally or increasing fermentable carbohydrate intake (Swanson, 2008) results in either reduced α-amylase secretion or concentration in the duodenum. As a result, researchers have been focusing on protein as a primary influencer in α-amylase secretion from the pancreas (Harmon, 2009). Early research by Taniguchi et al. (1995)

observed infusing casein into the small intestine resulted in greater concentrations of measurable glucose in the portal drained viscera, suggesting high quality protein may increase α-amylase secretion from the pancreas and improve starch digestion and thus performance of cattle. Following up on this work, Richards et al. (2002) observed infusing casein in the small intestine resulted in increased disappearance of starch from the small intestine. However, when starch was infused in addition to casein, the results of increased starch disappearance were not observed (Swanson et al., 2004). More recent research by Blom et al. (2016) and Brake et al. (2014) may provide some more insight into this phenomenon. When infusing either casein or glutamic acid and cornstarch into the small intestine, starch digestibility in the small intestine improved ($P < 0.01$), but it resulted in no difference in ethanol soluble sugars, which are small sugars produced through the breakdown of starches. This suggested while α-amylase secretion was increased, brush border membrane enzymes may have been the limiting factor to further increasing starch digestion post ruminally. While some improvement in total tract starch digestibility was observed due to protein being supplied post-ruminally, it was not as great as expected due to limitations in the further digestion of dextrins (Blom et al., 2016). Protein affects starch digestion but needs to be further explored in the following sections of the role of manipulating starch digestion in the rumen and small intestine nutritionally.

Manipulation of Starch Digestion

Ruminants have less ability than other mammals to digest starch in the small intestine because of limited α-amylase secretion from the pancreas (Richards et al., 2002). Digestion of non-structural carbohydrates primarily occurs in the rumen through

microbial activity. In typical dry rolled corn-based diets, 75-80% of the starch is digested in the rumen, of the remainder that enters the small intestine, 35-60% is further digested (Harmon, 2009). However, there is incentive to maximize ruminal starch digestion because the yield of energy from the total-tract becomes greater because of inefficiencies in starch digestion in the large intestine (Harmon, 2009). According to Owens (1986), the starch from corn is not wholly digested in the rumen, leaving anywhere between 18 to 42% for digestion in the small intestine. Owens (1986) stated 47 to 88% of the remaining starch is digested post ruminally. Post ruminal starch digestion is limited because pancreatic α-amylase activity does not adapt to high starch levels, reducing starch digestion in the small intestine (Kreikemeier et al., 1991). To improve digestibility of the diet, increasing starch digestibility in the small intestine could increase feed efficiency of the ruminant (Harmon, 2009). Small intestine starch digestion is beneficial because the starch is absorbed as a glucose source, unlike ruminal starch digestion, which requires fermentation and extraction of energy by ruminal microbes (Harmon, 2009). The release of α-amylase from the pancreas is responsive to protein in the diet, increasing excretion as protein entering at the small intestine increases, but not to an appreciable effect when additional starch is infused, discussed previously (Swanson et al., 2004). When WDGS were included at levels above 30% DM in SFC-based diets, starch digestion post ruminally was decreased linearly ($P = 0.05$) as WDGS increased. However, this may not have been affected by MP entering the small intestine, as total starch entering the small intestine in 45 and 60% WDGS diets was less than 0.2 kg/d (Luebbe et al., 2012b), which was the value Huntington et al. (2006) observed at which starch digestion was limited.

Ruminal starch digestion results in fermentation and heat losses by up to 12 to 20% of the energy of the starch (Orskov, 1985). According to Orskov (1985), up to 90% of the starch in cereal grains fed to ruminants is digested in the rumen, leaving the final 10% as an opportunity to be utilized by the animal. Internal digestion of starch is also dependent upon passage rate and particle size through the small intestine (Owens et al., 1986). Starch digestion may be further limited in the small intestine because starch particles entering the small intestine may have been particles indigestible in the rumen. This includes microbial polysaccharide capsules, partially broken-down water-soluble carbohydrates and starches from the rumen (Owens et al., 1986). This results in a product that is less digestible than the feed particles that entered the rumen.

High protein DGS in the diet may improve starch digestion post ruminally in DRC-based diets because starch digestion is limited in DRC-based diets as compared to SFC and HMC-based diets. As observed by Luebbe et al. (2012b), starch digestion post ruminally increased from 78% for DRC-based diets with no WDGS to 90% and 86% with the inclusion of 15 and 30% WDGS in the diet, respectively. Metabolizable protein balance was much greater in the 15 and 30% inclusion diet, increasing from 211 to 359 and 536 g/d, respectively. In the trial by Luebbe et al. (2012b) a SFC-based control diet had a starch digestibility of 81% post ruminally, which was similar to the DRC control, but the starch was entering the duodenum for the SFC diet was 0.49 kg/d as compared to 1.09 kg/d for the DRC. From the response to the 15 and 30% WDGS, the extra MP supplied may have provided a benefit for starch digestion post ruminally through the stimulation of the release α-amylase from the pancreas.

In a study by Salim et al. (2016), there was a tendency (P = 0.08) for pancreatic trypsin activity to increase as DDGS inclusion increased in the diet. Researchers hypothesized the increased MP supply from the diet resulted in the increased trypsin excretion from the pancreas (Salim et al., 2016), allowing for increased starch digestion post ruminally but α-amylase secretion was not increased (P = 0.14). Richards et al. (2002) evaluated the effect of high-quality protein in the small intestine and starch digestion post ruminally by infusing the small intestine with raw cornstarch with or without casein. As casein flow increased in the small intestine, the quantity of cornstarch in the small intestine that disappeared also increased (Richards et al., 2002). Of the 5800 g/d supplied to the small intestine, approximately 2400 g/d disappeared when 200 g/d of casein was infused, as compared to approximately 1795 g/d disappearing when 0 g/d of casein were infused into the small intestine.

Small intestinal starch digestion in the ruminant is not only limited by α-amylase secretion, but also through the brush border membrane enzymes that further degrade starch and allow for the absorption of monosaccharides and disaccharides. Some recent research evaluating the influx of casein and glutamic acid in the small intestine resulted in greater small intestine starch digestion with increasing amounts of glutamic acid (Blom et al., 2016). However, with increasing levels of both casein and glutamic acid supply in the small intestine reducing measurable starch, researchers also evaluated the concentration of ileal flow of ethanol-soluble starch, which was unaffected by protein supply in the small intestine (Blom et al., 2016). Starch digestion in the small intestine occurs through a series of three primary steps, which include amylase to hydrolyze starch to oligosaccharides and limit dextrins, hydrolysis of the oligosaccharides and limit

dextrins to glucose through membrane bound enzymes and then final absorption of glucose (Blom et al., 2016). Brake et al. (2014) and Blom et al. (2016) observed ethanol-soluble starch flow (short chain carbohydrates) indicates an increase in amylolytic capacity of the pancreas, without an increase in capacity of the brush border membrane enzymes (Blom et al., 2016). Absorption of glucose did not appear to be a limiting factor in starch digestion and absorption in the small intestine as flows to the ileum were low in research (Blom et al., 2016, Kreikemeier et al., 1991, Kreikemeier and Harmon, 1995). In the trial by Blom et al. (2016), starch digestion and likely absorption and utilization by the ruminant was improved through the infusion of both casein and glutamic acid supply in the duodenum. Similar levels of indigestible ethanol soluble starch were observed across treatments, despite more starch being digested, suggesting more uptake of glucose from starch digestion occurred at greater levels of glutamic acid and casein. In agreement with Harmon (2009), it appears ruminal digestion of starch should be maximized, because although starch digestion post ruminally may be improved, there is a limit with digestion due to brush border membrane enzymes. Additionally, N supply needs to be considered, as N is needed to ensure extra energy is stored as lean tissue rather than fat tissue, decreasing the size at which cattle finish.

Increasing pancreatic activity to allow the release of more α-amylase and increase starch digestion would be beneficial for producers to potentially capture more energy from the starch entering the small intestine to improve G:F and ADG, reducing costs to the feedlot.

Conclusion

Based on this review of the literature, methods of feeding cattle must be further studied as the human population grows and demands more high-quality protein sources. Corn silage, a traditional roughage source in the feedlot industry, is now being viewed as an energy source. As a result, producers need to be able to derive more from their silage source, which can be achieved through a couple of methods. The first is the use of hybrids, such as brown midrib hybrids with lower lignin concentrations and higher fiber digestibility, that has not been extensively evaluated in the finishing feedlot diet, such as brown midrib hybrids with lower lignin concentrations and higher fiber digestibility. A second method that needs to be further evaluated for beef finishing feedlot systems is kernel processing of corn silage during the harvesting process, and whether it improves beef cattle performance in the feedlot system. Finally, improving starch digestion in the diet through processing has been studied, but not as extensively using protein sources and amylase activity. The objectives the research in this dissertation were to:

1. Evaluate feeding brown midrib corn silage hybrids with or without kernel processing on feedlot cattle performance and metabolism
2. Evaluate feeding higher inclusions of corn silage in the diet on feedlot performance when cattle are fed to a common endpoint
3. Evaluate the use of high protein DDGS in the diet to improve starch digestion of cattle fed steam flaked or dry rolled corn-based diets on feedlot performance and ruminal metabolism.

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Chapter II. Effects of kernel processing at harvest of brown midrib corn silage on digestibility and finishing performance of steers

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Abstract

One finishing and one metabolism experiment evaluated kernel processing and the use of brown midrib corn silage hybrids in corn silage-based finishing diets. Crossbred yearling steers were used in Exp. 1 (n = 360, BW = 400 ± 0.5 kg) in a 2 × 3 factorial design with factors of kernel processed or not, and one of three silage hybrids included at 40% in the diet: a standard isogenic control (CON; hybrid TMF2H708), a brown midrib hybrid (*bm3;* hybrid F15579S2) and Unified™ corn silage with SilaSoft™ kernel technology brown midrib silage with a floury endosperm (*bm3*-soft; hybrid-F15578XT). Experiment 2 used ruminally cannulated yearling steers (n = 6; BW = 518 ± 40 kg) in a 6 × 6 Latin Square design. There were no interactions between corn hybrid and kernel processing ($P \geq 0.29$) Feeding both *bm3* hybrids increased dry matter intake (DMI) and average daily gain (ADG) over the CON silage hybrids ($P < 0.01$), resulting in a greater ($P = 0.03$) G:F than the CON treatment, with no differences between the two *bm3* hybrids ($P = 0.88$). For the main effect of kernel processing, processing silage decreased ($P = 0.02$) daily DMI with a similar ADG ($P = 0.93$), resulting in 2.9% greater G:F at a 40% inclusion of silage ($P = 0.10$). The improvement due to the kernel processing of the silage as an ingredient is calculated to improve silage by 7.3% (2.9/0.40), as compared to not kernel processing the corn silage hybrids. Neutral detergent fiber and ADF digestibility increased ($P \leq 0.04$) for *bm3* and *bm3*-soft as compared to CON in the diet. Digestibility of OM tended ($P = 0.08$) to be greater for *bm3* and *bm3*-soft, with no difference ($P = 0.47$) in starch digestibility between treatments. Kernel processing had no effect on nutrient digestibility ($P \geq 0.49$). Volatile fatty acid concentration was not affected by either corn silage hybrid or kernel processing

($P \geq 0.37$). Average ruminal pH tended ($P = 0.09$) to be lower for the brown midrib hybrids as compared to CON. The use of brown midrib corn silage increases fiber digestibility, improving feed efficiency and ADG as compared to isogenic corn silage. Kernel processing improves corn silage feeding value by 7.3%.

Key words: cattle, corn silage, growth performance, metabolism, kernel processing

Introduction

Corn silage has an average NDF content of 43% (NASEM, 2016), which limits intake by growing cattle due to gut fill (Tjardes et al., 2000). Brown midrib hybrids of corn silage are characterized by a lower lignin concentration than traditional isogenic corn hybrids, resulting in an increased NDF digestibility (Kuc and Nelson, 1964). As a result, DMI is less inhibited by gut fill, which allows lactating dairy cattle to increase voluntary DMI, improving milk yield due to greater energy intake (Block et al., 1981). In a study with growing beef steers fed a diet of 86% (DM basis) brown midrib silage, Tjardes et al. (2000) observed an improvement in NDF digestibility by 10.5 percentage units, but this did not translate to an improvement in ADG ($P = 0.23$). An increase in rumen passage rate due to better fiber digestibility in the rumen was observed for cattle consuming *bm3* corn silage, which may reduce ruminal digestibility as compared to an isogenic control with a slower passage rate (Oba and Allen, 2000). As a result, including brown midrib corn silage in the diet has the potential to affect both fiber and starch digestion in the rumen, thus affecting the growth of cattle (Oba and Allen, 2000).

The use of onboard rollers when harvesting corn silage has become more popular, despite limited research on its effect on beef cattle performance. Rollers compress the kernel, cob, and stover to increase the surface area of the particles to enhance starch and

some fiber digestion, and reduce dietary sorting (Johnson et al., 1999; Rojas-Bourrillon et al., 1987). This allows for microbes to increase attachment and potential colonization of the inner portion of the plant through mechanical disturbances during harvest (McAllister et al., 1994). Kernel processing increases starch digestibility (Bal et al., 2000), but can have a negative associative effect on NDF digestibility (Andrae et al., 2001), resulting in no net change in DM digestibility. There has been little research in beef cattle diets evaluating the effect of kernel processing and its interaction with corn silage hybrids on digestibility and beef cattle performance. The objectives of these studies were to determine the interacting effects of corn hybrid and kernel processing on performance, carcass data, energy values and nutrient digestibility in finishing feedlot diets.

Materials and Methods

All animal use procedures were reviewed and approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee.

Experiment 1 – Cattle Finishing Experiment

The three corn hybrids (Mycogen® seeds) utilized in both the metabolism and growing trial were a control (CON; hybrid TMF2H708), a brown midrib hybrid (*bm3*; hybrid F15579S2), and an experimental brown midrib hybrid known as Unified™ corn silage with SilaSoft™ kernel technology characterized by a floury endosperm (*bm3*-soft; hybrid F15578XT). The corn was planted in a single irrigated field at the Eastern Nebraska Research and Extension Center (ENREC) located near Mead, NE in 2016. In the field, the *bm3* and CON corn hybrids were planted in plots beside each other, at 5.71 and 6.83 ha each, respectively. The *bm3*-soft hybrid was planted on 4.89 ha beside the CON with a strip of sterile corn planted between the plots. A sterile strip of 0.55 ha was

planted to prevent cross pollination between fields. Fields were assumed to be representative of hybrids typically used in these experiments, with no replication of field. The field was managed in a corn and soybean rotation in previous years. Corn silage was harvested with a self-propelled forage harvester (JD 7250, John Deere, Moline, IL) set for a theoretical length of chop of 19 mm.

Corn silage was harvested between September 2 and 12, 2016. Harvest was initiated when the field was approximately 75% milkline and 37% DM. Dry matter samples were taken from each truckload of corn silage and dried in a 60°C forced-air oven for 48 h to determine DM of the silage at harvest. Each corn silage hybrid was split into two within the field, half the field being chopped to 19-mm chop length with 2-mm kernel processing, and the other half chopped at 19-mm chop length, with no kernel processing. No inoculants were used at silage harvest. Silages were stored in sealed AgBags® and opened after 21 d, and silage was sampled for fermentation analysis and DM (forced air oven at 60°C for 48 hours). All feeds were sampled weekly for DM during the feeding period at the silage face, and monthly composites were analyzed for nutrient composition.

Crossbred yearling steers (n = 360; initial BW 400 ± 0.5 kg) that had been grazing summer pasture were utilized in a randomized block design and sorted into 2 BW blocks and assigned randomly to one of 36 pens (10 steers/pen; 3 replications in light BW block, 3 replications in heavy BW block). Approximately 300 days prior to the trial starting, steers were purchased as weaned calves. At arrival, steers were individually identified and processed into the feedlot with 20 mL of fenbendazole (SafeGuard Drench, Merck Animal Health, Madison, NJ), a modified live viral vaccine for infectious bovine

rhinotracheitis, bovine viral diarrhea types I and II, parainfluenza3, bovine respiratory syncytial virus, *Histophilus somnus* bacterin (Ultrabac 7; Zoetis Inc. Kalamazoo, MI), an injectable anthelmintic (Dectomax, Zoetis Inc.) and *Mannheimia haemolytica* toxoid (Bovi-Shield Gold One Shot, Zoetis Inc.). Steers were then revaccinated approximately 14 to 28 d after their initial processing with a killed viral vaccine for clostridial infection (Ultracbac 7, Zoetis Inc) and modified live viral vaccine for infectious bovine rhinotracheitis, bovine respiratory syncytial virus, parainfluenza3 and bovine viral diarrhea types I and II (Bovi-Shield Gold 5, Zoetis Inc). Steers were grazed on corn residue throughout the winter months and grazed pastures in the summer months prior to starting this experiment.

All steers were limit-fed (Watson et al., 2013) a common diet of 50% alfalfa hay and 50% wet corn gluten feed (SweetBran®, Cargill Wet Milling, Blair, NE) at 2% of BW for 5 days prior to the initiation of the trial to equalize gastro-intestinal fill. Cattle were then weighed on d 0 and d 1 of the trial for initial BW (Stock et al., 1983). Steers were implanted with 200 mg trenbolone acetate, 20 mg estradiol, and 29 mg tylosin tartrate (Component TE200®; Elanco Animal Health) on d 1. At trial initiation, diets fed were 30% MDGS, 25% DRC and 5% supplement and 40% alfalfa hay (DM basis). Over a period of 21 d, corn silage replaced alfalfa hay on a 1:1 basis, replacing 10% alfalfa for 10% corn silage with each step, until 40% corn silage in the diet was achieved on d 21. Adaptation steps 1, 2, 3 and 4 were 4, 4, 6, and 7 d, respectively for a total of 21 d. Treatment silage was included in diets at 21 d post-harvest at the initiation of the second adaptation period. Treatments were arranged as a 2 × 3 factorial, that consisted of kernel processing (kernel processed or not; +KP and -KP), and three corn silage hybrids (CON,

bm3, *bm3*-soft; Table 2.1). Corn silage was included at 40% in the final diets and modified distillers grains plus solubles (MDGS) included at 30%, dry rolled corn (DRC) at 25% and supplement (5%, DM basis) including monensin (Rumensin®; Elanco Animal Health, Greenfield, IN) at 33 g/t (DM basis) and tylosin (Tylan®; Elanco Animal Health) at 9.7 g/t (DM basis). The diets used in the trial are outlined in Table 2.1. Diets were fed once daily, and feed bunks were assessed at 0530 each morning with the goal of trace amounts of feed available in the bunk. Feed refusals were removed from the bunk once weekly, weighed and subsampled to determine DM. Subsamples were dried in a 60°C oven forced-air oven for 48h to determine DM of orts (AOAC, 1999; method 4.1.03). Dietary ingredients were sampled weekly to determine DM using a forced air oven at 60°C for 48h (AOAC, 1999; method 4.1.03), and ingredient inclusion on an as-fed basis was adjusted weekly. Weekly composite dietary ingredient samples were analyzed for CP (ThermoFisher Scientific Flash*Smart* N/protein analyzer), NDF with α-amylase and sodium sulfite (Van Soest and Marcus, 1964; Van Soest et al., 1991), ADF (VanSoest et al., 1991), ether extract (Bremer, 2010), and starch (Megazyme International, AOAC International, 2000; Method 996.11; AACC Method 76.13). Corn silage was sent to a commercial lab for a fermentation analysis and four samples based on monthly composites and a trial composite were sent for analysis at Dairyland Labs (St. Cloud, MN) and Ward Labs (Kearney, NE). Steers were fed for 104 d prior to harvest. On the day of shipping, steers were fed 50% of the previous day's DM offer and live weights were not recorded. Steers were shipped in the evening and harvested the following morning at a local abattoir (Greater Omaha Packing Co., Omaha NE). The day of harvest, HCW was recorded, and carcass-adjusted final BW was calculated from a

common 63% dressing percentage. Liver abscess scores were categorized from 0 (no abscesses), A-, A, or A+ (severely abscessed) with the procedure from Brink et al. (1990). The liver scores were combined per pen to determine a proportion of animals with liver abscesses in each pen. The carcass adjusted final BW was used to determine ADG and G:F. Carcass characteristics including marbling score, 12th rib fat thickness, and LM area were measured and recorded after a 48-h chill. Yield grade was calculated through USDA (2016) carcass measurements, assuming 2.5% KPH, with the following formula: [YG = 2.50 + (0.0017 × HCW, kg) +(0.2 × KPH, %) + (6.35 × 12th rib fat, cm) – (2.06 × LM area, cm^2). The energy value of the diets was calculated by using pen data in the Galyean (2009) Net Energy calculator based on the NRC (1996) equations. The calculated energy value used initial and final BW of each block and the individual DMI and ADG of each pen, with a target endpoint of Choice.

Performance, carcass data, and energy values were analyzed using the MIXED procedures of SAS (SAS Inst. Inc., Cary, NC). Pen was the experimental unit, with the block of BW included as a fixed effect. The interaction of corn silage hybrid and kernel processing were evaluated, and if no interaction was observed, main effects of corn silage hybrid or kernel processing were evaluated. Liver abscesses were analyzed using the GLIMMIX procedure of SAS with a binomial distribution. Treatment differences were considered significant when $P \leq 0.05$. A tendency was declared when $P \leq 0.10$ and $P > 0.05$.

Experiment 2 – Cattle Metabolism Experiment

Six ruminally cannulated steers were used in a 6 × 6 Latin Square designed experiment. Steers were assigned randomly to each dietary treatment once for six

consecutive 21 d periods that allowed for 14 d adaptation periods, followed by 7 d for collections. Treatment design was the same as Exp. 1, a 2 × 3 factorial with kernel processed or not (+KP and -KP) and three corn silage hybrids (CON, *bm3*, *bm3*-soft; Table 2.1). Diets were mixed twice weekly and stored in a cooler (4°C) to ensure fresh feed. All steers were fed a supplement (5% DM basis) that included monensin (Rumensin®; Elanco Animal Health) at 33 g/t of DM and tylosin (Tylan®; Elanco Animal Health) was included at 9.7 g/t of DM.

Titanium dioxide was ruminally dosed at a rate of 5.0 g/steer twice daily at 0700 and 1500 h for 7 d prior to and for the duration of the collection period. Fecal grab samples, approximately 250 g each, were collected d 15 through d 18, 4 times daily at 0700, 1100, 1500, and 1900 h. Fecal samples were composited by day on a wet weight basis and lyophilized (Virtis Freezemobile 25ES, SP industries, Warminster, PA). These daily composites were then composited by steer within period to create a period composite from the freeze-dried samples. Samples were then subsequently analyzed for NDF using α-amylase and sodium sulfite (Van Soest et al., 1991), ADF (Van Soest et al., 1991), starch (Megazyme International, AOAC International, 2000; Method 996.11; AACC Method 76.13), and titanium concentration (Spectra MAX 250, Molecular Devices, LLC, Sunnyvale, CA; Myers et al., 2004). Wireless ruminal pH probes were inserted in the rumen on d 14 and recorded ruminal pH every minute daily until removed on d 21. Rumen pH data were analyzed for days 15-19 to capture the collection period and get four full days of rumen pH measurements. Rumen fluid samples were collected on d 21 of each period at 0700, 1000, 1300, 1600 and 1900 h and were analyzed for ruminal volatile fatty acids (VFA; Trace 1300, Thermo Fisher Scientific, Inc., Waltham,

MA) using procedures outlined by Ehrlich et al. (1981). The ingredients and diet refusals were analyzed for DM, OM, NDF, ADF, starch and CP using the same procedures described above. Dry matter of ingredients was determined weekly, using a forced air oven at 60°C for 48 h (AOAC, 1999; method 4.1.03).

In situ NDF degradability of each of the corn silages in the rumen was analyzed. Dacron bags [5 cm × 10 cm Ankom *in situ* bags (R510) with a 50 µm pore size; Ankom Technology, Macedon, NY] were filled with 1.25 g of dry corn bran (Cargill Wet Milling, Blair, NE) or one of the six experimental corn silages utilized in the experiment that had been lyophilized (Virtis Freezemobile 25ES, SP Industries). All samples were ground through a 2 mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ) before being weighed into the Dacron *in situ* bags. Four bags of each feed type were placed in mesh bags and incubated in the rumen of each steer for a period of 30 hours. Bags were removed at the same time (2000h) on d 21. Bags were rinsed 5 times in a washing machine (39°C) in addition to 0hr bags, through a 1-minute agitation and 2-minute spin cycle (Whittet et al., 2002), then frozen until analysis. Prior to analysis, bags were rinsed with distilled water. Neutral detergent fiber disappearance was determined for ingredient and bran samples by refluxing bags in neutral detergent solution in an ANKOM 200 Fiber Analyzer (Ankom Technology). Bags were agitated in NDF solution for 1 hr at 100°C and then rinsed with distilled water for 5 minutes 4 separate times. Neutral detergent fiber disappearance of the corn bran and ingredient samples were calculated by subtracting the remaining residue after 30h of incubation from an initial value (0hr bags; non-incubated) and dividing by the original NDF of the sample.

Total tract nutrient intake and digestibility data were analyzed using the MIXED procedure of SAS (SAS Inst. IN., Car, NC), with period and treatment as fixed effects, steer within period was included as a random effect. The interaction effect between corn silage hybrid and kernel processing was analyzed before analyzing for main effects of either corn silage hybrid or kernel processing. Volatile fatty acid data were evaluated using the GLIMMIX procedure of SAS with steer within period being considered a random effect and time and treatment as fixed effects. Treatment by time was included initially but was removed due to lack of significance ($P > 0.10$). A simple covariance structure was used for VFA. The in-situ model used the MIXED procedure of SAS, with steer within period being considered random effect and individual in-situ bag considered the experimental unit, and treatment fed, and ingredient utilized as fixed effects. Ruminal pH data were analyzed using the GLIMMIX procedure of SAS with d as the repeated measure and using an autoregressive covariance structure. For repeated measures analysis, covariance structures were chosen based on Akaike's information criterion (AIC). Treatments were considered fixed effects and steer within period considered a random effect. Treatment differences were considered significant when $P \leq 0.05$. A tendency was declared when $P \leq 0.10$ and $P > 0.05$.

Results and Discussion

Corn silage fermentation and nutrient analyses are in Table 2.2. Fermentation analyses show the 6 silage samples had a pH below 4.2 and total acids were greater than 7.0%. Silage dry matter averaged throughout the trial was numerically less for kernel processed silages as compared to non-kernel processed silages but was not statistically analyzed. Other trials have reported kernel processing decreases DM (Johnson et al.,

2003; Cooke and Bernard, 2005), but ZoBell et al. (2002) observed no differences in DM due to kernel processing. It is unclear as to why differences in DM would be observed due to kernel processing. Neutral detergent fiber was numerically greater for *bm3* and *bm3*-soft, with lower numerical ADF concentrations, suggesting CON had a greater portion of fiber dedicated to lignin. Starch concentration was greater in CON silage, which is typical of brown midrib hybrids (Bal et al., 2000, Ballard et al., 2001).

Experiment 1 – Cattle Finishing Experiment

There were no interactions between corn silage hybrid and kernel processing for growth performance parameters or carcass characteristics measured ($P \geq 0.29$; Appendix 2.1), and as a result, main effects of corn silage hybrid and kernel processing will be discussed (Table 2.3 & 2.4; respectively). The use of either brown midrib corn silage hybrid increased DMI over the CON treatment by 4.2% ($P < 0.01$; Table 2.3) with no difference between brown midrib hybrids ($P = 0.39$; Table 2.3). With the increase in DMI, there was an increase ($P < 0.01$) in ADG in *bm3* and *bm3*-soft diets, increasing from 1.87 kg/d with the CON to 2.03 and 2.06 kg/day for the *bm3* and *bm3*-soft, respectively. In addition to an increase in ADG of the brown midrib treatments over CON, G:F was statistically increased 4.9% ($P = 0.03$), with no difference ($P = 0.88$) between the brown midrib hybrids. Genero et al. (2016) also observed DMI was increased ($P < 0.01$) when brown midrib corn silage hybrid was included in the diet of lactating dairy cows at 54% of diet DM. This result is commonly observed in dairy research, because DMI for high producing dairy cattle is typically limited by gut fill (Oba and Allen, 2000). Net energy available for maintenance and gain calculated from

performance was not significantly affected ($P \geq 0.22$) using brown midrib corn silage, and dietary net energies were similar between treatments.

Dry matter intake was significantly decreased ($P = 0.02$; Table 2.4) by 0.4 kg/d due to kernel processing. There was no difference in ADG ($P = 0.93$) with the inclusion of kernel processed silage. As a result of no change in ADG paired with a reduction in DMI, kernel processed corn silage tended ($P = 0.10$) to increase G:F by 2.9% over non kernel processed corn silage. The value of corn silage was increased approximately 7.5% when the feed efficiency improvement due to kernel processing was divided by the corn silage inclusion (40%, DM basis) in the diet. Dry matter intake in kernel processing research has been variable and is likely partially dependent on physiological maturity of the corn silage, as studies by Bal et al. (2000) evaluated kernel processing in 50% milkline corn silage, while the current trial evaluated corn silage that was more mature at 75% milkline and 37% DM. In the study by Bal et al. (2000), kernel processing resulted in an increase of DMI by 0.6 kg/d ($P < 0.01$) when lactating cattle were fed a 67% kernel processed corn silage diet. However, in research by ZoBell et al. (2002), dry matter intake was not different ($P = 0.33$) when growing heifers consumed diets including corn silage at 61% DM. The reduction in intake in the current study paired with no change in ADG suggests cattle were obtaining more energy and ate the diets to a metabolic endpoint rather than to gut fill. Net energy of the diet calculated from performance was similar between kernel processed and non kernel processed corn silage. Net energy available for maintenance was 1.69 and 1.70 Mcal/kg for -KP and +KP, respectively ($P = 0.30$), and NEg was similar ($P = 0.27$) 1.07 and 1.08 Mcal/kg, respectively.

Carcass adjusted body weight was greater ($P < 0.01$; Table 2.3) for *bm3* and *bm3*-soft over CON, increasing from 594 kg for the CON treatment to 611 kg and 614 for *bm3* and *bm3*-soft, respectively. Carcass adjusted final body weight was unaffected ($P = 0.93$) by kernel processing. Hot carcass weight was ($P < 0.01$) greater for *bm3* over CON, increasing from 375 kg to 385 kg, and was greatest for *bm3*-soft at 387 kg, with no difference ($P = 0.49$) between brown midrib hybrids. Hot carcass weight was unaffected ($P = 0.91$) by kernel processing.

There was no difference in LM area due to corn silage hybrid ($P = 0.98$) despite larger final HCW for cattle fed either brown midrib hybrid. Backfat thickness was greatest for *bm3* over CON ($P = 0.04$) and *bm3*-soft was intermediate between the CON and *bm3* treatment. Marbling score was greater for cattle fed *bm3* and *bm3*-soft ($P < 0.01$) as compared to CON. Marbling score ($P = 0.96$) was unaffected by kernel processing. The greater backfat thickness and marbling score of brown midrib treatments suggested higher quality carcasses due to the feeding of brown midrib corn silage, likely because of increased ADG and G:F over CON, resulting in larger and more finished carcasses. This observation is supported by calculated yield grade, which was greater ($P = 0.02$) for both brown midrib hybrids of corn silage over CON. Conversely, in a study by Tjardes et al. (2000), performance was not improved ($P > 0.10$) in a 112-d growing study where cattle were fed diets containing 86% brown midrib corn silage or an isogenic control (DM basis). As observed in many of the performance characteristics, kernel processing did not affect LM area ($P = 0.77$), marbling score ($P = 0.96$) backfat thickness ($P = 0.57$) or yield grade ($P = 0.86$). This was an expected outcome, as

differences observed in performance only affected DMI and G:F, with no change in the ADG and thus growth curve of the cattle consuming kernel processed diets.

Experiment 2 – Cattle Digestion Experiment

There was no significant corn silage hybrid by kernel processing interactions on apparent total tract nutrient digestibility or intake of any nutrient ($P \geq 0.14$). As a result, main effects of corn silage hybrid and kernel processing will be discussed. Unlike in Exp. 1, dry matter intake across corn silage hybrids was not statistically different ($P = 0.17$; Table 2.5) and was unaffected by kernel processing ($P = 0.23$; Table 2.6). It is unclear why DMI was not different between treatments in this study, but has been observed in other research, as Hilscher (2018) observed feeding *bm3* at either 15 or 45% DM resulted in no differences in DMI in a feedlot finishing trial. No differences were observed in DM excretion ($P = 0.12$) due to corn silage hybrid, which resulted in no differences in DM digestibility ($P = 0.12$) between hybrids used. However, Tjardes et al. (2000) observed including brown midrib hybrid corn silage in the diet at 86% improved DM and OM digestibility as compared to an isogenic control. When included at levels similar to the current experiment (60% DM basis), Greenfield et al. (2001) observed an improvement in DM and OM digestibility with brown midrib corn silage by 7.1 and 4.7 percentage units respectively. Organic matter intake was not statistically different between corn silage hybrids ($P = 0.19$), but there was a tendency for greater ($P = 0.08$) OM digestibility of *bm3*-soft hybrid as compared to CON, which agrees with the research above. Organic matter excreted tended to be greater ($P = 0.09$) for *bm3*-soft over CON, with *bm3* being intermediate. In the current experiment, statistical trends of OM digestibility suggested an

improvement in nutrient utilization for either brown midrib hybrid, which was reinforced by improvements in ADF and NDF digestibility.

Kernel processing did not affect (P = 0.53; Table 2.6) DM excretion or DM digestibility (P = 0.99). Kernel processing did not change organic matter intake (P = 0.21) organic matter digestibility (P = 0.96) or excretion (P = 0.53). Kernel processing increased DM digestibility by 1.8 percentage units in a study by Wilkinson et al. (1978) in a diet with corn silage fed ad libitum. In other trials evaluating DM and OM digestibility, ZoBell et al. (2002) did not observe any differences in apparent total tract nutrient digestibility when kernel processed corn silage was used in the diet at 55% (DM basis).

As was expected, fiber digestibility was affected due to the brown midrib hybrids because of their lower lignin content compared to the standard isogenic control corn silage hybrid. Neutral detergent fiber intake was not different (P = 0.33) between corn silage hybrids or due to kernel processing (P = 0.18). However, NDF excreted by cattle decreased (P < 0.01) approximately 16.9% for both brown midrib hybrids as compared to CON. This reduction in excretion resulted in an improvement (P < 0.01) in fiber digestibility for the brown midrib hybrids increasing from 45.5% for the CON silage hybrid to 54.4 and 58.2% (*bm3* and *bm3*-soft; respectively), with no difference (P = 0.16) between the *bm3* and *bm3*-soft hybrids. Acid detergent fiber intake was not different (P = 0.12). As expected, the more available fibrous fraction of the silage resulted in a reduction in the ADF excreted by cattle fed *bm3* and *bm3*-soft from 1.00 kg/d for CON to 0.83 kg/d and 0.76 kg/d for *bm3* and *bm3*-soft. This resulted in an improvement of ADF digestibility increasing from 47.6% for CON to 54.2% and 55.9% for *bm3* and *bm3*-soft.

Neutral detergent fiber intake was not affected by kernel processing ($P = 0.18$), and there was no change in excretion ($P = 0.41$), resulting in no change in NDF digestibility due to kernel processing ($P = 0.86$). Kernel processing did not change ($P = 0.13$) ADF intake and as a result, no differences in ADF excreted ($P = 0.54$) were observed, leading to no change in digestibility ($P = 0.95$). Fiber digestibility in other research trials evaluating kernel processing have had conflicting results. ZoBell et al. (2002) observed kernel processing increased NDF digestibility but did not change ADG ($P = 0.39$) or daily DMI ($P = 0.33$). While the current study did not observe a difference in ADG, a reduction in intake was observed in the feedlot study ($P = 0.02$), resulting in a tendency ($P = 0.10$) for improved feed efficiency. In agreement with this, Cooke and Bernard (2005), and Johnson et al. (2003; experiment 2) observed improvements in NDF digestibility due to kernel processing. Andrae et al. (2001) observed kernel processing corn silage and including in a finishing diet at 60% (DM basis) resulted in a reduction in NDF and ADF digestibility ($P < 0.01$) with an improvement ($P < 0.01$) in starch digestibility, with no change ($P = 0.11$) on DM digestibility. In a dairy research trial evaluating kernel processing, Bal et al. (2000) observed no difference ($P > 0.10$) in apparent total tract NDF digestibility, but a reduction ($P < 0.01$) in ADF digestibility when silages were processed. Johnson et al. (2003; experiment 1) observed no change in NDF digestibility due to kernel processing. Differences in NDF digestibility due to kernel processing have been attributed to differences in cattle sorting the diet, improvements in starch digestion in the rumen creating a less hospitable environment for fibrolytic bacteria, and an increased passage rate through the rumen, decreasing exposure of fibrolytic bacteria to fiber (Andrae et al., 2001). In the current study, orts were analyzed

to account for sorting by animals, reducing the risk for differences in NDF digestibility due to sorting.

Starch intake was not different (P = 0.11; Table 2.5) between corn silage hybrids in the metabolism experiment, ranging from 3.33 kg/d for *bm3*-soft cattle, and 3.58 kg/d for both *bm3* and CON. As a result, starch digestibility remained unchanged due to silage hybrid (P = 0.47). There has been little research evaluating brown midrib hybrids with a floury endosperm as corn silage, but some research by Greenfield et al. (2001) suggested starch digestion of diets containing brown midrib corn silage was inhibited due to greater fiber digestion in the rumen, creating an unfavorable rumen environment for starch digestion. Grant et al. (2017) observed greater microbial crude protein synthesis in the rumen when feeding cattle diets including 50% brown midrib corn silage with a floury endosperm as compared to brown midrib corn silage without, suggesting an improvement in starch digestion in the rumen, but likely not the total tract. Starch intake was not affected (P = 0.13) by kernel processing and ranged from 3.58 to 3.41 kg/d, which resulted in no change in starch digestibility (P = 0.49). This is contrary to other research performed by Dhiman et al. (2002) who observed an improvement in starch digestion by 3.5% when kernel processing was applied to a diet that included 30 to 37% corn silage. However, this did not result in an improvement in lactational performance in dairy cattle (Dhiman et al., 2002). Due to no differences in starch digestibility, it is hypothesized starch digestibility in the rumen did not inhibit fiber digestibility.

Gross energy intake tended to be greater (P = 0.10) for the *bm3* as compared to both the CON and *bm3*-soft treatments, with *bm3* at 50.04 Mcal/d and for *bm3*-soft and CON at 46.28 Mcal/d and 46.42 Mcal/d, respectively. Digestible energy intake (Mcal/d)

also tended (P = 0.07) to be greater for the *bm3* over the CON and *bm3*-soft was intermediate, ranging from 30.93 Mcal/d for CON to 34.61 Mcal/d for *bm3* with *bm3*-soft in between at 32.69 Mcal/d. However, when DE was measured as Mcal/kg of diet consumed, both *bm3* and *bm3*-soft had greater DE ($P < 0.01$) as compared to CON, increasing from 3.09 Mcal/kg to 3.25 Mcal/kg and 3.33 Mcal/kg for *bm3* and *bm3*-soft, respectively. As a result, DE as a percent of GE was greatest ($P = 0.04$) for cattle fed *bm3* and *bm3*-soft over CON, at 69.0, 70.9, and 66.8%, respectively. Corn silage was included at 40% of all diets, and was the only ingredient changed between diets. Therefore, energetic differences in the diet were due to the corn silage. As a result, DE intake (Mcal/d) increased approximately 12.0% as steers consumed *bm3* over CON. When considering DE as a Mcal/kg of intake, *bm3* and *bm3*-soft were 6.5% greater ($P < 0.01$) than CON. This applies well to the digestibility results, as the cattle fed *bm3* and *bm3*-soft experienced a tendency for greater DM and OM digestibility. Digestible energy intake (Mcal/d) was not different ($P = 0.11$) between kernel processed treatments at 31.74 and 31.75 Mcal/d for -KP and +KP, respectively. The digestible energy per kilogram of intake was also not different ($P = 0.35$) between kernel processed treatments. As a result, digestible energy as a percent of gross energy was similar ($P = 0.82$) between treatments, at 69.0% and 68.8%. The lack of differences between kernel processing treatments agrees with the DM and OM digestibility data, which were not different ($P \geq 0.96$), but does not explain the reduction in DMI and performance response observed in Experiment 1.

There were no interactions for any measured ruminal pH variables ($P \geq 0.12$; Table 2.7). Maximum pH tended ($P = 0.11$) to be lower for cattle on *bm3* and *bm3*-soft

treatment as compared to CON. The CON treatment tended to have greater (P = 0.09) average pH at 6.12 as compared to 5.89 and 5.83 for *bm3* and *bm3*-soft, suggesting greater ruminal fermentation, likely due to increased NDF and ADF digestibility in the rumen by rumen microbes. There were no differences in magnitude of pH change and time spent below a pH of 5.6 and 5.0 for silage hybrid ($P \geq 0.19$). In a trial by Hilscher (2018), cattle fed *bm3* and *bm3*-soft hybrids resulted in a significant decrease ($P < 0.01$) in average ruminal pH throughout the feeding period, when silage was included in the diet at 80% (DM basis), suggesting greater acid production through improved fiber digestion in the rumen, as observed in the current study. Hourly average ruminal pH (Figure 2.1) shows the cattle consuming CON-KP treatments tended (P = 0.07) to have greater average ruminal pH during certain periods of the day compared to other treatments. This related well to an increase in acetate production, which is the primary VFA produced from fiber digestion (Hilscher, 2018). In the current study, this interaction between VFA and pH was not observed, as molar proportions of acetate, propionate, butyrate and the acetate: propionate ratio were unaffected by either hybrid or kernel processing treatment ($P \geq 0.71$; Table 2.7). Kernel processing did not significantly affect most ruminal pH variables measured ($P \geq 0.14$). Kernel processing did not affect total VFA concentration (P = 0.88) or molar proportions of acetate, propionate, and butyrate ($P \geq 0.37$).

In the *in situ* experiment, there were no interactions between ingredient incubated in the rumen, corn silage hybrid fed and kernel processing treatment or between kernel processing treatment and ingredient incubated in the rumen ($P \geq 0.44$; Table 2.8). A corn hybrid treatment by ingredient incubated in the rumen interaction was observed for NDF

disappearance (NDFD) from the Dacron bags ($P < 0.01$). When *bm3*-soft KP was incubated in the rumen, cattle fed the CON treatment had the greatest NDFD, while cattle fed *bm3*-soft had the lowest NDFD, with *bm3* intermediate. When *bm3*-soft was incubated in the rumen for 30 hours, CON and *bm3*-soft fed cattle had greater NDFD than *bm3* fed cattle. When *bm3*-KP, *bm3*, and bran were incubated in the rumen for 30 hours, cattle consuming the CON treatment tended ($0.05 \leq P \leq 0.10$) to have greater NDFD as compared to cattle fed either *bm3* or *bm3*-soft. Average ruminal pH tended to be greatest for cattle consuming CON, creating a more optimal environment for fiber to be degraded in the rumen for fibrolytic microbes. When either CON or CON KP were incubated in the rumen for 30 hours, there were no differences ($P \geq 0.34$) in NDFD when included in the rumen of cattle fed any of the hybrids.

When evaluating the individual ingredients without consideration for diet being fed, NDFD in situ results were different ($P < 0.01$) as well. The bran standard had the greatest NDFD at 34.2%, as compared to an average of 21.1% and 21.8% for *bm3*-soft and *bm3*, respectively, which were greater than CON at 14.1%. As with the performance and NDF digestibility data, brown midrib corn silage has greater fiber degradation when in the rumen, regardless of rumen environment. Kernel processing approached a tendency for greater NDFD across treatments ($P = 0.12$; data not shown). Compared to similar experiments evaluating in situ NDFD after 30 h were approximately at 35% in corn silage that was harvested at approximately ½ milkline (Burken et al, 2017b). As maturity of the silage increased, NDFD at 30-h decreased to approximately 25% (Burken et al., 2017b), which is more similar to the numbers observed in the current trial. Corn bran is typically used as an indication of fiber fermentation as influenced from rumen environment due to

in differing dietary treatments (Burken et al., 2017b). When evaluating in situ NDFD of corn bran for either 24 or 36 hours, NDFD observed ranges from 36 to 49%, which were well above what was observed in the current trial. It is unclear as to why rumen fiber NDFD were so low in this trial, but the trends still indicated brown midrib had greater NDFD as compared to standard isogenic controls, while the rumen environment of CON allowed for best NDFD, likely due to the higher average ruminal pH.

Conclusion

Feeding finishing cattle brown midrib corn silages improved ADG and G:F over the traditional isogenic control corn silage hybrid when fed at 40% of the diet. Results from the metabolism and feedlot trial suggest the improved G:F and ADG were likely due to improved fiber digestibility from the *bm3* and *bm3*-soft, with no extra benefit to starch digestion or energetic response due to the floury endosperm of the *bm3*-soft. Kernel processing in corn silage was not affected by corn hybrid but did improve feed efficiency of cattle consuming corn silage by approximately 2.9% when fed at 40% of diet DM, suggesting a 7.3% improvement in the silage as a feed, despite no observed differences in nutrient digestibility and measured metabolic parameters. Feeding brown midrib corn silage hybrids in finishing diets can provide a benefit for producers by improving feed efficiency and gain of cattle consuming it. Kernel processing improves the value of the corn silage approximately 7.3%, which may offset the extra costs of the machinery and to operate the rollers on the machine. When corn silage is increased in finishing diets, both kernel processing and brown midrib corn silage can provide a benefit to producers through enhanced fiber digestion.

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Table 2.1. Diet composition (% DM Basis) for cattle in Exp. 1 and Exp. 2

	Treatment[1]					
	CON		*bm3*		*bm3*-soft	
Ingredient	-KP	+KP	-KP	+KP	-KP	+KP
CON Corn Silage	40.0	40.0	0.0	0.0	0.0	0.0
bm3 Corn Silage	0.0	0.0	40.0	40.0	0.0	0.0
bm3-soft Corn Silage	0.0	0.0	0.0	0.0	40.0	40.0
MDGS[2]	30.0	30.0	30.0	30.0	30.0	30.0
Dry-rolled corn	25.0	25.0	25.0	25.0	25.0	25.0
Dry Supplement[3]						
Fine-ground corn	2.9844	2.9844	2.9844	2.9844	2.9844	2.9844
Limestone	1.5010	1.5010	1.5010	1.5010	1.5010	1.5010
Salt	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000
Tallow	0.1250	0.1250	0.1250	0.1250	0.1250	0.1250
Trace Mineral Premix[4]	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500
Vitamin ADE Premix[5]	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150
Rumensin-90[6]	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165
Tylan-40[7]	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080
Nutrient Composition[8]						
NDF, %	28.8	29.0	29.6	28.6	30.2	30.0
ADF, %	18.7	18.6	17.9	16.5	17.1	17.7
CP, %	17.1	17.3	17.6	17.9	17.5	17.9
Starch, %	35.2	34.7	32.9	33.7	33.1	32.3
Ether Extract, %	5.2	5.2	5.5	5.5	5.3	5.3

[1] Treatments were control (CON; hybrid-TMF2H708), a *bm3* hybrid (*bm3*; hybrid-F15579S2), and an experimental *bm3* hybrid (*bm3*-soft; hybrid-F15578XT) with a softer endosperm, and not kernel processed (-KP) and kernel processed (+KP)
[2]MDGS = Modified distillers grains plus solubles
[3]Supplement formulated to be fed at 5% of diet DM
[4]Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.29% Mg, 0.2% I, 0.05% Co.
[5]Premix contained 30,000 IU vitamin A, 6,000 IU Vitamin D, 7.5 IU vitamin E per gram.
[6]Premix contained 198 g/kg monensin
[7]Premix contained 88 g/kg tylosin
[8]Based on analyzed nutrients for each ingredient.

Table 2.2. Nutrient and fermentation analysis of silage hybrids (DM basis)[1]

	CON				*bm3*				*bm3*-soft			
Item	-KP	C.V.[2]	+KP	C.V.[2]	-KP	C.V.[2]	+KP	C.V.[2]	-KP	C.V.[2]	+KP	C.V.[2]
DM at harvest	40.3	2.8	40.8	2.3	39.8	2.3	38.5	1.3	40.4	2.7	39.3	1.7
DM[3]	40.8	1.8	38.8	1.6	38.6	2.5	36.5	2.7	40.6	2.1	38.8	1.6
CP	8.1	0.6	8.1	0.6	9.3	1.0	8.7	0.7	8.9	3.5	8.4	1.6
NDF, %	43.4	2.9	44.0	2.3	45.6	1.6	42.4	1.5	47.1	2.5	47.0	1.4
ADF, %	31.5	2.2	32.7	2.6	32.2	0.8	29.7	2.4	32.0	2.0	30.5	2.6
Starch, %	34.4	3.5	33.3	2.7	28.8	3.3	30.6	2.8	29.1	3.0	27.1	3.7
pH	3.9	1.8	4.0	3.5	4.2	0.0	4.1	3.4	4.0	1.8	3.9	0.0
Lactic acid, %	6.0	9.7	4.2	36.8	2.4	7.1	3.8	62.9	4.7	25.2	5.4	2.8
Acetic acid, %	1.0	17.8	2.6	62.2	5.1	2.2	4.0	36.7	2.8	36.3	2.1	34.0
Propionic acid, %	0.0	0.0	0.2	0.0	0.5	0.0	0.5	0.0	0.3	0.0	0.1	0.0
Butyric acid, %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Acids, %	7.0	11.1	7.0	4.4	8.0	5.3	8.3	5.9	7.8	2.0	7.6	9.6

[1] Treatments were control (CON; hybrid-TMF2H708), a *bm3* hybrid (*bm3*; hybrid-F15579S2), and an experimental *bm3* hybrid (*bm3*-soft; hybrid-F15578XT) with a softer endosperm, and not kernel processed (-KP) and kernel processed (+KP)

[2]C.V. = coefficient of variation and is calculated by dividing the standard deviation by the mean and is expressed as a percentage.

[3]DM was calculated using weekly samples and oven dried for 48 h at 60°C.

Note: Fermentation analysis was conducted only on a composite of samples taken throughout the trial and analyzed at Dairyland Labs (St. Cloud, MN). All other analyses (DM, CP, NDF, ADF, starch) are based on composites of weekly samples taken during the metabolism trial, and analyzed at the UNL lab.

Table 2.3. Main effects of corn silage hybrid on steer feedlot performance and carcass characteristics (Exp. 1)

	Treatment[1]			SEM	*P* – Value[2]
	CON	*bm3*	*bm3*-soft		
Performance					
Initial BW, kg	400	400	400	0.4	0.86
Final BW, kg[3]	594[a]	611[b]	614[b]	3.2	<0.01
DMI, kg/day	14.2[a]	14.7[b]	14.9[b]	0.13	<0.01
NDF Intake, kg/d	4.1[a]	4.3[b]	4.5[c]	0.039	<0.01
ADG, kg[3]	1.87[a]	2.03[b]	2.06[b]	0.027	<0.01
Gain:Feed[3]	0.132[a]	0.138[b]	0.139[b]	0.0020	0.03
NEm, Mcal/kg[4]	1.68	1.71	1.71	0.015	0.25
NEg, Mcal/kg[4]	1.06	1.09	1.06	0.013	0.22
Carcass Characteristics					
HCW, kg	375[a]	385[b]	387[b]	1.8	<0.01
LM Area, cm[2]	80.45	80.49	80.35	0.559	0.98
Marbling Score[5]	476[a]	516[b]	511[b]	6.1	<0.01
Backfat Thickness, cm	1.38[a]	1.47[b]	1.41[ab]	0.025	0.04
Yield Grade[6]	3.40[a]	3.58[b]	3.54[b]	0.045	0.02

[1]Treatments were control (CON; hybrid-TMF2H708), a *bm3* hybrid (*bm3*; hybrid-F15579S2), and an experimental *bm3* hybrid (*bm3*-soft; hybrid-F15578XT) with a softer endosperm
[2]*P*-Value for the main effect of corn silage hybrid
[3]Calculated from hot carcass weight, adjusted to a common 63% dressing percentage
[4]NEm and NEg calculated using methodology of NRC (1996) using a tool developed by Galyean (2009).
[5]Marbling Score 400-Small00, 500 = Modest00
[6]Calculated YG (yield grade) = [2.5 + (6.35 × fat thickness, cm) + (0.2 × 2.5% KPH) + (0.0017 × HCW, kg) – (2.06 × LM area, cm^2)](USDA, 2016)

Table 2.4. Main effect of kernel processing on steer feedlot performance and carcass characteristics (Exp. 1)

	Treatment[1]		SEM	*P* - Value[2]
	-KP	+KP		
Performance				
pens, n	18	18		
Initial BW, kg	400	400	0.3	0.86
Final BW, kg[3]	606	607	2.6	0.93
DMI, kg/day	14.8	14.4	0.11	0.02
NDF Intake, kg/d	4.2	4.4	0.03	0.01
ADG, kg[3]	1.99	2.00	0.022	0.93
Gain:Feed[3]	0.134	0.138	0.0016	0.10
NEm, Mcal/kg[4]	1.69	1.70	0.012	0.30
NEg, Mcal/kg[4]	1.07	1.08	0.010	0.27
Carcass Characteristics				
HCW, kg	382	382	1.5	0.91
LM Area, cm^2	80.34	80.53	0.456	0.77
Marbling Score[5]	501	501	5.0	0.96
Backfat Thickness, cm	1.41	1.43	0.020	0.57
Yield Grade[6]	3.51	3.51	0.036	0.86

[1]Treatments were no kernel processing (-KP) and kernel processed (+KP)
[2]*P*-Value for the main effect of kernel processing.
[3]Calculated from hot carcass weight, adjusted to a common 63% dressing percentage
[4]NEm and NEg calculated using methodology of NRC (1996) using a tool developed by Galyean (2009).
[5]Marbling Score 400-Small00, 500 = Modest00
[6]Calculated YG (yield grade) = [2.5 + (6.35 × fat thickness, cm) + (0.2 × 2.5% KPH) + (0.0017 × HCW, kg) – (2.06 × LM area, cm^2)]; (USDA, 2016).

Table 2.5. Main effect of corn silage hybrid on digestibility of corn silage-based finishing diets (Exp. 2)

	Treatment			SEM	
	CON	*bm3*	*bm3*-soft		*P* – Value[2]
Dry Matter					
Intake, kg/day	10.10	10.60	9.90	0.29	0.17
Excreted, kg/day	3.6	3.6	3.2	0.16	0.12
Digestibility, %	64.61	68.01	66.14	1.103	0.12
Organic Matter					
Intake, kg/day	9.50	9.98	9.27	0.269	0.19
Excreted, kg/day	3.11	3.08	2.69	0.141	0.09
Digestibility, %	67.48	68.95	71.12	1.085	0.08
NDF					
Intake, kg/day	2.89	3.09	2.96	0.092	0.33
Excreted, kg/day	1.58[a]	1.39[ab]	1.23[b]	0.069	<0.01
Digestibility, %	45.5[a]	54.4[b]	58.2[b]	1.88	<0.01
ADF					
Intake, kg/day	1.89	1.84	1.73	0.053	0.12
Excreted, kg/day	1.00[a]	0.83[b]	0.76[b]	0.048	<0.01
Digestibility, %	47.6[a]	54.2[ab]	55.9[b]	2.27	0.04
Starch					
Intake, kg/day	3.58	3.58	3.33	0.091	0.11
Excreted, kg/day	0.42	0.38	0.33	0.043	0.33
Digestibility, %	88.5	89.5	90.5	1.118	0.47
Energy Intake					
Gross Energy Intake, Mcal/d	46.42	50.04	46.28	1.333	0.10
DE, Mcal/d	30.93	34.61	32.69	1.045	0.07
DE, Mcal/kg intake	3.09[a]	3.25[b]	3.33[b]	0.049	<0.01
DE, % of GE	66.8[a]	69.0[b]	70.9[b]	1.05	0.04

[1]Treatments were control (CON; hybrid-TMF2H708), a *bm3* hybrid (*bm3*; hybrid-F15579S2), and an experimental *bm3* hybrid (*bm3*-soft; hybrid-F15578XT) with a softer endosperm
[2]*P*-value for the main effect of corn silage hybrid

Table 2.6. Main effect of kernel processing on digestibility of corn silage-based finishing diets (Exp. 2)

	Treatment		SEM	
	-KP	+KP		*P*-Value[2]
Dry Matter				
Intake, kg/day	10.40	10.00	0.24	0.23
Excreted, kg/day	3.50	3.40	0.13	0.53
Digestibility, %	66.26	66.25	0.901	0.99
Organic Matter				
Intake, kg/day	9.79	9.38	0.219	0.21
Excreted, kg/day	3.02	2.91	0.115	0.53
Digestibility, %	69.15	69.21	0.886	0.96
NDF				
Intake, kg/day	3.05	2.90	0.075	0.18
Excreted, kg/day	1.43	1.37	0.056	0.41
Digestibility, %	52.52	52.91	1.534	0.86
ADF				
Intake, kg/day	1.87	1.77	0.044	0.13
Excreted, kg/day	0.88	0.85	0.039	0.54
Digestibility, %	52.64	52.47	1.853	0.95
Starch				
Intake, kg/day	3.58	3.40	0.075	0.13
Excreted, kg/day	0.39	0.36	0.035	0.50
Digestibility, %	89.02	89.93	0.913	0.49
Energy				
Gross Energy Intake, Mcal/d	48.86	46.31	2.880	0.11
DE, Mcal/d	31.74	31.75	2.113	0.11
DE, Mcal/kg intake	3.25	3.20	0.057	0.35
DE, % of GE	69.0	68.8	1.72	0.82

[1]Treatments were no kernel processing (-KP) and kernel processed (+KP)
[2] *P*-Value for the main effect of kernel processing.

Table 2.7. Effect of corn silage hybrid and kernel processing on rumen fermentation characteristics of cattle fed corn silage-based finishing diets (Exp. 2)

	Treatment[1]							*P*-Value[2]		
	CON		*bm3*		*bm3*-soft					
Item	-KP	+KP	-KP	+KP	-KP	+KP	SEM	Silage	Kernel	Int.
Ruminal pH										
Maximum pH	6.97	7.15	6.84	6.77	6.61	6.89	0.171	0.11	0.33	0.56
Average pH	6.01	6.24	5.91	5.86	5.89	5.79	0.154	0.09	0.88	0.43
Minimum pH	5.09	5.25	5.07	4.93	5.14	4.58	0.184	0.21	0.21	0.12
Variance	0.185	0.18	0.17	0.17	0.11	0.20	0.035	0.64	0.33	0.27
Time < 5.6, min/d	328	213	405	465	469	655	172.7	0.19	0.74	0.63
Area < 5.6[3]	80.20	50.64	95.86	138.61	94.23	210.11	53.081	0.21	0.30	0.33
Time <5.0, min/d	5	1	12	40	12	60	20.2	0.19	0.14	0.36
Area < 5.0[3]	0.19	0.01	0.63	5.74	0.93	4.39	2.380	0.33	0.14	0.47
Ruminal VFA[4]										
Total, mM	108.13	113.36	106.58	96.87	108.63	109.45	9.898	0.63	0.88	0.74
Acetate[5]	57.50	57.51	56.82	53.71	58.95	59.95	4.445	0.65	0.85	0.89
Propionate[5]	30.53	26.00	29.70	25.81	28.35	25.99	4.468	0.96	0.37	0.97
Butyrate[5]	13.22	14.61	12.64	11.56	13.34	14.74	1.733	0.46	0.69	0.71
A:P[6]	2.47	2.62	2.18	2.35	2.48	2.60	0.408	0.72	0.67	0.99

[1]Treatments were control (CON; hybrid-TMF2H708), a *bm3* hybrid (*bm3*; hybrid-F15579S2), and an experimental *bm3* hybrid (*bm3*-soft; hybrid-F15578XT) with a softer endosperm, and not kernel processed (-KP) and kernel processed (+KP)

[2]Int = *P*-value for the interaction of corn silage hybrid × kernel processing. Silage = *P*-value for the main effect of corn silage hybrid. Kernel = *P*-Value for the main effect of kernel processing.

[3]Area < 5.6 and < 5.0 = ruminal pH units below 5.6 and 5.0 by minute.

[4]Ruminal volatile fatty acids (VFA).

[5]VFA concentration in mol/100 mol

[6]Acetate:Propionate

Table 2.8. Effect of corn silage hybrid on 30-h in situ NDF disappearance from corn bran and corn silage hybrids (Exp. 2)

		Treatment[1]				*P*–Value[6]
Item, % NDFD	Ing. Average[2]	CON	*bm3*	*bm3*-soft	SEM[5]	Ing. × Hybrid
bm3-soft KP	20.1[y]	23.1[a]	20.1[ab]	17.1[b]	2.196	0.01
bm3-soft	22.0[y]	24.0[a]	17.5[b]	24.5[a]		
bm3 KP	22.3[y]	23.9	24.1	18.9		
bm3	21.2[y]	23.3[a]	17.3[b]	23.0[a]		
CON KP	15.0[z]	15.8	16.1	13.1		
CON	13.1[z]	14.5	12.7	12.0		
Bran	34.2[x]	37.2	33.5	31.9		
SEM[3]	1.27					
P – Value[4]	0.01					

[a-c] Within a row, values lacking common superscripts differ when the *P* - Value was significant ($P < 0.05$)

[x-z] Within a column, values lacking common superscripts differ when the *P* - Value was significant ($P < 0.05$)

[1] Treatments were CON; hybrid-TMF2H708), a *bm3* hybrid (*bm3*; hybrid-F15579S2), and an experimental *bm3* hybrid (*bm3*-soft; hybrid-F15578XT) with a softer endosperm

[2] Average of NDFD, % of ingredients across all dietary treatments

[3] Standard error of the mean for ingredients used across all dietary treatments

[4] *P*-Value for overall NDFD, % of ingredients used across all dietary treatments

[5] SEM for the interaction between ingredient and corn silage hybrid treatment

[6] *P*–value for the interaction between the ingredient and corn silage hybrid treatment

Appendix 2.1. Effect of corn silage hybrid and kernel processing on steer feedlot performance and carcass characteristics (Exp. 1)

	Treatment[1]							*P*–Value[2]		
	CON		*bm3*		*bm3*-soft					
Item	-KP	+KP	-KP	+KP	-KP	+KP	SEM	Silage	Kernel	Int
Performance										
Initial BW, kg	400	400	400	400	400	400	0.5	0.86	0.86	0.81
Final BW, kg[3]	595^{a}	594^{a}	610^{ab}	612^{ab}	614^{b}	614^{b}	4.5	<0.01	0.93	0.94
DMI, kg/day	14.3^{b}	14.1^{b}	15.0^{a}	14.4^{b}	15.0^{a}	14.7^{a}	0.19	<0.01	0.02	0.46
ADG, kg[3]	1.88^{a}	1.86^{a}	2.02^{b}	2.04^{b}	2.06^{b}	2.06^{b}	0.04	<0.01	0.93	0.90
G:F[3]	0.131^{a}	0.133^{a}	0.134^{b}	0.142^{b}	0.138^{b}	0.140^{b}	0.003	0.03	0.10	0.47
NEm, Mcal/kg	1.67	1.68	1.70	1.72	1.70	1.72	0.020	0.25	0.30	0.99
NEg, Mcal/kg	1.05	1.07	1.08	1.09	1.08	1.10	0.018	0.22	0.27	0.99
Carcass Characteristics										
HCW, kg	375	374	384	386	387	387	2.6	<0.01	0.91	0.91
LM Area, cm^2	80.18	80.71	80.24	80.75	80.59	80.12	0.790	0.98	0.77	0.77
Marbling Score[5]	474^{a}	479^{a}	524^{b}	509^{b}	507^{b}	515^{b}	8.7	<0.01	0.96	0.35
12$^{th\text{-}rib}$ Fat, cm	1.34	1.42	1.47	1.47	1.43	1.40	0.035	0.04	0.57	0.29
Yield Grade[6]	3.38	3.43	3.59	3.58	3.55	3.54	0.063	0.02	0.86	0.87

[1]Treatments were control (CON; hybrid-TMF2H708), a *bm3* hybrid (*bm3*; hybrid-F15579S2), and an experimental *bm3* hybrid (*bm3*-soft; hybrid-F15578XT) with a softer endosperm, and not kernel processed (-KP) and kernel processed (+KP)

[2]Int = *P*-value for the interaction of corn silage hybrid × kernel processing. Silage = *P*-value for the main effect of corn silage hybrid. Kernel = *P*-Value for the main effect of kernel processing.

[3]Calculated from hot carcass weight, adjusted to a common 63% dressing percentage

[4]NEm and NEg calculated using methodology of NRC (1996) using a tool developed by Galyean (2009).

[5]Marbling Score 400-Small00, 500 = Modest00

[6]Calculated YG (yield grade) = [2.5 + (6.35 × fat thickness, cm) + (0.2 × 2.5% KPH) + (0.0017 × HCW, kg) – (2.06 × LM area, cm^2)]; (USDA, 2016).

Appendix 2.2. Effect of corn silage hybrid and kernel processing on digestibility of corn silage-based finishing diets (Exp. 2)

	Treatment[1]							*P*-Value[2]		
	CON		*bm3*		*bm3*-soft					
Item	-KP	+KP	-KP	+KP	-KP	+KP	SEM	Silage	Kernel	Int.
Dry Matter										
Intake, kg/day	9.91	10.20	10.97	10.29	10.27	9.44	0.407	0.17	0.23	0.35
Excreted, kg/day	3.40	3.76	3.78	3.39	3.32	3.02	0.222	0.12	0.53	0.20
Digestibility, %	65.7	63.6	65.5	66.8	67.6	68.4	1.560	0.12	0.99	0.51
Organic Matter										
Intake, kg/day	9.37	9.63	10.31	9.66	9.68	8.86	0.380	0.19	0.21	0.33
Excreted, kg/day	2.94	3.29	3.26	2.91	2.85	2.54	0.199	0.09	0.53	0.17
Digestibility, %	68.7	66.3	68.3	69.6	70.5	71.7	1.535	0.08	0.96	0.40
NDF										
Intake, kg/day	2.82	2.95	3.24	2.93	3.09	2.83	0.130	0.33	0.18	0.20
Excreted, kg/day	1.52	1.63	1.50	1.28	1.28	1.19	0.097	0.01	0.41	0.25
Digestibility, %	45.8	45.2	53.4	55.4	58.4	58.1	2.657	0.01	0.86	0.87
ADF										
Intake, kg/day	1.86	1.91	1.97	1.71	1.77	1.69	0.076	0.12	0.13	0.14
Excreted, kg/day	0.96	1.04	0.89	0.78	0.80	0.73	0.067	0.01	0.54	0.39
Digestibility, %	48.5	46.6	54.9	53.5	54.5	57.3	3.210	0.04	0.95	0.73
Starch										
Intake, kg/day	3.56	3.60	3.64	3.52	3.55	3.12	0.129	0.11	0.13	0.22
Excreted, kg/day	0.37	0.47	0.41	0.34	0.39	0.26	0.061	0.33	0.50	0.16
Digestibility, %	89.6	87.3	88.5	90.5	89.0	91.9	1.581	0.47	0.49	0.24
Energy Intake										
Gross Energy Intake, Mcal	46.32	46.53	52.04	48.04	48.22	44.35	1.885	0.10	0.11	0.46
DE, Mcal/day	31.59	30.27	35.71	33.51	33.92	31.46	1.478	0.07	0.11	0.92

DE, Mcal/kg intake	3.19	2.99	3.25	3.25	3.31	3.36	0.069	0.01	0.37	0.18
DE, % of GE	68.24	65.38	68.51	69.49	70.33	71.39	1.481	0.04	0.82	0.34

[1]Treatments were control (CON; hybrid-TMF2H708), a *bm3* hybrid (*bm3*; hybrid-F15579S2), and an experimental *bm3* hybrid (*bm3*-soft; hybrid-F15578XT) with a softer endosperm, and not kernel processed (-KP) and kernel processed (+KP)

[2] Int =*P*-value for the interaction of corn silage hybrid × kernel processing. Silage = *P*-value for the main effect of corn silage hybrid. Kernel = *P*-Value for the main effect of kernel processing.

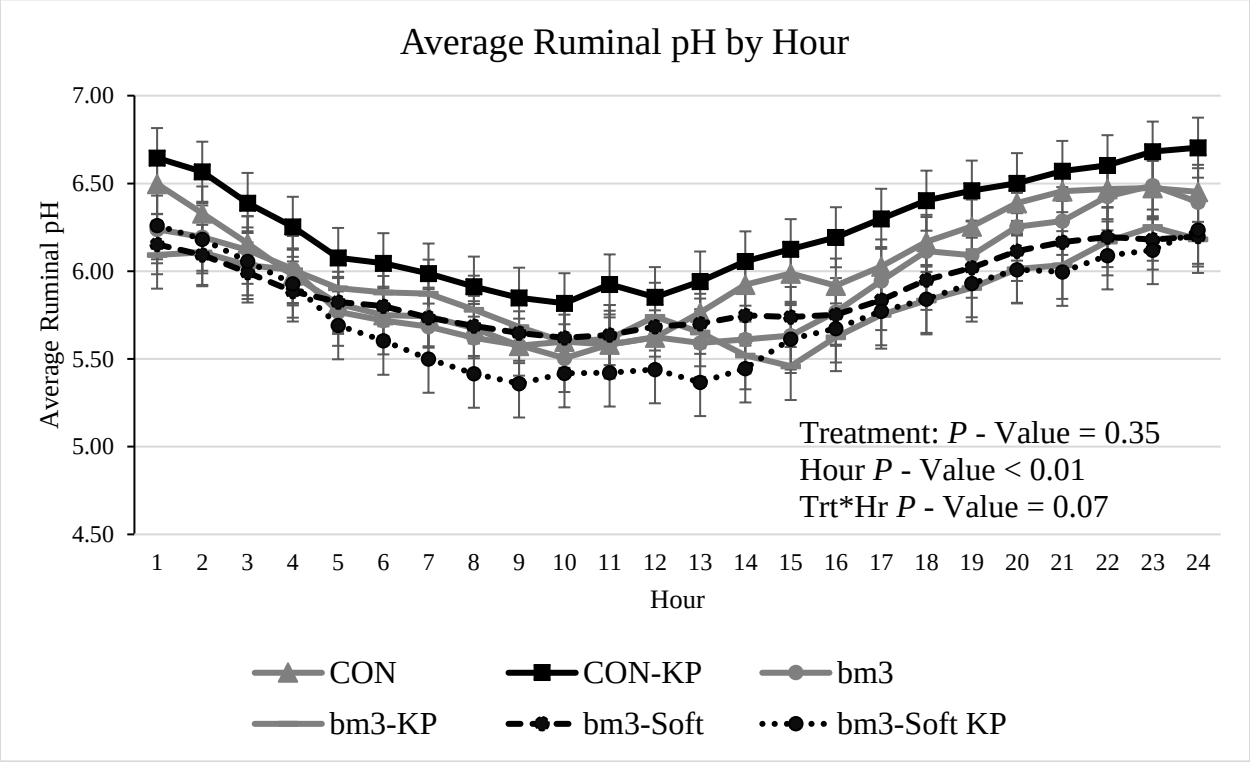

Figure 2.1. Average hourly ruminal pH from days 15-19 of each period in Exp. 2. Hour 1 is one-hour post-feeding. Treatments were control (CON; hybrid-TMF2H708), a *bm3* hybrid (*bm3*; hybrid-F15579S2), and an experimental *bm3* hybrid (*bm3*-soft; hybrid-F15578XT) with a softer endosperm, and not kernel processed (-KP) and kernel processed (+KP)

Chapter III. Effects of varying levels of silage inclusion and brown midrib corn silage on finishing and economic performance of steers

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Abstract

The effect of corn silage hybrid and varying inclusion of silage in corn-based finishing diets were evaluated for impact on finishing cattle performance and carcass characteristics. Steers (n = 288, BW = 318 ± 0.7 kg) were assigned randomly to one of six treatments in a 2 × 3 factorial. Two hybrids of corn silage included an isogenic corn silage (CON; hybrid TMF2H708) and a brown midrib hybrid (*bm3;* hybrid F27F627) and were fed at three inclusions of 15%, 45%, or 75/15% (DM basis). The 75/15% treatment provided 75% silage up to d70 and was then reduced to 15% until the end of the trial. Steers were ultrasounded to determine backfat deposition rate for a target endpoint of 1.4 cm, and as a result, steers fed 15% had 153 days fed (DOF) and the 45% and 75/15% had 181 DOF. Animals fed 45 and 75/15% had greater final BW due to greater DOF, but lower G:F (0.162) than cattle fed 15% (0.170; $P < 0.01$). Steers fed 45% and 75/15% had a lower ADG than 15% ($P < 0.01$). Cattle fed 75/15% had greater LM area, and both 45% and 75/15% had lower dressing percentage ($P < 0.01$) than 15%. Backfat thickness was greater for steers fed 45% (1.5 cm) over 15% (1.3 cm; $P < 0.01$), and 75/15% (1.4 cm) was intermediate between the two ($P > 0.12$) despite using ultrasound to target for the same backfat thickness. Dry matter intake was greater for cattle fed *bm3* ($P < 0.01$), but did not improve ADG or G:F ($P > 0.18$). Feeding corn silage at a consistent 45% inclusion throughout the feeding period resulted in similar performance to cattle fed an average of 45% corn silage in the 75/15 treatment.

Key words: brown midrib, cattle, corn silage, economics, inclusion

Introduction

As the number of acres devoted to corn have increased since the 1980s, specifically in the early 2000s due to greater demand for ethanol, competition for corn as a feedstuff has been increasing. As corn grain prices increase, corn silage has been shown to be an economical alternative to include in feedlot finishing diets because of its use as both a roughage and energy source (Goodrich et al., 1974). Corn silage has been limited in finishing diets in the past due to reduction in G:F as corn silage is increased in the diet (Erickson, 2001; Goodrich et al., 1974). Recent research evaluating increasing corn silage in the diet since the expansion of the ethanol industry has suggested less of a reduction in G:F than previously observed if silage is combined with distillers grains plus solubles. Rather than decreasing G:F 8-10% as corn silage increased from 15% to 45% in the diet, only a 5% reduction was observed when 40% modified distillers grains plus solubles (MDGS) was included in the diet (Burken et al., 2017a). Despite the positive economic benefits of including increasing levels of corn silage in finishing diets, producer adoption has been limited. Furthermore, there is limited research evaluating increasing corn silage in the diet and feeding to a common finishing point rather than to a common days on feed (DOF). By increasing corn silage in the diet and reducing energy available for growth, it is likely those cattle will need to grow longer and larger to meet a common backfat endpoint.

In order to improve corn silage as a roughage source, the brown midrib mutation has been incorporated into corn to produce corn plants with lower lignin concentrations (Kuc and Nelson, 1964). Compared to standard isogenic corn, brown midrib corn has greater fiber digestibility, which can improve ADG of growing steers when fed at inclusions above 40% DM (Hilscher, 2018; Ovinge et al., 2018). As a result, cattle

consuming brown midrib corn silage, especially in dairy diets where inclusion is greater, brown midrib corn silage increases voluntary DMI by as much as 9% (Oba and Allen, 1999). Especially during the growth phase when ruminal fill and fiber digestibility may limit intake, improving fiber digestibility may allow for improved animal performance.

Producers are willing to background cattle for a period to adapt to feedlot conditions and promote skeletal growth prior to feeding a finishing diet. This allows producers to have cattle finished at greater final BW and HCW but does reduce feed efficiency of the animal through the feeding period (Lancaster et al., 2014, Gardine, 2017). Therefore, the objectives of this experiment were to determine the effects of feeding elevated inclusions of either a control or brown midrib corn silage in the diet on growth performance and economic projections of beef cattle in the feedlot.

Materials and Methods

All animal use procedures were reviewed and approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee.

The two corn silage hybrids (Mycogen® Seeds) utilized in this trial were a standard isogenic control (CON; hybrid TMF2H708) and a brown midrib hybrid (*bm3*; hybrid F27F627) that were planted in two adjacent plots in a single irrigated field at the Eastern Nebraska Research and Extension Center (ENREC) located near Mead, NE in 2016. The CON and *bm3* plots were approximately 5.69 and 4.80 ha each, respectively. The field was harvested at approximately 37% DM and 75% milkline with a self-propelled forage harvester (JD 7250, John Deere, Moline, IL) set for a theoretical length of chop of 19 mm and kernel processed to 2 mm. Dry matter samples were obtained from each truckload and dried in a 60°C forced-air oven for 48h to determine DM of the silage

at harvest. Inoculants were not used at silage harvest. Silages were harvested between September 2 and 12, 2016 and were stored until initiation of the trial on February 15, 2017. As a result, silages were allowed to ferment for approximately 6 months prior to silage bags being opened and fed.

Crossbred steers (n = 288, initial BW = 318 ± 0.7 kg) were received as weaned steers at ENREC near Mead, NE and then grazed cornstalks until trial initiation. The trial was a randomized block design with cattle sorted into 2 BW blocks and assigned randomly to one of 36 pens (8 steers/pen; 5 replications in light BW block, 1 replication in heavy BW block). Prior to the trial starting, steers were individually weighed and processed into the feedlot with 20 mL of fenbendazole (SafeGuard Drench, Merck Animal Health, Madison, NJ), an injectable anthelmintic (Dectomax, Zoetis Inc., Kalamazoo MI), *Mannheimia haemolytica* toxoid (Bovi-Shield Gold One Shot, Zoetis Inc.), and a modified live viral vaccine for bovine viral diarrhea types I and II, infectious bovine rhinotracheitis, parainfluenza3, bovine syncytial virus, and *Histophilus somnus* bacterin (Ultrabac-7, Zoetis Inc.). Steers were revaccinated approximately 14 to 28 d later with a killed viral vaccine for clostridial infection (Ultrabac 7, Zoetis Inc.) and a modified live viral vaccine for infectious bovine rhinotracheitis, bovine respiratory syncytial virus, bovine viral diarrhea types I and II, and parainfluenza3 (Bovi-Shield Gold 5, Zoetis Inc.).

Prior to trial initiation, steers were limit-fed (Watson et al., 2013) for 5 d to prior to initial body weights for gut fill equalization. Steers were weighed on consecutive days of d0 and d1 for initial BW determination (Stock et al., 1983). Treatments were arranged in a 2 × 3 factorial design consisting of two corn silage hybrids, brown midrib hybrid corn silage (*bm3*; hybrid F27F627; Mycogen® Seeds) and a standard control corn silage

(CON; hybrid TMF2H708, Mycogen® Seeds) at one of three levels of 15, 45 or 75% inclusion in the diet (DM basis). The 75% treatment was reduced to 15% corn silage after 70 d. Steers were implanted on d1 with 100 mg trenbolone acetate, 14 mg estradiol benzoate (Synovex® Choice, Zoetis Inc.). Silage replaced a 1:1 ratio of high moisture corn (HMC) and dry rolled corn (DRC) on a 1:1 DM basis. Treatments were CON15, CON45, CON75/15, *bm3*-15, *bm3*-45, and *bm3*-75/15 (Table 3.1). Fermentation analyses of corn silage hybrid samples taken at the beginning and end of trial are presented in Table 3.2.

Steers were adapted to the 15% treatment over a period of 24 d, in which alfalfa was decreased from 30% inclusion in the diet (DM basis) to 0% and replaced by a 1:1 ratio of DRC:HMC in the diet. Corn silage was decreased from 30 to 15% (DM basis) in the final step. The first period was 5 d, and the diet was 15% corn with 30% each of alfalfa and corn silage. After 5 d, alfalfa was dropped 10% in exchange for corn, and after another period of 7 d, alfalfa was dropped to 10% in exchange for corn. Following another 7 d period, alfalfa was reduced to 0% in the diet, and after 5 d, corn silage was reduced to 15% and corn grain in the diet was 60%. Wet distillers grains plus solubles and supplement were included in each diet at 21% and 5% (DM basis), respectively. Steers fed the 75% treatment were adapted to the 15% on d 70 using the same adaptation steps over 24 days. Steers were adapted to the 45% corn silage treatment over a period of 10 d, the diet fed for the first 5 d consisted of 15% alfalfa which was reduced to 7.5% alfalfa in the second period of 5 d. Alfalfa was exchanged for HMC and DRC on a 1:1 basis. Steers fed the 75% corn silage diet were not adapted for any period of time before receiving their diet. All steers were fed a supplement formulated to provide 33 g/t of DM

monensin (Rumensin®; Elanco Animal Health, Indianapolis, IN) and 9.7 g/t of tylosin (Tylan®; Elanco Animal Health). Feedbunks were assessed daily at 0530 for a small amount of feed left in the bunk each morning. Feed refusals were weighed back when necessary and subsamples were dried for 48 hrs in a 60°C forced-air oven to determine DM refused (AOAC, 1999, method 4.1.03). Ingredient samples were taken weekly and analyzed for DM with the method mentioned above.

Steers were reimplanted with 100 mg trenbolone acetate, 14 mg estradiol benzoate, (Synovex® Choice, Zoetis Inc.) on d 70 and ultrasounded to determine backfat thickness. Backfat thickness measurements were recorded to determine backfat rate of deposition so all cattle could be slaughtered at similar backfat thickness. Harvest date was determined using ultrasound backfat thickness deposition rates taken on d 70 and d 125-126. Backfat thickness on d 125-126 was observed over a period of two days to ensure cattle were not out of pens too long during the heat of the summer. The first three replications were ultrasounded the first day, and the final three replications were measured on d 2. Cattle were slaughtered at a commercial abattoir (Greater Omaha Pack, Omaha, NE) when projected to reach a backfat thickness of 1.40 cm based on determined backfat deposition rates. Steers fed 15% corn silage in their diet were slaughtered at 153 DOF, and steers in the 45% and 75/15% treatments were slaughtered after 181 DOF. On the day of shipping, steers were fed 50% of the previous day's DM offer and live weights were recorded using a platform scale at 1500 h prior to being loaded for shipping. A 4% pencil shrink was applied to this BW for final live BW and to be used in the dressing percentage calculation (HCW / shrunk live final BW).

Hot carcass weight and liver abscess scores were determined on the day of slaughter. Liver abscess scores were scored using the Brink et al. (1990) methods, with 0 for no abscesses and A-, A, and A+ scores for severely abscessed livers. These scores were combined to determine the proportion of liver abscesses per pen. The carcass-adjusted final BW was determined using a 63% common dressing percentage from the HCW determined at slaughter. This value was used to determine ADG and G:F for the experiment. Final backfat thickness measurements were taken at the abattoir 48 hours after slaughter. Marbling score, 12^{th} rib fat thickness, and LM area were measured after a 48-h chill. Yield grade was calculated using the USDA (2016) method, assuming a 2.5% KPH value using the formula YG = (2.50 + (0.0017 × HCW, kg) + (0.2 × KPH, %) + (6.35 × 12th rib fat, cm) - (2.06 × LM area, cm^2). The feeding value of corn silage was calculated relative to the corn grain blend in the diet, based on the DM inclusion level of silage in the diet using the following equation: [1 – ({G:F of higher inclusion diet – G:F of lower inclusion diet}/ G:F of lower inclusion diet) / amount of inclusion level substitution] × 100 + 100 (Burken et al., 2017a). Dietary net energy values were calculated by using pen data in the Galyean (2009) Net Energy calculator based on NRC (1996) equations. The calculated energy value used initial and final BW of each block and DMI and ADG of individual pens with a target endpoint of Choice.

Economics were evaluated using a corn silage pricing application (Edwards and Hart, 2018) from Iowa State University accounting for silage shrink (15% DM basis), manure value of spreading the manure 1 year in 4 to replace the silage removal of phosphorus, incurring one fourth the credit for manure and one fourth hauling expenses, and the opportunity cost of corn grain and stover removal. Brown midrib and CON

silages were priced at the same value as one another for ease of analysis. The average yield of corn silage was calculated given the average yield of typical corn fields in the area with a 6% yield drag to account for the fact corn silage is harvested earlier in maturity than corn grain. Manure value was calculated using BFNMP$ system (Bremer et al., 2008; Watson et al., 2012) for cattle fed a 45% silage-based diet with 21% WDGS. Initial purchase price was calculated using the average initial purchase weight of a pen multiplied by the average price/0.454 kg to get a net return of $0/head for cattle on the 15% silage treatment. Sale price was based on market averages for September of 2017. Cattle interest charges were 7.5% over their feeding period (DOF/365) with a $200 deposit on cattle. Corn was priced on average market prices for September 2017, with an additional $2.17/0.91 t DM for processing costs. Feed interest costs were 7.5%. Supplement including monensin and tylosin was $300/0.91 t (DM basis) with 1% pencil shrink applied, WDGS was 90% the price of corn (DM basis) with a 5% pencil shrink applied. Medicinal and processing charges were $20/head and yardage was charged at $0.50/hd/day.

Assumptions made on the corn silage was that the expected corn yield would be approximately 14.8 t/ha (220 bu/acre), at 15.5% moisture. Grain as a percent of total dry matter was assumed to be 50% of the total dry matter of the silage, as determined by Lauer and Undersander (2004) and Burken et al. (2017a), when corn silage is harvested at approximately 50-75% milkline. The estimated dry matter of the silage was 35%, and yield was estimated as 63 t/ha (28 tons/ac) of corn silage would be produced. Current corn stover opportunity cost was $50/0.91 t, assuming 50% of the corn stover was removed post grain harvest. It was estimated that phosphate and potash costs to replace

nutrients removed in the cornstalks (forage portion of corn silage) removed would be approximately $0.34 and $0.25/0.454 kg, respectively. Custom harvest costs were estimated to be $108.94/ha ($269.20/ac) and hauling and storing costs $3.28/0.91 t. Harvest of grain and stover was considered $15.47 and $13.82/ha ($38.22 and $34.14/acre) to account for opportunity costs of combining, and $0.10 and $1.00/25.40 kg for hauling and storing. Drying for corn grain was estimated at $0.04/25.04 kg. These values all accounted for the opportunity cost of producing grain and stover in comparison to the value of the corn silage, which was then used in economic calculations. Shrink of the silage was considered 15%. In the sensitivity analysis evaluating differing prices of cattle and corn to determine profitability, corn price affected corn silage price, so as corn price increased, corn silage price also increased.

Growth performance and carcass characteristics were analyzed using the Mixed procedure of SAS (SAS Inst, Inc., Cary, N.C.) Pen was considered the experimental unit, with the body weight block considered a fixed effect. The treatment design was a 2 × 3 factorial, so interactions between corn silage hybrid and corn silage inclusion level were analyzed and reported. If no significant interactions were reported, the main effects of either corn silage hybrid or corn silage level are presented. Arithmetic means are presented due to block effect skewing means away from true averages of the trial because there was one replication in the heavy block, and five replications in the light block. Treatment differences were considered significant when $P \leq 0.05$. A tendency was declared when $P \leq 0.10$ and $P > 0.05$.

Results and Discussion

Corn silage inclusion

There were no interactions between corn hybrid and corn silage inclusion for growth performance or carcass characteristics measured ($P \geq 0.08$; Appendix 3.1). Cattle fed the 75/15% treatment consumed 0.28 kg/d less ($P = 0.01$; Table 3.3) feed daily than either 15% or 45% treatment, which were not different from one another ($P = 0.86$; data not shown). Average daily gain was greatest ($P < 0.01$) for cattle consuming the 15% treatment as expected, gaining 0.09 kg/d more than 45% and 0.13 kg/d more than the 75/15% treatment, due primarily because of the higher grain and energy content of the 15% treatment. Cattle consuming 45 and 75/15% treatments were on feed 28 more days than cattle consuming 15%. There was slight tendency ($P = 0.09$) for cattle fed 45% to gain 0.04 kg/d more than 75/15% treatment. It was expected cattle consuming a lower energy diet with 45% corn silage or an average of 45% inclusion throughout the trial (75/15%) would have lower ADG and feed efficiency as compared to 15%. In a trial by Brennan et al. (1987) evaluating the replacement of corn grain with corn silage as an energy source and fed ad libitum, cattle had reduced DMI as corn silage increased in the diet, likely due to a gut fill response. As expected, cattle consuming 15% silage had greater G:F than both the 45% and 75/15% treatment, by approximately 4.7%. This agrees with research by Burken et al. (2017a) who observed increasing corn silage from 15 to 45% in the diet with 40% MDGS resulted in a reduction in feed efficiency by approximately 5.0%. Corn silage research prior to the 2000s evaluated corn silage in finishing diets without current byproducts of the dry and wet milling industries such as distillers grains plus solubles (DGS) or wet corn gluten feed (WCGF). More recent research evaluating increasing corn silage in the diet with the inclusion of modified distillers grains plus solubles (MDGS) as a protein and energy source suggests cattle are

not being as hindered by increasing the corn silage in the diet as previously observed. According to Goodrich et al. (1974), increasing corn silage in the diet from 10 to 40% (DM basis) resulted in a reduction in feed efficiency from 0.165 to 0.146, which is approximately 11.5%. As diets and new ingredients have been evaluated, corn silage has become less inhibitory to growth performance than it once was. One of the objectives of this study was to create similar consumption of silage over the feeding period between the 45% and 75/15% treatment. Steers fed the 75/15% treatment consumed approximately 147 kg/hd ($P < 0.01$, Table 3.3) more silage throughout the trial than the 45% treatment cattle. Over a period of 181 d, this is approximately 0.8 kg/d more per head.

In a study by Burken et al. (2017) evaluating increasing corn silage from 15 to 45% and increasing MDGS in the diet from 20 to 40%, when MDGS was included in the diet at 40%, no differences in gain were observed as silage was increased from 15 to 45%. At 20% inclusion, ADG was decreased 13% as silage was increased in the diet. Feed efficiency was reduced by approximately 4.7% as corn silage was increased in the diet from 15 to 45%. As compared to previous work evaluating high corn silage diets (Erickson, 2001), corn silage has a greater feeding value in finishing diets that contained MDGS when corn silage was increased 30% in the diet, increasing from 56% the value of corn in 20% MDGS diets to 88% in 40% MDGS diets (Burken et al., 2017a; Experiment 1). The feeding value of corn silage in 45% corn silage diets in this experiment was 84%, which was similar to the 84% value for corn silage reported by Burken et al. (2017a; Experiment 2). In previous corn silage inclusion work by DiCostanzo et al. (1997), corn silage had a feeding value of 61%, 61%, and 51% in relation to corn grain in the diet, for

replacements of 12%, 24%, and 36%, respectively in diets without DGS. The inclusion of DGS in the diet appears to provide a benefit for feeding value of corn silage.

There can be a negative associative effect between starch and fiber, as starch concentration increases in the diet, fiber digestibility can be reduced. Associative effects are described as the predicted digestibility of a mixed diet being different than the direct measurement of the separate individual ingredients (Moe, 1981). Negative associative effects have been observed in diets that have a mixture of both forage and concentrate and fed at high DMI (Merchen and Bourquin, 1994). There are several reasons why negative associative effects occur in diet digestibility when concentrates and forages are fed together. Typically, as a diet becomes more fermentable through added concentrate, fiber digestibility is hindered. This occurs both through an increase in passage rate through the rumen, reducing time available for rumen microbes to attach and degrade fiber particles, as well as a reduction in fibrolytic bacteria activity as amylolytic bacteria create a lower ruminal pH and less favorable environment for fibrolytic bacteria. As fermentability of the diet in the rumen increases, fiber digestibility is hindered (Owens et al., 1986). Increasing passage rate through the rumen reduces fiber digestion and potentially hinders starch digestion in the small intestine through faster passage rate, limiting enzymatic activity of amylase released from the pancreas (Joanning et al., 1981). Research by Joanning et al. (1981) evaluated negative associative effects between concentrate and fiber feeding a diet of 90% corn grain, 90% corn silage or a 30:60 blend of corn silage and corn grain. When comparing linearly, the expected DM digestibility of the blend of corn grain and silage was approximately 11.3% lower than what was predicted (Joanning et al., 1981). With the inclusion of readily digestible fiber source in

the diet such as distillers grains, this negative effect on fiber digestibility may be less. The use of DGS is complementary to high fiber diets that include corn silage because DGS have low starch and high protein values, allowing for better fiber digestion in the rumen (Loy et al., 2007). Specifically, in lighter weight cattle, MP requirements are high, and DGS can help meet those needs because of its high protein content (33%) and high RUP (63%; Castillo-Lopez et al., 2013). In early corn silage inclusion research, DDGS were unavailable, but their value in high forage diets is well documented (Loy et al., 2007; Ahern et al., 2016) and confirmed in our current study. Recent research by Ahern et al. (2016) evaluating the inclusion of DGS in high-forage diets observed increasing WDGS and DDGS compared to corn-based diets resulted in linear improvements in ADG and feed efficiency ($P < 0.01$). In grass-hay and sorghum silage-based diets, a pooled analysis comparing the use of WDGS to DRC resulted in similar ADG when WDGS was 30% of the diet, while it required 55% DRC to have similar ADG.

Carcass characteristics of cattle were affected by treatment, most specifically those cattle fed the higher silage diets were fed for 28 d longer than 15% treatment, resulting in greater final carcass adjusted body weight, final hot carcass weight, and lower dressing percentage. Cattle fed the 15% treatment weighed 36 kg less ($P < 0.01$; Table 3.3) than cattle fed 45% and 27 kg less than 75/15% treatment cattle despite greater ADG, due to the fact they were fed 153 d rather than 181. There was a tendency ($P = 0.06$) for cattle fed 45% to weigh more than 75/15% treatment cattle. Hot carcass weight followed a similar trend, with cattle fed 181 d on the 45 and 75/15% treatments weighing more ($P < 0.01$) than cattle fed 15% treatment for 153 d. There was a tendency ($P = 0.06$) for cattle consuming 45% silage to have greater HCW than cattle fed 75/15%

treatment. Typically, in other studies evaluating increasing corn silage in the diet, cattle fed 45% have had smaller final carcass adjusted body weights as compared to 15% (Burken et al., 2017a). However, this was because cattle were fed to a common day on feed rather than common endpoint, suggesting even in previous work, cattle fed higher levels of silage could have been taken to a larger more mature carcass end weight. In a trial by Gill et al. (1976) cattle fed a 75% corn silage diet were fed for 28 d longer than cattle fed either 14% or 30% corn silage inclusion in the diet. Feeding 75% corn silage in the diet resulted in a 14% reduction in ADG as compared to either 14% or 30% inclusion (Gill et al., 1976), but were fed to similar final body weights. Feeding cattle to a common endpoint in the current study allowed comparisons to be made based on fat endpoint rather than common DOF. Using a fat endpoint provides more realistic values when comparing cattle economically, as extra pounds gained and larger frame size of 45% average treatments offset extra costs of extra yardage and feed accumulated in 28 extra DOF. As noted previously, increasing corn silage in the diet requires extra days on feed to get cattle to a similar endpoint. In Gill et al. (1976), it took 28 extra days to get to a common final body weight. Those diets had greater inclusion of corn silage than the current study and less byproducts available to provide the cattle with the RUP needed, especially during the early growth phase, when protein requirements were high.

Dressing percentage was significantly ($P < 0.01$; Table 3.3) lower for both the 45 and 75/15% treatments as compared to the 15% treatment. This is consistent with previous research, where cattle consuming greater levels of forage experience more gut fill, resulting in lower dressing percentages as compared to cattle consuming low fiber diets. In a study by Peterson et al. (1973), dressing percentage was reduced as corn silage

was increased in the diet from 0 to 100% of the diet (DM basis). Even with differences in dressing percentage, final shrunk body weights followed a similar trend to the final carcass adjusted body weights, as those cattle consuming 15% weighed less ($P < 0.01$) than both 45% and 75/15% because of fewer days on feed.

Carcass characteristics differed between treatments, as cattle were brought to a similar backfat thickness rather than days on feed. The objective was to create similar carcass fatness across treatments in this trial. Although similar backfat thickness of 1.4 cm was a priority in this trial, there were statistical differences between corn level treatments. Cattle on the 15% treatment were 1.3 cm, 45% averaged 1.5 cm, and 75/15% were 1.4 cm. Cattle on the 45% had the greatest ($P < 0.01$) backfat thickness, with 75/15% being intermediate, and 15% being least. The cattle on the 15% treatment had slowed backfat deposition in the final 25 DOF, resulting in average backfat of 1.3 cm. This may be due to an extremely hot period of the summer during which cattle had reduced intake and likely growth performance as they dealt with the adverse weather conditions. Once the 15% cattle were slaughtered, weather became more favorable, likely allowing those fed longer to resume backfat deposition rates that were predicted. Despite differences in backfat thickness, marbling score was not significantly affected by treatment ($P = 0.33$); cattle fed 28 d longer were larger and had similar body compositions to those cattle fed higher energy diets for a shorter period. Cattle consuming the 75/15% treatment had the biggest ribeye area at 88.0 cm^2 as compared to 84.7 cm^2 for 15% treatment. The 45% treatment tended ($P = 0.08$) to have a greater ribeye area than 15% at 87.2 cm^2. The carcass results suggest a similar response to growth performance results. Feeding cattle similar levels of silage through the entirety of

the feeding period whether at 45% for the entire period or at 75/15% through the feeding period results in very similar carcass composition. When comparing 15% to 45% silage inclusion, carcasses were lighter due to less days and similar marbling, but less LM area. These data suggest you can grow cattle bigger with elevated corn silage in the diet.

The net energy available for maintenance, calculated with the Galyean (2009) Net Energy calculator based on the NRC (1996) was greatest ($P < 0.01$) for the 15% treatment, with no difference between the 45 and 75/15% treatments ($P = 0.42$). The net energy available for gain, followed this same statistical trend, as the cattle consuming 15% silage had more energy available for growth as compared to both the 45 and 75/15% treatments ($P < 0.01$). This result was also observed in a study by Brennan et al. (1987) as cattle fed diets that were 100% concentrate-based consumed more energy as compared to cattle fed diets with corn silage replacing the concentrate in the diet.

Corn silage hybrid

Main effects of corn silage hybrid are found in Table 3.4. Unlike observed in other experiments, the use of brown midrib corn silage did not appear to provide a growth performance benefit as compared to an isogenic control corn silage. There were no differences in corn silage hybrid on ADG ($P = 0.17$; Table 3.4), with both treatments gaining approximately 1.75 kg/d. Cattle fed brown midrib did consume more daily, eating 10.8 kg/d as compared to 10.5 kg/d for cattle on the CON treatment ($P = 0.01$). These differences in DMI did not result in a statistical difference in G:F ($P = 0.21$). In a study by Tjardes et al. (2000), including brown midrib corn silage in the diet at 86% (DM basis), increased NDF and ADF digestibility were increased as compared to an isogenic control, allowing for increased passage rate and greater DMI. As in the current trial, this

resulted in an increase in DMI with no change in ADG (P = 0.23). Increasing NDF digestibility allows for increased DMI but increasing DMI can also reduce digestibility due to increased passage rate (Oba and Allen, 1999). This may have been the cause for no difference in ADG as observed in the current trial.

Recent research evaluating brown midrib corn silage in growing diets with 80% silage, using *bm3* increased ADG and DMI of growing steers with no effect on feed efficiency (Hilscher, 2018), which was not observed in the current trial. In previous research by Ovinge et al. (2018), the use of brown midrib hybrids in the diet at 40% inclusion (DM basis) resulted in increases (P < 0.01) in ADG from 1.87 for an isogenic control to 2.03 and 2.06 kg/d for brown midrib and brown midrib with a floury endosperm, respectively. Additionally, feed efficiency of cattle consuming brown midrib corn silage increased (P < 0.01) 4.9% compared to the isogenic control. The improvements in ADG and G:F were attributed to improvements in NDF digestibility, increasing from 45.5 to 54.4 and 58.2% for brown midrib and brown midrib with a floury endosperm respectively.

Carcass characteristics followed a similar trend to growth performance parameters, as carcass characteristics did not differ between cattle consuming either brown midrib or control corn silage had similar final carcasses. Carcass adjusted final body weight did not differ (P = 0.63) between corn silage hybrids, as was HCW (P = 0.15). Final dressing percentage did not differ between groups (P = 0.23). Cattle fed *bm3* tended to have greater backfat thickness (P = 0.06), but this did not translate to any differences in marbling score (P = 0.34). Ribeye area was similar (P = 0.39) between cattle consuming brown midrib corn silage hybrids.

The lack of response to the *bm3* as compared to CON is difficult to explain, given the response observed in previous experiments. In this experiment, silages were stored for a significantly longer time than they had been in previous work from our laboratory (Ovinge et. al., 2018) that were fed after 21 days of fermentation. As silages spend more time fermenting, NDF digestibility increases 1.2 percentage units per month for approximately 6 months (Hallada et al., 2008). However, when evaluating length of ensiling and its' effect on corn hybrids, Der Bedrosian et al. (2012) observed brown midrib silage always had greater NDF digestibility than a standard isogenic control for all lengths of ensiling (up to 360 d). When harvested at greater DM, NDF digestibility decreased by approximately 5 percentage units for brown midrib hybrids. Dry matter of the corn silages was quite low during the current study, which suggests corn silage may have been harvested slightly immature, and paired with the long ensiling time, may have played a role in the lack of performance response between the two hybrids.

Corn Silage Economics

Based upon the economic analysis and the differences in cattle final body weights, feeding either 45 or 75/15% was more ($P < 0.01$; Table 3.3) profitable than feeding 15% silage in the diet. A sensitivity analysis based on the changing price of corn and initial purchase price of the cattle is in Table 3.5 and presents how returns differ as input costs change. Based on the current trial, feeding 45% silage was the most profitable as those cattle made $43.41/hd, cattle fed 75/15% profited $27.06/hd while those fed 15% had a net return of $0.03/hd.

In the sensitivity analysis (Table 3.5), feeding higher levels of corn silage through the feeding period was more economical as corn prices become more expensive. Current

corn prices at approximately $3.25/24.05 kg appear to provide a breakpoint at which corn silage may not be economical even when considering the opportunity of applying the manure back to the land and creating a system approach for cattle feeders. As the price of corn changes, the price of corn silage relative to it changes as well. Using the corn pricing spreadsheet developed, the rule of thumb that corn silage should be priced at approximately 10 times the price of corn grain may not be accurate. As the price of corn grain increases from $3.05/24.05 kg, the price of corn silage is approximately 12.8 times the price of corn, this number is decreased as the price of corn is increased towards $4.05/24.05 kg, when the price of corn silage is only approximately 11.6 times the price of corn grain. The price of corn silage as the price of corn grain increases considers the opportunity cost of giving up grain and stover, and as the price of corn grain increases, there is less incentive for farmer feeders to produce corn silage as a feed product because the economic benefit of selling grain outweighs the cost of grain and the cost of storing and harvesting corn silage, except that it provides an economic incentive when selling that feed back to the cattle. The economics paired with these data suggest that even at lower corn prices, corn silage may be an economical alternative to grow cattle longer and larger, especially when the economics of manure applied back to the land and the opportunity cost of corn grain and stover is considered.

In the sensitivity analysis (Table 3.5), the sale price of $1.18/0.454 kg and a corn bushel price of $3.05/24.05 kg resulted in a $40.43/hd advantage for 45 over the 15% treatment, and a $25.46/hd advantage for 75/15% over the 15%. As the price of cattle increases to $1.58/0.454 kg, the profitability of the 45% treatment over the 15% increases to $71.43/hd, and the 75/15% treatment advantage increases to $49.21/hd. Across corn

prices and sale price treatments, profitability advantage of 45% over the 15% treatment is reduced approximately $0.10/hd as the corn price is increased from $3.05 to $4.05/24.05 kg, and is relatively stable across all treatments.

Corn silage hybrids were priced like one another in the economic analysis and were treated similar in terms of yield. There was only one field of each hybrid, and, as a result, yields were not measured or considered in the analysis, because it would not be representative of treatments. Due to a lack of differences in growth performance and carcass characteristics and DOF between corn silage hybrids, economic profitability remained similar between the two treatments (P = 0.72; Table 3.4). In earlier research of *bm3* hybrids, Ballard et al. (2001) observed *bm3* had lower yields and smaller ears of corn as compared to isogenic controls. This could potentially affect costs of the corn silage and increase cost of the diet for *bm3* as compared to the isogenic control. However, more recent research by Grant et al. (2017) suggests *bm3* hybrids are no longer at a yield disadvantage to isogenic controls but input costs for the seed may still be higher. These factors need to be considered if producers are going to economically compare *bm3* to CON in feedlot diets.

Conclusion

Feeding 45% silage throughout the entirety of the feeding period resulted in similar growth performance and carcass characteristics as cattle fed 75% silage for 70d and 15% for the remaining 113d. When evaluated economically, feeding 45% silage resulted in similar economic profitability at similar corn and live cattle prices as compared to feeding cattle 75% for 70d and 15% for the remainder of the feeding period. As compared to 15% silage inclusion in the diet, cattle fed greater inclusions of silage

had poorer feed efficiency and ADG, but at a common backfat thickness, were larger and more profitable when fed 45% silage. Feeding 45% corn silage diets resulted in reductions in feed efficiency of approximately 4.7%, suggesting including DGS in the diet can meet nutrient requirements of cattle fed high silage diets. This trial suggests feeding a greater inclusion of silage in the diet for the entirety of the feeding period results in similar performance to producers feeding a backgrounding diet followed by a finishing diet in the feedlot, while having the potential to be more profitable, especially as the price of corn is increased. Feeding corn silage with the *bm3* trait did not result in significant differences in performance in this study across the three inclusions of corn silage.

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Table 3.1. Diet composition (DM Basis) for beef cattle fed two corn silage hybrids at three inclusion levels in feedlot diets

Item[1]	15		45		75/15	
	bm3	Control	*bm3*	Control	*bm3*	Control
CON Corn Silage		15.0		45.0		75.0
bm3 Corn Silage	15.0		45.0		75.0	
Dry-rolled corn	30.0	30.0	15.0	15.0	-	-
High Moisture Corn	30.0	30.0	15.0	15.0	-	-
WDGS[2]	21.0	21.0	21.0	21.0	21.0	21.0
Supplement[3]	4.0	4.0	4.0	4.0	4.0	4.0
Fine Ground Corn	1.1000	1.1000	1.1000	1.1000	1.1000	1.1000
Limestone	1.6400	1.6400	1.6400	1.6400	1.6400	1.6400
Salt	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000
Tallow	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
Trace Mineral Premix[4]	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500
Vitamin ADE Premix[5]	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150
Rumensin-90[6]	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165
Tylan-40[7]	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080

[1] Treatments were control (CON; hybrid TMF2H708, Mycogen® Seeds), and a brown midrib hybrid (*bm3*; hybrid- F27F627; Mycogen® Seeds), cattle fed 75/15 treatment were fed 75% corn silage diet for the initial 70 days on feed, followed by 15% for the remainder of the feeding period and dietary inclusion throughout the entire feeding period (15, 45% of diet DM)
[2]WDGS = Wet Distillers Grains Plus Solubles
[3] Supplement formulated to be fed at 5% of diet DM
[4]Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.29% Mg, 0.2% I, 0.05% Co.
[5]Premix contained 30, 000 IU vitamin A; 6, 000 IU Vitamin D; 7.5 IU vitamin E per gram.
[6]Premix contained 198 g/kg monensin
[7]Premix contained 88 g/kg tylosin

Table 3.2. Nutrient and fermentation analysis of silage hybrids (DM basis)[1]

Item	*bm3*	C.V.	Control	C.V.
DM, %[2]	33.2	4.8	30.7	1.8
CP, %	7.9	0.9	8.7	4.1
NDF, %	33.3	-	38.4	-
ADF, %	22.2	-	24.6	-
Starch, %	38.3	-	37.9	-
pH	4.3	1.3	4.2	0.02
Lactic acid, %	2.7	4.7	2.9	24.8
Acetic acid, %	3.4	6.8	4.3	24.0
Propionic acid, %	0.5	50.4	0.7	22.6
Butyric acid, %	0.1	0.0	0.1	0.0
Total Acids, %	6.9	10.4	6.4	19.2

[1] Treatments were control (CON; hybrid-TMF2H707, a brown midrib hybrid (*bm3*; hybrid- F27F627; Mycogen® Seeds),

[2]DM was calculated using weekly samples and oven dried for 48 h at 60°C.

Note: Fermentation analysis was conducted on bi-monthly composite silage samples and analyzed at Dairyland Labs (St. Cloud, MN).

Table 3.3. Main effect of corn silage inclusion on steer feedlot performance and carcass characteristics

	Treatment[1]			SEM	*P*–Value[2]
	15	45	75/15		
pens, n	12	12	12		
DOF	153	181	181		
Performance					
Initial BW, kg	317	318	317	0.5	0.57
Final BW, kg[3]	596[a]	632[b]	623[b]	3.3	<0.01
DMI, kg/d	10.7[a]	10.7[a]	10.4[b]	0.080	<0.01
Total Silage Intake, kg/hd	208[a]	872[c]	725[b]	6.84	<0.01
ADG, kg[3]	1.82[a]	1.73[b]	1.69[b]	0.019	<0.01
Gain:Feed[3]	0.170[a]	0.162[b]	0.162[b]	0.0013	<0.01
FSBW, kg[4]	599[a]	646[b]	636[b]	3.1	<0.01
NEm, Mcal/kg[5]	1.97[a]	1.91[b]	1.92[b]	0.009	<0.01
NEg, Mcal/kg[5]	1.32[a]	1.27[b]	1.28[b]	0.008	<0.01
Returns, $/hd	0.03[a]	43.41[b]	27.06[b]	7.18	<0.01
Carcass Characteristics					
HCW, kg	376[a]	398[b]	393[b]	2.1	<0.01
Dressing Percentage	62.73[a]	61.65[b]	61.75[b]	0.2	<0.01
LM Area, cm[2]	84.71[a]	87.16[ab]	88.00[b]	1.055	0.05
Marbling Score[6]	460.4	480.4	473.0	10.5	0.33
Backfat Thickness, cm	1.34[a]	1.52[b]	1.41[ab]	0.057	0.05
Yield Grade[7]	3.17	3.41	3.21	0.093	0.11

[a,b]Means with superscripts differ ($P < 0.05$)

[1]Treatments were 75% corn silage diet for the initial 70 days on feed, followed by 15% for the remainder of the feeding period (75/15) and dietary inclusion throughout the entire feeding period (15, 45% of diet DM)

[2] *P*-Value for the main effect of corn silage inclusion level

[3]Calculated from hot carcass weight, adjusted to a common 63% dressing percentage

[4]Final shrunk body weight calculated from pen weights prior to transport to slaughter plant, with 4% pencil shrink applied

[5]NEm and NEg calculated using methodology of NRC (1996) using a tool developed by Galyean (2009).

[6]Marbling Score 400 = Small[00], 500 = Modest[00]

[7]Calculated YG (yield grade) = [2.5 + (6.35 × fat thickness, cm) + (0.2 × 2.5% KPH) + (0.0017 × HCW, kg) – (2.06 × LM area, cm[2])]; (USDA, 2016).

Table 3.4. Main effect of corn silage hybrid on steer feedlot performance and carcass characteristics

	Treatment[1]		SEM	*P*-Value[2]
	bm3	CON		
Performance				
pens, n	18	18		
Initial BW, kg	318	317	0.4	0.84
Final BW, kg[3]	620	615	2.9	0.63
DMI, kg/day	10.8	10.5	0.068	0.01
Total Silage Intake, kg/hd	636	616	6.84	0.17
ADG, kg[3]	1.76	1.74	0.016	0.17
Gain:Feed[3]	0.164	0.166	0.0011	0.21
FSBW, kg[4]	628	626	2.7	0.59
NEm, Mcal/kg[5]	1.92	1.95	0.008	0.02
NEg, Mcal/kg[5]	1.28	1.29	0.007	0.02
Returns, $/hd	25.64	21.36	6.16	0.57
Carcass Characteristics				
HCW, kg	390	387	1.8	0.15
Dressing Percentage	62.19	61.89	0.206	0.23
LM Area, cm^2	86.91	87.10	0.906	0.39
Marbling Score[6]	477	466	9.0	0.34
Backfat Thickness, cm	1.47	1.37	0.049	0.06
Yield Grade[7]	3.17	3.36	0.080	0.06

[1]Treatments were control (CON; hybrid TMF2H708; Mycogen® Seeds) and a brown midrib hybrid (*bm3*; hybrid-F27F637; Mycogen® Seeds),

[2] *P*-Value for the main effect of corn silage hybrid

[3]Calculated from hot carcass weight, adjusted to a common 63% dressing percentage

[4]Final shrunk body weight calculated from pen weights prior to transport to slaughter plant, with 4% pencil shrink applied

[5]NEm and NEg calculated using methodology of NRC (1996) using a tool developed by Galyean (2009).

[6]Marbling Score 400 = Small^{00}, 500 = Modest^{00}

[7]Calculated YG (yield grade) = [2.5 + (6.35 × fat thickness, cm) + (0.2 × 2.5% KPH) + (0.0017 × HCW, kg) – (2.06 × LM area, cm^2)]; (USDA, 2016).

Table 3.5. Sensitivity analysis of price of corn ($/24.05 kg) and sale price of cattle ($/0.454 kg) and its effect on profitability with increasing corn silage inclusion in the diet

	Sale Price, $/0.454 kg	Corn Price, $/24.05 kg					
Treatment[1]	0.7808	3.05	3.25	3.45	3.65	3.85	4.05
15		(509.32)	(522.21)	(535.11)	(548.00)	(560.89)	(573.79)
45		(499.89)	(512.87)	(525.87)	(538.84)	(551.82)	(564.82)
75/15		(507.61)	(520.57)	(533.55)	(546.50)	(559.46)	(572.44)
	0.9808						
15		(246.30)	(259.19)	(272.09)	(284.98)	(297.87)	(310.77)
45		(221.38)	(234.35)	(247.35)	(260.33)	(273.30)	(286.31)
75/15		(232.72)	(245.68)	(258.66)	(271.61)	(284.57)	(297.55)
	1.1808						
15		16.71	3.82	(9.08)	(21.97)	(34.86)	(47.76)
45		57.14	44.16	31.16	18.19	5.21	(7.79)
75/15		42.17	29.21	16.23	3.28	(9.68)	(22.66)
	1.3808						
15		279.73	266.84	253.94	241.05	228.16	215.26
45		335.65	322.68	309.68	296.70	283.73	270.72
75/15		317.06	304.11	291.12	278.17	265.21	252.23
	1.5808						
15		542.74	529.85	516.96	504.06	491.17	478.27
45		614.17	601.19	588.19	575.22	562.24	549.24
75/15		591.95	579.00	566.02	553.06	540.10	527.12

[1]Differences in dietary treatments were corn silage inclusion (15, 45, 75/15% of total diet DM)

Appendix 3.1. Growth performance and carcass characteristics of steers fed brown midrib or isogenic corn silage at increasing inclusions in the diet

	Treatment[1]						SEM	*P*-Value[2]		
	bm3			CON				Corn* Level[3]	Corn Silage	Level
	15	45	75	15	45	75				
Performance										
Initial BW, kg	318	318	317	317	318	317	0.7	0.84	0.47	0.57
Final BW, kg[3]	601[a]	635[b]	624[b]	592[a]	629[b]	623[b]	4.4	0.63	0.16	<0.01
DMI, kg/day	10.87[a]	10.85[a]	10.58[b]	10.59[a]	10.57[a]	10.31[b]	0.11	1.00	0.01	0.01
ADG, kg[3]	1.85[a]	1.75[b]	1.69[b]	1.80[a]	1.72[b]	1.69[b]	0.03	0.52	0.17	0.01
Gain:Feed[3]	0.170[a]	0.162[b]	0.160[b]	0.170[a]	0.162[b]	0.164[b]	0.0018	0.40	0.21	<0.01
FSBW, kg[4]	603[a]	643[c]	638[b]	595[a]	648[c]	634[b]	4.1	0.26	0.59	<0.01
NEm, Mcal/kg	1.96	1.90	1.91	1.97	1.93	1.94	0.012	0.48	0.02	<0.01
NEg, Mcal/kg	1.31	1.26	1.26	1.32	1.28	1.30	0.011	0.56	0.02	<0.01
Total Silage Intake, kg	282[a]	884[c]	742[b]	278[a]	861[c]	708[b]	7.89	0.14	<0.01	<0.01
Returns, $/hd	5.96[a]	46.85[b]	22.18[b]	-5.98[a]	37.87[b]	30.34[b]	9.6	0.57	0.49	<0.01
Carcass Characteristics										
HCW, kg	378[a]	400[b]	393[b]	373[a]	396[b]	393[b]	2.8	0.64	0.15	<0.01
Dressing Percentage	62.77[a]	62.20[b]	61.62[b]	62.70[a]	61.10[b]	61.88[b]	0.324	0.08	0.23	<0.01
LM Area, cm[2]	85.07[a]	87.17[b]	86.32[b]	84.36[a]	87.18[b]	89.70[b]	1.41	0.29	0.39	0.05
Marbling Score[5]	451	490	489	470	471	457	14.1	0.14	0.34	0.33
Backfat Thickness, cm	1.40[a]	1.52[b]	1.53[b]	1.29[a]	1.52[b]	1.28[b]	0.076	0.23	0.06	0.05
Yield Grade[6]	3.223	3.43	3.42	3.11	3.39	3.01	0.125	0.27	0.06	0.11
Liver Abscess, %[7]	6.3	0.0	2.8	6.3	4.2	4.2	-	-	-	-

[a,b]Means with superscripts differ ($P < 0.05$)

[1]Treatments were control (CON; hybrid TMF2H708; Mycogen® Seeds) and a brown midrib hybrid (*bm3*; hybrid-F27F637; Mycogen® Seeds), and cattle were fed 75% corn silage diet for the initial 70 days on feed, followed by 15% for the remainder of the feeding period (75/15) and dietary inclusion throughout the entire feeding period (15, 45% of diet DM)

[2]P-Values were calculated for interaction of corn * level = corn hybrid * silage inclusion level, corn silage = corn silage hybrid, and level = corn silage inclusion

[3]Calculated from hot carcass weight, adjusted to a common 63% dressing percentage

[4]Final shrunk body weight calculated from pen weights prior to transport to slaughter plant, with 4% pencil shrink applied

[5]Marbling Score 400 = Small^{00}, 500 = Modest^{00}

[6]Calculated YG (yield grade) = [2.5 + (6.35 × fat thickness, cm) + (0.2 × 2.5% KPH) + (0.0017 × HCW, kg) – (2.06 × LM area, cm^2)]; (USDA, 2016).

[7]Liver Abscess data did not converge

CHAPTER IV. Effects of high protein DDGS in SFC or DRC-based diets on finishing performance of steers and metabolism of heifers

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Abstract

The effect of high protein dried distillers grains plus solubles in steam flaked corn (SFC) or dry rolled corn (DRC)-based diets on finishing performance and ruminal metabolism was evaluated. In Exp. 1, crossbred steers (n = 360, BW = 288 ± 0.5 kg) were blocked into 3 BW blocks and assigned randomly to one of 36 pens. In Exp. 2 six ruminally and duodenally cannulated heifers were utilized in a 6 × 6 Latin Square experiment. Treatment design was a 2 × 3 factorial in both experiments with factors of SFC or DRC-based diets, and the other factor was a control diet with no DGS (CON), or a diet including either regularly produced DDGS (DDGS), or high protein DDGS (HiPro) at 30% of diet DM. There was an interaction (P = 0.02) between distillers grains plus solubles (DGS) treatment and corn processing for G:F, as including DDGS in DRC diets increased G:F from 0.157 to 0.163, with no difference when using HiPro (P = 0.20; 0.161). In SFC-based diets, there was a tendency (P = 0.10*)* for DDGS and HiPro to reduce G:F from 0.175 in CON diets to 0.171 in DDGS and HiPro. Dried distillers grains plus solubles had greater (P < 0.01) ADG and carcass-adjusted final BW than CON, and tended (P = 0.10) to be greater than HiPro. Dry matter intake was lower *(*P < 0.01) and NEm and NEg greater (P < 0.01) for SFC than DRC-based diets with no difference (P = 0.98) in ADG. There was an interaction of apparent total tract and post ruminal starch digestibility ($P \leq 0.02$), where starch digestibility was greatest for SFC-CON, SFC DDGS and SFC HiPro and decreased to 95.1% in DRC-CON, to 92.0% in DRC-DDGS and even further to 88.7% for DRC-HiPro. Post ruminal starch digestibility was similar to apparent total tract digestibility. There was no interaction for other nutrient digestibility and apparent and true ruminal starch digestibility were greater (P = 0.02) for SFC over

DRC. Dry matter and OM apparent total tract digestibility were least ($P < 0.01$) for HiPro and greatest for CON, with DDGS being intermediate. Digestible energy (Mcal/kg) tended ($P = 0.08$) to be greater for CON over HiPro and DDGS. Dry matter intake, bacterial OM flow, feed OM flow, bacterial N flow and bacterial starch flow were all greater ($P < 0.01$) for HiPro and DDGS as compared to CON. Average ruminal pH was unaffected by treatment ($P \geq 0.30$). The use of either DGS product did result in a reduction in energy intake and starch digestibility, without affecting other ruminal metabolic parameters.

Key words: corn processing, digestion, dry distillers grains plus solubles, feedlot performance

Introduction

Distillers grains plus solubles have proven to be a valuable feedstuff to the feedlot industry since the expansion of ethanol production during the early 2000s. The method traditionally used to produce distillers grains plus solubles (DGS) is known as dry-milling, where whole corn is ground and fermented through a series of steps to produce ethanol and the byproduct resulting is DGS. As the ethanol industry has progressed, the dry-milling process to increase ethanol output has been changed, and currently bran and germ can be removed prior to fermentation (Hubbard et al., 2009). The endosperm and gluten remaining are ground and fermented for ethanol, resulting in a byproduct known as high-protein DDGS (HiPro), which has greater protein than regularly produced dried distillers grains plus solubles (DDGS) at 38% CP (Hubbard et al., 2009) as compared to traditional at 31% (NASEM, 2016).

Starch digestion in the ruminant can occur in both the rumen and small intestine, and to varying degrees, is dependent on starch availability, fermentability, and nitrogen availability to stimulate both microbial growth and pancreatic secretions. Apparent total tract starch digestibility is enhanced by steam flaking, increasing from 92.2% for dry rolled corn (DRC) to 98.6% with steam flaked corn (SFC)-based diets (Theurer, 1986). In the rumen, SFC is approximately 84.8% available as compared to 76.2% for DRC (Theurer, 1986). As a result, the feed efficiency improvement in cattle due to SFC in the diet is approximately 11% over DRC-based diets (Luebbe et al., 2012). However, when wet distillers grains plus solubles (WDGS) is added to diets with SFC, no change in G:F is observed, while cattle fed DRC-based diets experience greater feed efficiency as WDGS is included in the diet up to 40% (DM basis; Corrigan et al., 2009).

Starch digestion post ruminally is limited in ruminants due to limited α-amylase secretion from the pancreas (Swanson et al., 2014). In the small intestine, as starch flow increases, starch digestibility decreases, resulting in much of the energy in the small intestine being lost as CO_2 and not being utilized for growth by the cattle (Huntington et al., 2006). Starch digestion can be improved through increased α-amylase secretion when increased levels of casein are introduced at the entrance of the duodenum (Swanson et al., 2014). Distillers grains plus solubles have a high RUP content of approximately 68%, which makes it a good candidate for providing protein to the pancreas, improving starch digestion. However, according to Salim et al. (2016), the inclusion of DGS in the diet did not result in in increased α-amylase activity. Improvements of starch digestibility with increasing levels of DDGS in the diet may likely be due to the dilution of starch when DGS replaces corn in the diet. Performance responses may be due to improved starch

digestibility post-ruminally, cattle deriving energy from the breakdown of the excess protein post-ruminally or changes in nutrient concentrations between DGS and other ingredients (Salim et al., 2016). We hypothesized including HiPro in DRC-based diets would improve starch digestion post-ruminally, improving performance of cattle in the feedlot. As many studies have compared DRC and SFC in the feedlot (Owens et al., 1997, Cooper et al., 2002), an internal control was used to determine response of cattle as compared to other trials and to determine the energetic value of corn as compared to DDGS and HiPro DDGS in the diet. The objectives of these studies were to evaluate the inclusion of HiPro DDGS in the diet and its' effect on growth performance and metabolism in SFC or DRC-based diets.

Materials and Methods

All animal use procedures were reviewed and approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee.

Exp. 1-Cattle Finishing Experiment

Recently weaned crossbred steers (n = 360, BW = 288 ± 0.5 kg) that had been received at the Eastern Nebraska Research and Education Center (ENREC) near Mead, Nebraska during October of 2017 were individually identified and processed. Steers were processed into the feedlot with 20 mL of fenbendazole (SafeGuard Drench, Merck Animal Health, Madison, NJ), a modified live viral vaccine for bovine respiratory syncytial virus, parainfluenza3, bovine viral diarrhea Types I and II, *Hisophilus somnus* bacterin, and infectious bovine rhinotracheitis (Bovi-Shield Gold 5, Zoetis Inc., Kalamazoo, MI) an injectable anthelmintic (Dectomax, Zoetis Inc.) and *Mannheimia haemolytica* toxoid (Bovi-Shield Gold One Shot, Zoetis Inc.). Steers were then

revaccinated approximately 14 to 28 days after initial processing with a killed viral vaccine for clostridial infections (Ultrabac 7, Zoetis Inc.), and a modified live viral vaccine for bovine respiratory syncytial virus, parainfluenza3, bovine viral diarrhea Types I and II, *Hisophilus somnus* bacterin, and infectious bovine rhinotracheitis (Bovi-Shield Gold 5, Zoetis Inc.) The trial was initiated in November of 2017, and steers were limit-fed (2% of BW) a diet of 1:1 inclusion of alfalfa hay and wet corn gluten feed (SweetBran®, Cargill Wet Milling, Blair, NE) for 5 days prior to initial body weights for gut fill equalization (Watson et al., 2013) and individual body weights were collected on days 0 and 1.

On d 1 of the experiment, steers were implanted with 200 mg trenbolone acetate, 40 mg estradiol (Revalor®-XS, Merck Animal Health). Steers were stratified by body weight in a randomized block design and assigned randomly to one of 36 pens (10 steers/pen) to either a light block that included one replication, a medium block that included four replications, or a heavy block that included one replication. The treatment design was a 2 × 3 factorial consisting of either SFC or DRC as a grain source and one of three distillers grains plus solubles (DGS) treatments, a control with no DGS (CON), a diet including 30% (DM basis) regularly produced DDGS (DDGS), and a diet including 30% (DM basis) HiPro. Diets used are presented in Table 4.1. Both DDGS and HiPro were obtained from Corn Plus (Winnebago, MN). All steers were fed a supplement formulated to provide 33 g/t of DM monensin (Rumensin, Elanco Animal Health, Indianapolis, IN) and 9.7 g/t of tylosin (Tylan, Elanco Animal Health).

Steers were adapted to the 87% corn diets over a period of 24 days and four steps. Alfalfa was reduced from 57% to 0% in steps of 15, 15, 15, and 12% over periods that

were 5, 6, 6, and 7 d, respectively. Dry rolled corn replaced the alfalfa that was removed at each step increasing from 30 to 45% to 60% to 75% to 87% on a DM basis. Steers fed the diets that included 30% DDGS and HiPro with 57% corn were adapted over a period of 17 days and three steps. The initial step included 52% alfalfa, 20% DRC, and 15% of either DGS source. Alfalfa was reduced 20%, 20% and 12%, and corn was increased 15%,15%, and 7%, and DGS source was increased 5%, 5%, and 5%, each step over periods that were 5, 6, and 6, days respectively. All dietary treatments included 8% sorghum silage and 5% supplement throughout all adaptation steps.

Dry rolled corn was processed and obtained at the research feedlot near Mead, NE. Steam flaked corn was processed to a flake density of 335 g/L (26 lb/bu) off site at a commercial feedlot (Raikes Feedyard, Ashland, NE), and delivered every three days and used in both the metabolism and finishing trial. Dried distillers grains plus solubles and HiPro were obtained from ICM (St. Joseph, MO) and delivered prior to initiation of the trial.

Dietary treatments were fed once daily at ad libitum intake, and feedbunks were assessed daily at 0530 to allow for a small amount of feed left in the feed bunk each morning. Feed refusals were weighed back when necessary and subsamples were dried for 48 hours in a 60°C forced-air oven to determine DM refused (AOAC, 1999, method 4.1.03). Ingredients were sampled weekly and analyzed for DM with the method mentioned above. Weekly composite dietary ingredient samples were analyzed for CP (ThermoFisher Scientific Flash*Smart* N/protein analyzer), NDF with α-amylase and sodium sulfite (Van Soest and Marcus, 1964; Van Soest et al., 1991), ADF (VanSoest et

al., 1991), ether extract (Bremer, 2010), and starch (Megazyme International, AOAC International, 2000; Method 996.11; AACC Method 76.13).

Cattle were slaughtered at a commercial abattoir (Greater Omaha Pack, Omaha, NE) after 202 DOF. On the day of shipping, steers were fed 50% of the previous day's DM offer. Steers were shipped in the evening and harvested the following morning at the local abattoir (Greater Omaha Packing Co., Omaha, NE). The day of harvest, hot carcass weight and liver abscess scores were recorded. Liver abscess scores were scored using the Brink et al. (1990) methods, with 0 (no abscesses) and A-, A, and A+ scores for severely abscessed livers. These scores were combined to determine the proportion of liver abscesses per pen. The carcass-adjusted final BW was determined using a 63% common dressing percentage from the HCW determined at slaughter and this value was used to determine ADG and G:F for the experiment. Marbling score, 12^{th} rib fat thickness, and LM area were observed after a 48-h chill. Yield grade was calculated using the USDA (2016) method, assuming a 2.5% KPH value using the formula YG = (2.50 + (0.0017 × HCW, kg) + (0.2 × KPH, %) + (6.35 × 12th rib fat, cm) - (2.06 × LM area, cm^2). Energy value of the diets was calculated using Galyean (2009) Net Energy calculator based on the NRC (1996) Equations. The calculated energy value used average initial and final BW for each block, with individual pen DMI and ADG as inputs.

Growth performance and carcass characteristics were analyzed using the Mixed procedure of SAS (SAS Inst, Inc., Cary, N.C.) Pen was considered experimental unit, with the block considered the fixed effect. Data were analyzed in a 2 × 3 factorial and simple effects will be discussed unless there was not an interaction ($P \geq 0.10$), at which point main effects of DGS or corn processing method will be discussed. Liver abscesses

were analyzed using the GLIMMIX procedure of SAS with a binomial distribution. Treatment differences were considered significant when $P \leq 0.05$. A tendency was declared when $P \leq 0.10$ and $P > 0.05$.

Exp. 2-Cattle Metabolism Experiment

Six ruminally and duodenally cannulated beef heifers were assigned randomly in a 6 × 6 Latin square design. Steers were assigned randomly to each dietary treatment for six, 21 d periods, allowing for 14 d adaptation periods, followed by 7 d collection periods. The treatment design was the same as in Exp. 1, in a 2 × 3 factorial and was run concurrently with Exp. 1. Diets were the same as in Exp. 1 (Table 4.1) and were mixed twice weekly and stored in a cooler (0°C) to ensure fresh feed. Diets were adapted between periods over a period of 5 days. On d 1 of the new period, the previous periods diet was included at 70%, and the new periods diet at 30%, d 2 and 3, each diet was included at 50:50, d 4, 30% old period, 70% new period, and d 5-100% new diet.

Feed refusals were collected from d 16 to 19, weighed, subsampled and analyzed to determine nutrient refusal. Heifers were fed individually in 2.2 × 3.7 m pens with ad libitum access to water. Heifers were dosed with a 5.0 g bolus of titanium dioxide inserted through the rumen cannula twice daily at 0800 and 1600 h for seven d prior to collection and for the duration of the collection period to determine fecal output. Fecal grab samples (approximately 300 g) and duodenal fluid samples (approximately 200 g) were collected 4 times per day (0800, 1200, 1600, and 2000 h) over a 4 d period, d 17 through 20. Fecal samples were composited on a wet basis into a daily composite, freeze dried (Virtis Freezemobile 25EX, SP industries, Warminster, PA), and composited by heifer for each period. Duodenal samples were freeze dried (Virtis Freezemobile 25EX,

SP industries, Warminster, PA) and composited on a dry basis by heifer for each period. Dry matter of ingredients was determined weekly, using a forced air oven at 60°C for 48h (AOAC, 1999; method 4.1.03). All samples were ground in a Wiley Mill (Thomas Scientific, Swedesboro, NJ) to pass through a 1-mm screen, and further subsamples of fecal and duodenal samples were ground to pass through a 0.5 mm screen (Cyclotec 1093, Foss Tecator AB, Hoganas, Sweden). All fecal, duodenal, and ingredient samples were analyzed for NDF (Van Soest et al., 1991), OM (600°C for 6 h), ADF (Van Soest et al., 1991), Ti concentration (Spectra MAX 250, Moleculare Devices, LLC, Sunnyvale, CA; Myers, 2004) and starch (Megazyme International, AOAC International, 2000; Method 996.11; AACC Method 76.13). Dried distillers grains plus solubles and HiPro were both analyzed for ether extract to remove the fat in the sample prior to being refluxed for NDF and ADF analysis.

Ruminal pH was recorded every minute using wireless pH probes (Dascor Inc,; Escondido, CA) from d 15 to 21 and analyzed hourly. Ruminal pH averages were evaluated from d 16-20, to coincide with collection week and allow for pH to be measured at the same time for all animals. Rumen fluid samples were collected using a vacuum pump on d-21 at 0800, 1000, 1200, 1400, and 1600 h for ruminal volatile fatty acids (VFA; Trace 1300, Thermo Fisher Scientific, Inc., Waltham, MA) and ammonia (NH_3). Volatile fatty acids were analyzed with procedures outlined by Ehrlich et al., (1981) using gas chromatography and NH_3 were analyzed using procedures outlined by Smith and Murphy (1993) using spectrophotometry at 550 nm.

Whole rumen contents were collected at 1600 h on d 21 to analyze for purine analysis. The whole rumen contents (2 kg) were mixed with 2 L of a 10% formalin

solution and frozen at -20°C. Whole rumen contents were blended within heifer for each period and centrifuged to isolate a bacterial pellet (Leupp et al., 2009). All rumen content samples were blended for approximately one minute and strained using four layers of cheesecloth. Liquid was then poured into 250-mL centrifuge bottles and centrifuged at 500 × *g* for 20 min. Bacteria were further separated by centrifuging at 30, 000 × *g* for 20 min and were frozen and subsequently freeze dried. Duodenal contents and bacterial isolates from the whole rumen contents were analyzed for purine concentration to determine microbial flow using the procedure outlined by Zinn and Owens (1986) with a slight modification using more dilute $HClO_4$ (as described by Crawford et al., 2008). Using a spectrometer set at 260 nm, purine concentration was determined, and true ruminal digestibility was calculated from the difference between the nutrient ingested and the amount present in duodenal samples after microbial nutrient concentrations were accounted for. The purine:nitrogen ratio determined for each animal within period was used for analysis to determine flow of nutrients to the duodenum. The purine:nitrogen ratio measured was 0.153 ± 0.011 across the six treatments. Whole rumen bacterial isolates were composited by treatment and evaluated for OM and starch to correct for microbial OM and starch reaching the duodenum, so true rumen digestibility could be calculated.

Digestibility of the diets and total nutrient intake were analyzed using the MIXED procedure of SAS (SAS Inst., Inc., Car, NC), with period and treatment considered fixed effects, and heifer within period was included as a random effect. The interaction effect between corn processing treatment and DGS treatment were initially analyzed, and if an interaction was not identified, main effects of DGS and corn processing were analyzed.

Volatile fatty acid and ammonia data were evaluated using the GLIMMIX procedure of SAS with the random effect of heifer within period being considered and fixed effect of time and experimental treatment. A simple covariance structure was used for VFA. Ruminal pH was analyzed with day analyzed as a repeated measure and analyzed hour × day interactions using an autoregressive covariance structure with the GLIMMIX procedure of SAS. For repeated measures analyses, covariance structures were determined based on Akaike's information criterion (AIC). Each experimental treatment was considered a fixed effect and a random effect was considered heifer within period. Treatment differences were considered significant when $P \leq 0.05$. A tendency was declared when $P \leq 0.10$ and $P > 0.05$.

Results and Discussion

Exp. 1-Cattle Finishing Experiment

There was an interaction ($P = 0.02$) between corn processing and DGS treatment for G:F in Experiment 1. When cattle were fed DRC-CON diets, G:F increased by 4.4% with the inclusion of 30% DDGS in the diet from 0.157 to 0.163 (DM basis); whereas G:F increased by 2.5% when HiPro was included in the diet as compared to CON, increasing from 0.157 to 0.161 (Table 4.2). In contrast, SFC-based treatments tended ($P = 0.10$; Data not shown) to experience a reduction in feed efficiency of 2.3% when either DDGS or HiPro was included in the diet at 30% (DM basis) as compared to CON, reducing from 0.175 to 0.171 for both DDGS and HiPro. According to Vander Pol et al. (2008), feed efficiency was optimized in DRC-based diets when WDGS were included in the diet at approximately 30% (DM basis). When included in SFC-based diets, however, 30% WDGS (DM basis) resulted in similar feed efficiency to DRC-based diets. In the

current study, DRC-based diets did not have as great of G:F as compared to SFC-based diets ($P < 0.01$) for any treatment, but G:F did approach SFC-based diets when either DGS source was fed. In the internal validation between the two CON treatments for corn processing, an 11% improvement in feed efficiency was observed due to SFC, which is consistent with the value Zinn et al. (2002) observed of an average of 12.2% improvement in feed efficiency when using SFC. In a trial by Luebbe et al. (2012), G:F was improved ($P < 0.01$) when cattle consuming SFC or DRC based diets with no DDGS from 0.162 to 0.180, which was approximately 11%, agreeing with the current study. In a review by Owens et al. (1997), it was concluded ADG does not change dramatically when cattle are consuming DRC or SFC based diets, but the reduction in DMI results in an improvement in G:F, which agrees with the current study, where no differences ($P = 0.99$) were observed in ADG due to corn processing method.

There was a tendency for an interaction ($P = 0.07$) between corn processing method and DGS treatment for NEm and a clear interaction ($P < 0.01$) for NEg (Mcal/kg). In SFC-based diets, the inclusion of either DGS treatment resulted in a reduction of NEm from 2.11 Mcal/kg to 2.03 and 2.05 Mcal/kg for both HiPro and DDGS, respectively. The NEg followed a similar pattern for SFC-based diets, decreasing from 1.44 Mcal/kg to 1.37 for both DDGS and HiPro in the diet. In DRC-based diets, NEm was unaffected ($P \geq 0.71$) by DGS treatment, averaging 1.94, 1.94, and 1.93 Mcal/kg for CON, DDGS and HiPro. The NEg followed a similar pattern, in that NEg averages were not different at ($P \geq 0.61$) 1.29, 1.29, and 1.28 Mcal/kg for CON, DDGS and HiPro. Owens et al. (1997) calculated the energetic value of SFC compared to DRC is approximately 12 to 18% greater. In the current study, SFC CON G:F was

approximately 8% greater than DRC CON. The calculated feeding value of DDGS in DRC-based diets was 100% that of DRC, while HiPro was 99% that of DRC. As compared to SFC, DDGS had a feeding value of 89%, and HiPro had a feeding value of 87% that of SFC. Feeding value and energetic response of cattle to DGS has been well documented. In a meta-analysis by Klopfenstein et al. (2008), the response of cattle to DGS were affected by degree of corn processing, as it positively improves HMC and DRC-based diets. In SFC-based diets, increasing the inclusion of DGS has resulted in negative effects on ADG, suggesting the components of DGS that typically improve the energy content and response in DRC-based diets do not positively enhance the already readily available and fermentable starch that found in SFC.

There was an interaction (P = 0.02) in LM area between corn processing treatment and DGS treatment. The use of DDGS increased LM for both SFC and DRC-based diets over the CON, but HiPro caused a reduction in LM area for SFC-based diets as compared to the CON, while it increased from the CON in DRC-based diets. The growth response observed in DRC-based diets through increased ADG and DMI when cattle consumed DDGS and HiPro was likely why the LM area of both the SFC-DDGS and DRC-DDGS were greater than either CON treatment. However, a reduction in LM area was observed in SFC-HiPro, likely due to the response in intake, cattle consuming SFC-based diets typically ate less, while gaining similar to DRC-based diets. This was likely why the animal had a lower LM area, the growth observed in other treatments was not present, and a potential negative associative effect between the HiPro and SFC may have occurred. Additionally, the HiPro and DDGS diets lacked urea in the supplement, which suggests ammonia may have been limiting for rumen microbes and thus limited

MP production from the rumen, which will be discussed further in the paper. No other interactions were observed for growth performance or carcass characteristics ($P \geq 0.22$), so main effects of corn processing or DGS treatment will be discussed.

Effect of DGS Treatment on Growth Performance

Final carcass adjusted body weight was increased ($P < 0.01$; Table 4.3) by 26.5 kg with DDGS and 18.5 kg with HiPro. This increase in body weight was likely due to the ADGresponse, as ADG increased 9% with DDGS from 1.45 kg/d to 1.58 kg/d and 6.3% with HiPro (1.54 kg/d), and DDGS tended ($P = 0.10$) to have greater ADG than HiPro. Dry matter intake was likewise increased ($P < 0.01$) by 8% with DDGS, and 6.3% with HiPro over CON, likely causing the ADG response. In a meta-analysis by Klopfenstein et al. (2008), an evaluation of nine experiments feeding WDGS at various levels in corn-based diets resulted in improved ADG as compared to diets where DGS were not included, and a tendency was observed that DMI was increased using DDGS, whether fed at low, medium or high levels (Klopfenstein et al., 2008). In a trial evaluating the inclusion of DDGS in the diet the inclusion of DDGS in the diet from 10 to 40% (DM basis) did not affect DMI, but ADG was greatest in diets fed 20% DDGS, with G:F linearly increasing ($P = 0.08$) with increasing DDGS inclusion (Buckner et al., 2007). In a trial by Corrigan et al. (2009) including WDGS in the diet at 40% as compared to 0% resulted in an increase ($P < 0.01$) in DMI in a metabolism study, and a quadratic reduction in response to increasing WDGS levels in a feedlot study evaluating different levels of WDGS in the diet. Vander Pol et al. (2009) observed a quadratic response with increasing WDGS in the diet, and maximal DMI occurring at 30% inclusion, which was the inclusion of the current study. Distillers grains plus solubles

have been documented to have a greater energy value relative to corn, partially due to their high fat content, 8.64 and 8.02% in this study for DDGS and HiPro, respectively, because the fat is partially rumen protected and better digested in the small intestine as an energy source. Additionally, excess protein above animal requirements is deaminated and used by cattle as an energy source, especially when fed above levels of 20% in the diet (DM basis; Klopfenstein et al., 2008). In a study by Widmer et al. (2008) evaluating the use of HiPro DDGS in pig finisher rations, HiPro DDGS resulted in a reduction in ADG as compared to regularly produced DDGS in the diet. Although this is a monogastric research example, it is important to note HiPro does not appear to provide a benefit in swine nutrition as compared to regularly produced DDGS. In a study by Hubbard et al. (2009), dairy cattle consuming a diet of 20% HiPro DDGS in replacement of forage and a soy-based protein had no change in DMI but did have greater fat corrected milk (FCM) but not protein content of the milk, this was likely due to greater fat and energy concentration than typical soy-protein sources utilized in the dairy industry. According to Hubbard et al. (2009), RUP estimates of HiPro DDGS are 62.0 ± 8.76, 56.1 ± 5.34, and 30.9 ± 5.93% of CP for 16, 24, and 48 hours spent in the rumen respectively. It is theorized the greater energetic response from high DGS levels in the diet may be due to the energetic efficiency of using RUP for energetic rather than protein requirements (Klopfenstein et al., 2008), but providing further RUP in the form of HiPro does not appear to provide a benefit.

Hot carcass weight was greatest ($P < 0.01$; Table 4.3) for cattle fed DDGS at 383 kg with CON being lowest at 366 kg and HiPro intermediate ($P = 0.11$) at 378 kg. Marbling score was statistically unaffected by the inclusion of either DGS treatment in

the diet (P = 0.20), whereas backfat thickness was increased with the inclusion of either DGS treatment in the diet (P = 0.03). Backfat thickness on the CON treatment was 1.22-cm and was increased to 1.31-cm for the DDGS treatment and 1.38 cm for the HiPro treatment, with a larger average yield grade (P < 0.01) for DDGS and HiPro over CON, cattle fed those treatments were likely more finished than the CON treatment, with no differences in marbling score. Liver scores were unable to converge through the statistics program, but averaged 3.5% for the CON, 1.8% for DDGS and 1.8% for HiPro. Consistent with ADG, cattle were fatter with equal days on feed when fed either DGS source, which agrees with the meta-analysis by Klopfenstein et al. (2008).

An MP deficiency was likely not the cause for improvements in ADG and DMI for cattle consuming HiPro and DDGS as compared to CON, as MP requirements for the CON diet were met with 2% followed by 1% inclusion of Soy-Pass in the diet to meet RUP requirements during the early phases of the feeding period when MP requirements were higher because of the larger MP requirements of growing calves. Many experiments do not cite deficient MP diets as the cause for DDGS to outperform CON, as an MP source such as corn gluten meal is commonly used to meet MP requirements in control diets that don't include DGS (Corrigan et al., 2009; Huls et al., 2008). Growth performance responses to the inclusion of DGS in the diet have been attributed to the energy supplied by fat found in the DGS grains. In the current study, ether extract concentrations of the DDGS and HiPro were 8.64 and 8.02% respectively (data not shown). More recent research evaluating the nutrient profile of DDGS, researchers determined when protein is fed above requirements it contributes to the energetic response observed when cattle are fed DDGS as compared to control diets without the

inclusion of DGS (Conroy et al., 2016). The measured CP concentrations of the DDGS and HiPro were 32.0 and 39.6%, respectively. Excess MP can be recycled to urea for an RDP source in the rumen, or for energy production, which, when accounting for ruminal fermentation, results in an energy value approximately 43% above digested carbohydrates (Kleiber, 1961). Increasing the crude protein content with HiPro did not appear to provide additional energetic benefits beyond what the DDGS supplied, as cattle consuming HiPro had similar intakes and ADG. As observed in growing trials evaluating RUP supplementation in the diet, there may be a diminishing response with increasing RUP levels in finishing diets (Hilscher, 2018) suggesting the excess protein in HiPro did not provide additional benefit energetically speaking as compared to DDGS.

Effect of Corn Processing Treatment on Growth Performance

As hypothesized, processing corn more intensely affected growth performance and some carcass characteristics, regardless of DGS treatment or lack thereof. While cattle fed SFC and DRC had similar final carcass adjusted body weights at 596 kg (P = 0.94), their average daily DMI was different ($P < 0.01$). As is well documented in literature (Owens et al., 1997), SFC has more energy available due to more fermentable and available starch in the rumen, reducing DMI through an energetic response in the animal. In the current study, DMI was decreased by 6.7%, decreasing from 9.4 to 8.8 kg/d, with no observed difference in ADG (P = 0.98) at 1.53 kg/d. This agrees with Owens et al. (1997) conclusion that ADG is unaffected by corn processing method between SFC and DRC, but changes in efficiency are due to reduction in DMI. Feed efficiency was improved using steam-flaking and was decreased approximately 6.4% across treatments from 0.173 to 0.162 in DRC-based diets. In a trial by Corrigan et al.

(2009), cattle consuming SFC-based diets had lower minimum pH values, and greater swings in pH change throughout the day than cattle consuming DRC-based diets and spent more time below a pH of 5.0 than DRC, at 206 min/d as compared to 60 min/d for DRC.

Hot carcass weight remained unaffected by corn processing treatment ($P = 0.95$), and most other carcass characteristics followed similar trends. Marbling score ($P = 0.40$), yield grade ($P = 0.19$) and backfat thickness ($P = 0.90$) were unaffected by corn processing treatment, as the observed average backfat thicknesses of 1.30 cm for both SFC and DRC-based treatments. These results were expected as ADG was unaffected by treatment and all treatments performed similarly. In a trial by Huck et al. (1998), differences in carcass characteristics were unaffected by corn treatment, as observed in the current trial when feeding 74.5% (DM basis) of either SFC or DRC in the diet.

Exp. 2-Cattle Metabolism Experiment

There was an interaction ($P \leq 0.04$; Table 4.3) between corn processing method and DGS treatment on starch excreted and apparent total tract starch digestibility. As DGS were included in DRC-based diets, starch excretion increased when HiPro was included in the diet over both DDGS and CON treatments, increasing from 0.24 kg/d for CON and 0.33 kg/d for DDGS to 0.46 kg/d in HiPro. In SFC-based diets, starch excreted was similar between DGS treatments ($P \geq 0.13$) at 0.16 kg/d as compared to 0.09 kg/d in CON. Apparent total tract starch digestibility also had an interaction between DGS and corn processing treatment ($P < 0.01$). In SFC-based diets, the CON diet tended ($P = 0.06$) to have greater starch digestibility than both HiPro and DDGS, decreasing from 97.8% to 96.1 and 96.2% digestibility, with no difference ($P = 0.97$) between the DGS

treatments. The stability of starch digestion in SFC-based diets results are consistent with May et al. (2009), who observed no difference in starch digestibility when cattle were fed 0 or 25% DDGS in the diet, or by Vander Pol et al. (2009) who fed 0 and 40% WDGS in the diet. Starch availability is greater for SFC because corn has been more extensively processed when steam-flaked, improving enzymatic starch availability (Zinn, 1990). Research by Hales et al. (2012) observed apparent total tract starch digestibility was unaffected by the inclusion of 30% WDGS in the diet as compared to a CON treatment of either DRC or SFC.

In DRC-based diets, starch digestibility was decreased ($P < 0.01$) as the level of crude protein in the diet increased through the inclusion of HiPro and DDGS. When no DGS were included in the CON diet, apparent total tract starch digestibility averaged 95.1% and was reduced to 92.0% with the inclusion of DDGS in the diet. This was further reduced to 88.7% average apparent total tract starch digestibility when HiPro was included in the treatment, which was statistically different from DDGS ($P < 0.01$). There was an interaction between corn processing and DGS treatment for post ruminal starch digestibility ($P = 0.02$: Table 4.4), observing a similar trend to apparent total tract starch digestibility, with SFC CON having the greatest at 86.0%, and being like SFC DDGS and SFC HiPro, with DRC CON at 77.6%, dropping to 74.7% for DRC DDGS and 59.3% for DRC HiPro.

In a review by Harmon (2009) evaluating starch digestion in the small intestine, the secretion of α-amylase can be manipulated through nutrient supply. Increasing flow of high-quality rumen undegradable protein such as casein to the small intestine has increased pancreatic α-amylase flow in cattle (Swanson et al., 2002, 2004, Richards et al.,

2003). However, increasing the amount of starch flow through the duodenum can decrease secretion of α-amylase by up to 60% as compared to control infusions of hydrolyzed starch (Walker and Harmon, 1995). When starch and casein were infused into the duodenum together, results mimicked the responses observed when only starch is infused into the duodenum, a reduction in α-amylase (Swanson et al., 2002) or through greater pancreatic juice secretion due casein but resulted in no net influx change in α-amylase secretion because it became less concentrated (Swanson et al., 2004). In the current study, protein reaching the duodenum was greater ($P < 0.01$) for cattle consuming the DDGS and HiPro diets because of the inclusion of DGS, which have both a high CP (32.0 and 39.6%, respectively) and RUP content (63%, Castillo-Lopez et al., 2013). However, cattle consuming DDGS or HiPro consumed more DM ($P < 0.01$), resulting in no net differences ($P = 0.31$) between DGS treatments of starch entering the rumen or small intestine. Research indicates increasing both protein and starch flow to the small intestine results in no net difference in starch digestion post ruminally and results observed in the current study agree. Numerically, it is observed feeding CON diets had less starch entering the duodenum, which may increase digestibility of starch because of less starch flow, allowing for less dilution of α-amylase. According to Barajas and Zinn (1998), starch digestion is not enhanced in SFC or DRC based diets with the inclusion of RUP beyond protein requirements or may need specific amino acids to stimulate pancreatic excretion.

In a study by Blom et al. (2016) evaluating the effects of protein infusion in the small intestine to enhance pancreatic α-amylase secretion, it was observed that casein and glutamic acid supply at intermediate levels of 31 g/d to the small intestine increased small

intestine starch digestion. Although there was increased amylolytic activity in these cases, the starch broken down to oligosaccharides may have exceeded capacity of brush border membrane oligosaccharidases (Blom et al., 2016), thus causing the bottleneck in starch digestion to be limiting further along in the starch digestion process. Ethanol soluble starches were not measured in this study, and because apparent starch digestibility did not increase, the likely cause of a reduction or lack of increase in starch digestion was likely due to a lack of response from α-amylase. In a trial by Brake et al. (2014) evaluating starch digestion post ruminally through the addition of supplements that supplied high quality protein like casein, or just essential or nonessential amino acids (NEAA), they observed post ruminal starch digestibility was only increased when essential amino acids (EAA) were supplied. When NEAA were included in a supplement at the duodenum, post ruminal starch disappearance was 83.6% as compared to 93.7% for an essential amino acid supplement but ethanol-soluble starch was reduced as compared to essential amino acid profiles. However, when measuring just small intestine starch disappearance, they observed a tendency for greater starch disappearance as compared to essential amino acids. No change in post ruminal starch digestibility due to NEAA offered offers some challenges for researchers as DDGS do not supply all essential amino acids, and the amino acid profile is changed through ruminal fermentation, which makes it difficult to feed for optimal starch digestion. Pairing their data with the ruminal and postruminal starch digestibility data, we can assume starch digestion was limited in the current trial despite greater protein supply post ruminally. According to Snook (1971), secretion of α-amylase is dependent on a combination of both carbohydrate and amino acid flow to the small intestine. In the current study, DDGS are likely supplying less

EAA than the requirements for the pancreas are, limiting starch digestion. The ready availability of SFC was unaffected by protein supply to the small intestine and was at much lower levels than in DRC-based diets for all treatments. Dry rolled corn is less fermentable, and the protein supply by HiPro did not result in an improvement in post ruminal starch digestibility (59.1%; Table 4.4).

There was no interaction ($P \geq 0.15$) between corn processing method and DGS treatment in apparent rumen starch digestibility or true rumen starch digestibility. However, there was an effect of DGS source and corn processing method ($P \leq 0.01$) on apparent rumen starch digestibility and an effect of corn processing ($P < 0.01$) on true starch rumen digestibility. Steam flaked corn had greater apparent and true starch digestibility as compared to DRC, which was observed in a study by Cooper et al. (2002) comparing starch digestibility of varying corn processing methods. This agrees with other research because SFC has more readily available and fermentable starch as compared to DRC (Huntington, 1997, 2006).

Apparent ruminal starch digestibility was reduced from 80.3% for CON to 72.1% and 72.2% for DDGS and HiPro, respectively, but this was not observed in true ruminal starch digestibility that accounted for microbial activity ($P = 0.11$). Luebbe et al. (2012) observed no differences in apparent rumen starch digestibility as WDGS was increased in the diet but did observe greater true ruminal starch digestibility when 60% WDGS was included in the diet. Both feed and total starch reaching the rumen were unaffected by DGS treatment ($P \geq 0.21$), despite CON based diets having greater starch content as a percentage of the diet (66.2 vs. 44.0% for both DGS treatments). There was an observed interaction between corn processing and DGS for microbial starch ($P = 0.02$), which was

greatest for cattle fed SFC-HiPro diets at 0.50 kg/d flowing to the duodenum, as compared to 0.16 kg/d for DRC HiPro, and 0.09 and 0.21 kg/d for DDGS DRC and SFC, respectively. Cattle consuming CON based diets had lowest microbial starch flows at 0.06 and 0.09 kg/d. Microbial starch responded similarly in a trial by Luebbe et al. (2012), in which maximal starch flows were observed when WDGS were included in the diet at 30%, as compared to SFC and DRC control diets.

An increase in DMI as observed in the study for cattle consuming DDGS or HiPro likely resulted in greater passage rate and flow through to the small intestine. Organic matter entering the small intestine was greater (P = 0.01) for DDGS and HiPro as compared to CON, suggesting a faster flow rate to make up for greater flows through the gastrointestinal tract. An increased passage rate through both the rumen and small intestine may have affected starch digestion through limited interaction between starch and α-amylase secretion in the small intestine, reducing starch digestion (Luebbe et al., 2012).When feeding DGS in the diet above 30% DM limited the interaction between starch and α-amylase because of too much organic matter flowing through the duodenum (Luebbe et al., 2012). A trial by Uwitze et al. (2010) observed feeding DDGS in diets at 25% (DM basis) resulted in a reduction in apparent total tract starch digestibility, decreasing from 98.4 to 97.3%. Despite the fact the starch concentration in the diet on a percent basis was lower for DDGS and HiPro diets, starch intake was not different (P = 0.15) between treatments, which resulted in similar starch flow to the small intestine of starch (P = 0.31), with greater OM flow for DDGS and HiPro (P = 0.01). Considering OM flow to the duodenum was 5.33 and 5.54 kg/d for DDGS and HiPro, respectively, as

compared to 3.68 kg/d for CON, dilution of the starch is a logical explanation for the reduction in starch digestion post ruminally.

There was a tendency ($P = 0.13$) for an interaction between corn processing method and DGS treatment for apparent ruminal NDF digestibility. DRC-CON had the greatest apparent NDF digestibility at 56.4%, while SFC-CON had the lowest at 11.7%. Including DDGS and HiPro in DRC-based diets resulted in no net change in apparent NDF ruminal digestibility but increased ($P = 0.04$) through the inclusion of DDGS in SFC diets, with no difference ($P = 0.23$) in SFC-HiPro diets. In a trial by Luebbe et al. (2012), apparent NDF ruminal digestibility increased with the inclusion of WDGS in SFC-based diets, which was observed with the inclusion of DDGS in the current study. This do not agree with VFA data (Table 4.5) which shows SFC having greater acetate and lower propionate proportions than DRC.

Effect of DGS Treatment on Nutrient Digestibility

No other interactions were observed for apparent total tract nutrient digestibility between corn processing method and DGS treatment. Dry matter intake, excretion and digestibility were all affected by DGS treatment ($P < 0.01$; Table 4.3). Dry matter intake was decreased in the CON treatment ($P < 0.01$) by 1.76 kg/d as compared to DDGS and HiPro, which were not different from one another ($P = 0.65$), as was observed in Exp. 1. Dry matter excreted followed this trend, as CON had less DM excreted throughout the trial ($P < 0.01$) at approximately 1.64 kg/d as compared to DDGS at 2.44 kg/d and 2.84 kg/d from HiPro, which were not different from one another ($P = 0.11$). This resulted in statistically different DM digestibility of diets, with cattle fed CON having a DM digestibility of approximately 76.9% as compared to DDGS at 71.7% and HiPro at

68.1%, which was lower than DDGS ($P = 0.04$). Organic matter intake, excretion and digestibility followed a similar trend to DM, with CON cattle consuming less OM ($P = 0.02$), excreting significantly less ($P < 0.01$), which resulted in an improvement in OM digestibility ($P < 0.01$) for CON at 78.8% compared to DDGS and HiPro. Dried distillers grains plus solubles had greater ($P = 0.04$) OM digestibility than HiPro did, decreasing from 73.6% for DDGS to 69.7% for HiPro. Cattle consuming DDGS and HiPro diets were consuming greater OM in the diet and experienced lower DMD and OMD. Typically, lower OMD and DMD values have been observed for diets including DGS because of the NDF present in the DGS, compared to corn (Klopfenstein et al., 2008). Digestibility of diets including either DGS source had lower DM and OM digestibility, despite greater ADG and DMI which is consistent with other research (Klopfenstein et al., 2008). Typically, digested OMD and TDN are related, however, as measured by Hamilton (2016), as WDGS increased in the diet, OMD was reduced, despite improved growth performance response through increased ADG.

Fiber intake and excretion were affected by treatment, but digestibility remained unchanged ($P \geq 0.36$) due to DGS treatment. Control diets had lower NDF concentrations than DDGS and HiPro, because DDGS and HiPro had greater NDF than the corn they replaced (Table 4.2; nutrient composition). This resulted in NDF intake and excretion being greater for DDGS and HiPro diets as compared to CON, ($P < 0.01$) from 0.98 kg/d for CON to 1.83 kg/d for DDGS and 1.98 kg/d for HiPro, with no difference between DGS treatment ($P = 0.23$). Apparent total tract nutrient digestibility of NDF was unaffected by DGS treatment, however, and remained similar across the three DGS treatments ($P = 0.49$). Acid detergent fiber intake and excretion were similar to NDF

intake and excretion, but HiPro consumed the greatest ($P < 0.01$) amount of ADF at 1.09 kg/d, DDGS consumed 0.85 kg/d of ADF and CON, as expected consumed the least amount of ADF at 0.54 kg/d. Excretion followed this similar trend, as HiPro and DDGS both excreted the most ($P < 0.01$) ADF, with no difference between the two DGS treatments ($P = 0.15$). However, apparent total tract nutrient digestibility of ADF was unaffected ($P = 0.36$) by dietary treatment. In a trial by Vander Pol et al. (2008), ruminal pH was unaffected by including 40% WDGS in the diet, which, despite NDF being greater, did not change digestibility or ruminal fermentation characteristics likely due to small particle size of DGS. In a trial increasing dietary inclusions of DDGS fed to growing lambs, Felix et al. (2012) observed no change in NDF digestibility. Fiber digestibility was quite low, ranging from 27 to 55% for NDF, which was likely caused by the small particle size nature of the diet as well as high fermentability of the diet in the rumen, limiting cellulolytic microbes (Felix et al., 2012). Low NDF digestibility in the rumen could have been potentially affected by ammonia levels, which are necessary for fibrolytic bacteria growth, which will be discussed in further depth later. In a trial by May et al. (2008) evaluating the inclusion of WDGS in both receiving and finishing diets including SFC, WDGS included in the diet at 30% (DM basis) resulted in greater fecal pH values, suggesting more microbial activity post ruminally for animals fed WDGS.

Apparent ruminal NDF digestibility was not different ($P = 0.80$) between DGS treatments, which disagrees with results from Luebbe et al. (2012), who observed increasing WDGS increased rumen NDF digestibility, and Vander Pol et al. (2009) who observed greater ruminal NDF with 40% WDGS as compared to a control. As a result of no differences in rumen NDF digestibility, NDF flowing to the duodenum was greater (*P*

< 0.01) for DDGS and HiPro compared to CON due to greater intakes of NDF. Neutral detergent fiber excreted was greater ($P < 0.01$) for DDGS and HiPro at 1.11 and 1.23 kg/d, respectively compared to 0.62 kg/d for CON. The lack of effect of DGS treatment on apparent total tract NDF digestibility agrees with research by May et al. (2009), Uwitze et al. (2010) and Corrigan et al. (2009) who did not observe an improvement in NDF digestibility due to the inclusion of DDGS or WDGS in the diet. Ruminal acetate proportion was lower ($P < 0.01$) for DDGS and HiPro as compared to CON and had greater propionate proportions ($P < 0.01$).

Feeding either DGS source resulted in greater ($P = 0.05$) bacterial OM and tended ($P = 0.12$) to increase microbial N flow to the duodenum, which was observed by Luebbe et al. (2012) who observed bacterial OM flow to the rumen in SFC-based diets was greatest when WDGS were included in the diet at 30% (DM basis). Bacterial flow of N in the trial by Luebbe et al. (2012) averaged approximately 162 g/d for 30% WDGS in the diet as compared to 119 g/d for a CON. These values reflect what was observed in the current study, as bacterial N flow was approximately 115 g/d for CON, DDGS had 160 g/d, and 168 g/d for HiPro. Microbial efficiency (g N/kg of OM truly fermented) was similar ($P = 0.13$) between DGS treatments at 15.31, 19.47 and 17.97 for CON, DDGS, and HiPro respectively. True ruminal OM digestibility was not different ($P = 0.38$) between DGS treatment, however, for apparent OM digestibility in the rumen, CON had greater ($P = 0.01$) apparent OM digestibility than HiPro and DDGS. Organic matter intakes were much lower ($P = 0.02$) for CON based diets, which resulted in less OM flow through the rumen to the duodenum. In similar trials evaluating SFC with or without the inclusion of WDGS, Luebbe et al. (2009) did not observe large changes in intake, but it

was attributed to greater fat concentration of the WDGS in the diet which was closer to 7%, while the current study had an ether extract concentration of 5% for DGS diets (Table 4.1). Corrigan et al. (2009) observed including 40% WDGS in the diet resulted in an increase in DMI. The increase in DMI may have resulted in an increase in passage rate, potentially reducing digestibility of the diet (Corrigan et al., 2009). There was an interaction ($P = 0.05$) between corn processing and DGS treatment on post-ruminal OM digestibility, SFC-CON having the greatest post ruminal OM digestibility, and DRC-HiPro having the least, which pairs well with what was observed in post ruminal starch digestibility. Fecal output increased ($P < 0.01$) with the inclusion of either DGS source, resulting in a reduction in total tract OM digestibility ($P < 0.01$), which was expected given the greater DMI. A reduction in total tract OM digestibility due to DGS inclusion has been observed in other research studies, especially as WDGS is included at greater inclusions (Corrigan et al., 2009, May et al., 2009 and Uwitze et al., 2010).

Gross energy intake was greatest for cattle consuming DDGS and HiPro ($P < 0.01$; Table 4.3) over CON, which resulted in greater DE intake as well ($P = 0.04$). When evaluating DE intake (Mcal/kg), CON and DDGS tended ($P = 0.08$) to consume more than the HiPro based diets. Digestible energy calculated as a percentage of gross energy was greatest ($P < 0.01$) for CON at 75.9%, at 71.0% for DDGS, and lowest for HiPro at 67.4%. Dietary calculated TDN tended ($P = 0.08$) to be greater for CON and DDGS over the HiPro treatment at 77.3 and 76.2 for CON and DDGS, and 73.0 for HiPro. In byproduct based diets, TDN and OM digestibility are typically related (Hamilton, 2016). In the current study, DDGS and HiPro TDN values were greater than OMD by 2.66 and 3.30 percentage units for DDGS and HiPro respectively.

Effect of Corn Processing on Nutrient Digestibility

As in the finishing trial, DMI tended (P = 0.07; Table 4.3) to be lower for heifers consuming SFC rather than DRC-based diets by approximately 0.93 kg/d. This resulted in less (P = 0.04) DM excreted from the SFC treatment by 0.45 kg/d and no difference (P = 0.13) in overall apparent total tract dry matter digestibility. Organic matter intake and excretion followed a similar trend, as cattle consuming SFC treatment tended (P = 0.06) to consume approximately 0.94 kg/d less OM than cattle consuming DRC. Excretion of OM was less (P = 0.02) for cattle consuming SFC compared to DRC. Apparent total tract OM digestibility tended to be approximately 2.55 percentage units less (P = 0.08) for DRC than SFC treatment. According to Cooper et al. (2002), in a trial evaluating total tract DM digestibility of SFC and DRC-based diets, DM and OM apparent total tract digestibility were reduced by 4% when DRC-based diets were fed as compared to SFC included in the diet at 82% of the diet (DM basis). Apparent ruminal OM digestibility was lower (P = 0.05) for SFC, but it tended (P = 0.09) greater for true ruminal fermentation for SFC as compared to CON. True ruminal OM digestibility was 64.6% for DRC and 70.3% for SFC, which was relevant to the 65% true OM digestibility Cooper et al. (2002) observed at 64.4% for DRC and 69.3% for SFC. Likewise, Luebbe et al. (2012) observe true ruminal OM digestibility of 71.6 and 77.8% for DRC and SFC, respectively.

Apparent and true starch rumen digestibility, starch intake, bacterial starch flow, feed starch flow and total starch flow to the duodenum were affected (P < 0.01) by corn processing method. Starch intakes were less for SFC as compared to DRC, which had been observed by May et al. (2009). In contrast, Corrigan et al. (2009) and Barajas and

Zinn (1998) and Luebbe et al. (2012) observed similar starch intakes between corn processing methods. Dry rolled corn had lower apparent and true rumen starch digestibility, as well as greater ($P < 0.01$) overall starch intake compared to SFC. Post ruminal digestibility, fecal output and total tract digestibility of starch were lower for DRC compared to SFC. Total tract starch digestibility of SFC was greater ($P < 0.01$) than DRC which agrees with Zinn et al. (1995), Corona et al. (2006) and Luebbe et al. (2012) and Huntington (1997).

Neutral detergent fiber intake followed DM intake, and tended ($P = 0.09$) to be greater for cattle consuming DRC based treatments. Contrary to this, cattle consuming more NDF on the DRC-based treatment tended ($P = 0.09$) to excrete 0.14 kg/d less in feces than the SFC treatment. This change in excretion resulted in a change in NDF digestibility of the diet, decreasing ($P < 0.01$) from 51.3% for the DRC treatment to 32.9% for the SFC treatment. Acid detergent fiber did not follow the same trend as NDF, as intake of ADF was not different ($P = 0.18$) between SFC or DRC based treatments, at 0.87 kg/d for DRC and 0.79 kg/d for SFC. Excretion of ADF was similar, with no statistical difference ($P = 0.20$) between treatments, but as with NDF, there was numerically greater ADF excretion from SFC at 0.43 kg/d as compared to 0.38 kg/d from DRC treatment. Apparent total tract ADF digestibility was greater ($P = 0.03$) as in NDF for the DRC treatment as compared to SFC similar to NDF results. Starch intake was greater ($P = 0.03$) for DRC treatment at 4.42 kg/d as compared to 3.89 kg/d for SFC treatment. Fiber digestibility was likely greater for the DRC-based diets because of less starch digestion in the rumen, likely improving the rumen environment for fiber digestibility. Neutral detergent fiber apparent total tract digestibility was evaluated in a

study by Corrigan et al. (2009), and digestion of fiber was similar, whether NDF or ADF. There were no observed differences ($P = 0.62$) in average ruminal pH across treatments, despite greater ruminal starch digestibility for SFC, which was observed by Corrigan et al. (2009) when comparing SFC to DRC. It was hypothesized with the increase in NDF in the diet, average ruminal pH would increase, as observed by Galyean et al. (1976). Apparent NDF ruminal digestibility was lower ($P < 0.01$) for SFC-based diets as compared to DRC, decreasing from 51.9% for DRC to 21.8% for SFC. According to Luebbe et al. (2012), comparing DRC to SFC based diets resulted in no differences in either apparent NDF or post ruminal NDF digestibility. Apparent NDF ruminal digestibility is not reported in many studies comparing SFC and DRC, but apparent NDF total tract digestibility is often decreased in SFC as compared to DRC based diets. There were no differences in bacterial efficiency (g N/kg of OM truly fermented) due to corn processing treatment ($P = 0.81$), and values were 17.39 and 17.77 for DRC and SFC, respectively. These values are similar to observed microbial efficiencies by Cooper et al. (2002), who observed bacterial efficiencies of approximately 17.4 and 18.5 for SFC and DRC, respectively.

Gross energy intake was greater ($P = 0.04$) for the DRC treatment at 40.26 Mcal/d as compared to 34.97 Mcal/d for the SFC treatment. This resulted in a tendency for greater ($P = 0.08$) DE intake for DRC as compared to SFC based diets. As observed, SFC starch digestibility, increased the energy available to the animal, improving growth performance in the finishing trial. This was evident in the metabolism trial, there were no differences in DE intake ($P = 0.74$), digestible energy as a percentage of GE daily intake ($P = 0.24$) or TDN values ($P = 0.74$) between DRC and SFC.

Effect of Corn Processing and DGS treatment on Ruminal Metabolism

There was an interaction ($P < 0.01$; Table 4.5) between corn processing method and DGS treatment for proportionate butyrate and propionate concentration in the VFA samples. For the interaction in propionate proportion, all treatments were similar ($P \geq 0.10$) except for SFC-CON, which had the lowest proportion of measured propionate at 29 mol/100 mol while all others averaged above 37 mol/100 mol. For butyrate proportions, SFC-HiPro, DRC-CON, and SFC-DDGS were the lowest butyrate ratios, while DRC-HiPro had the greatest butyrate concentration at 20 mol/100 mol. Acetate proportion was affected by both corn processing treatment ($P < 0.01$) and DGS treatment ($P < 0.01$). Steam flaked corn had greater ($P < 0.01$) acetate proportions than DRC. In DGS treatments, CON had the greatest acetate proportion at 43 mol/100 mol, while DDGS and HiPro were similar ($P = 0.46$) to each other at 36 and 38 mol/100 mol respectively. The acetate to propionate ratio was greater ($P < 0.01$) for SFC than DRC across all diets. Total VFA concentration in measured samples was not impacted ($P = 0.96$; Table 4.5) by DGS treatment, averaging approximately 132 mM. Total VFA concentration was greater ($P = 0.03$) for DRC at approximately 145 mM for the DRC treatment and 119 mM for the SFC treatment. Many trials have evaluated the change in VFA, and as in a trial by Corrigan et al. (2009), proportions of VFA were not affected by corn processing treatment ($P > 0.22$). The acetate: propionate ratio was greater ($P < 0.05$) for SFC, as was observed by Corrigan et al. (2009) when evaluating SFC and DRC diets. With the increased NDF content of DGS treatment, it was expected acetate levels may have been increased, but the opposite was observed, as CON diets had greatest acetate levels. In a trial by Vander Pol et al. (2009), including WDGS in the diet at 40%

increased ruminal propionate concentrations, which was observed for the inclusion of either DGS source, but was also observed for DRC-CON diets. It is unclear why in this trial SFC-CON had lower propionate and greater acetate than DRC-CON, as this is opposite what Luebbe et al. (2012) observed. In a trial by Vander Pol et al. (2009) molar proportions of propionate were greater and acetate were less ($P < 0.05$) when WDGS was included in the diet as compared to a control diet, which was observed in the measured acetate proportion in the current trial. The acetate to propionate ratio was thus less ($P < 0.01$) for DRC than SFC, which was not observed by Corrigan et al. (2009). Measured VFA proportions do not add up to 100 because other VFAs measured were not included in Table 4.5 due to insignificance.

Measured ammonia concentration was affected by DGS treatment ($P < 0.01$; Table 4.5). When DDGS was included in the diet, ammonia concentrations decreased from 17.0 mg/dL in the CON treatment to 8.2 mg/dL in the DDGS and 6.4 mg/dL in the HiPro diet, with no differences between the two DGS treatments ($P = 0.34$). In agreement with our finding, May et al. (2008) and Uwitze et al. (2010) observed reductions in ruminal ammonia concentrations when DGS were included in the diet. In the diets, DDGS replaced urea as an RDP source, which is 100% degradable (NASEM, 2016). Rumen degradable protein may have been limiting in HiPro, as values were close to the 5.0 mg/dL minimum levels (Satter and Slyter, 1974) which are needed to ensure maximal bacterial production. The lack of difference in NDF digestibility and lower acetate values for DDGS and HiPro treatments suggests RDP may have been limiting, as easily accessible ammonia is the energetic source for fibrolytic bacteria. Excess protein in the HiPro and DDGS treatments was thought to recycle back through the saliva back into

the rumen but it is unknown how efficient this process is at supplying RDP back to the rumen. In CON diets, ammonia concentrations may have been greater due to urea being supplied in the supplement of the diet to make up for the lack of protein provided because there were no DGS included in the diet. Corn processing treatment affected ($P < 0.01$) ruminal ammonia levels, where average ruminal levels throughout the day were 13.0 mg/dL in DRC-treatments but were lower in SFC treatments at an average of 8.0 mg/dL. Similar results were observed by Cooper et al. (2002), who observed feeding DRC resulting in greater ruminal ammonia concentrations at 12 h post feeding as compared to SFC-based diets. Additionally, May et al. (2009), observed DRC based diets with or without DDGS included at 25% (DM basis) had more measured ammonia than SFC-based diets. According to Cooper et al. (2002), the reduction in ruminal ammonia concentrations were likely due to greater ruminal starch fermentation.

There were no observed interactions for ruminal pH measurements ($P \geq 0.34$; Table 4.6; Figure 4.1) so main effects of DGS or corn processing treatment will be discussed. There was no interaction between DGS and corn processing throughout the day, but there was an effect of hour, as ruminal pH changed throughout the day. In Figure 4.1, hour 0 is when cattle were fed their diets first thing in the morning at 0800h. For minimum and maximum ruminal pH through the six periods, DGS treatment did not have an affect ($P \geq 0.21$). Average ruminal pH was not affected by DGS treatment ($P = 0.62$), and was 5.97, 5.96 and 6.11 for CON, DDGS, and HiPro, respectively. Ruminal pH variance was affected ($P < 0.01$) by DGS treatment, as the CON had greater variance than either DDGS or HiPro which were like one another ($P = 0.41$). There was a tendency ($P = 0.08$) for heifers fed the HiPro treatment to spend less time under a

ruminal pH of 5.6 than either CON or DDGS, which were not different from one another ($P = 0.93$). Heifers fed CON and DDGS spent 443 and 428 min/d under a ruminal pH of 5.6, while those fed HiPro only spent on average 126 min/d below a pH of 5.6. While this tendency was not observed in area below 5.6 ($P = 0.11$), area below 5.6 followed the same numerical trend as time below 5.6, CON had an area of 141, DDGS 136 and HiPro only 19. Time and area spent below 5.0 was not affected by DGS treatment ($P \geq 0.44$). Average ruminal pH is typically reduced with an increase in starch fermentation in the rumen and an increase in total rumen VFA concentration measured. According to Corrigan et al. (2009), there was no difference in average ruminal pH between DRC and SFC, but cattle did spend more time below a pH of 5.0. Corn processing did not affect ($P \geq 0.21$) for any rumen pH parameters measured. It is unclear this as to why ruminal pH was similar between treatments, but with lower average acetate proportionally, this may have affected the ruminal pH. Ruminal fermentation may not have been increased in the study through SFC, as observed through no differences in ruminal pH or VFAs.

When evaluating the two experiments together, some of the growth performance response can be explained through the metabolism experiment. In most growth performance parameters, HiPro and DDGS were similar to one another. In the metabolism experiment, similar results were observed, feeding HiPro and DDGS resulted in similar starch intakes, digestibility, and greater DMI than the CON treatment. Discrepancies exist because ADG and DMI increased for DDGS and HiPro in the growth performance trial, but starch digestibility decreased with those treatments, especially in DRC-based treatments, which did have lower duodenal starch digestibility for DDGS and HiPro treatments as compared to DRC-CON. This suggests, cattle consuming DDGS and

HiPro were deriving energy from a nutrient other than starch. Based on the RUP and protein flow in these diets, in addition to the higher DMI, excess RUP likely contributed to the observed ADG response.

The role protein plays in starch digestion post-ruminally needs to be further investigated. What the exact role protein plays in small intestine starch digestion is unclear. Based on other research, providing high-quality protein such as casein in the small intestine can increase α-amylase secretion, but changing how much protein and the quality of that protein entering the small intestine and how it affects starch digestion and absorption is unclear. There is an energetic response to excess protein flow in the small intestine, which may have been the reason for the performance response in the current study. The excess protein above the traditional DDGS in this case may have not been fully realized because starch digestion was reduced, limiting energy response to starch digested.

Conclusion

Feeding DDGS and HiPro increased DMI and ADG, improving feed efficiency in DRC based diets, without affecting G:F in SFC based diets. Cattle consuming DDGS and HiPro had greater final carcass weights and LM areas as compared to CON based diets. Despite DDGS improving DRC based diets, HiPro did not further improve growth performance. These findings disagree with our hypothesis that feeding HiPro in the diet would increase starch digestibility post ruminally and thus growth performance. Apparent and true ruminal starch digestion were lower for cattle consuming HiPro and DDGS. The improvement in performance of cattle fed DDGS and HiPro was likely due to factors other than starch digestion. It has been suggested it is done through increased nutrient

throughput through increased DMI, increased fat content of the HiPro and DDGS, and through the catabolism of excess protein as an energy source. Based on these data, steam flaking improves efficiency and carcass characteristics as compared to dry rolled corn. Including DDGS and HiPro did not improve G:F when replacing SFC, but improved G:F when replacing DRC. Starch digestion supported the improvement in efficiency due to SFC, but it was less clear with the inclusion of DDGS and HiPro in DRC based diets. Steam flaked corn resulted in a reduction in apparent total tract NDF digestibility, but it was unclear as to the causes for this, because ruminal pH and VFAs were not affected. Feeding DGS reduced ammonia levels, and decreased OM, DM and starch digestibility. This trial suggests DRC based diets are improved when DDGS or HiPro are added, but not if fed in SFC diets.

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Table 4.1. Diet composition (DM basis) in Exp. 1 and Exp. 2

	Treatment[1]					
	CON		DDGS		HiPro	
Ingredient	DRC	SFC	DRC	SFC	DRC	SFC
Dry-Rolled Corn	87.0	-	57.0	-	57.0	-
Steam Flaked Corn	-	87.0	-	57.0	-	57.0
DDGS	-	-	30.0	30.0	-	-
High Protein DDGS	-	-	-	-	30.0	30.0
Sorghum Silage	8.0	8.0	8.0	8.0	8.0	8.0
Dry Supplement[2]						
Fine Ground Corn	1.3925	1.3925	2.7925	2.7925	2.7925	2.7925
Limestone	1.6900	1.6900	1.6900	1.6900	1.6900	1.6900
Tallow	0.1250	0.1250	0.1250	0.1250	0.1250	0.12500
Urea	1.4000	1.4000	-	-	-	-
Salt	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000
Beef Trace Mineral[3]	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500
Vitamin A-D-E[4]	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150
Rumensin-90[5]	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165
Tylan 40[6]	0.0110	0.0110	0.0110	0.0110	0.0110	0.0110
Nutrient Composition[7]						
Crude Protein, %	12.91	12.64	15.22	15.04	17.50	17.33
Starch	62.68	62.85	44.58	44.70	44.13	44.20
NDF, %	14.35	13.44	21.73	21.73	23.39	22.80
ADF, %	7.53	7.25	10.56	10.37	12.97	12.80
Ether Extract, %	3.96	3.10	5.35	4.79	5.17	4.61

[1]Treatments were control (CON), regularly produced DDGS included in the diet at 30% (DDGS) or high protein DDGS included in the diet at 30% (HiPro), fed with either dry rolled corn (DRC) or steam flaked corn (SFC)
[2]Supplement formulated to be fed at 5.0% of diet DM.
[3]Premix contains Zn-6.0%, Fe-5.0%, Mn-4.0%, Cu-2.0%, Mg-0.29%, I-0.2%, Co-0.05%.
[4]Premix contained Vitamin A-30 000 IU, Vitamin D-6 000 IU, Vitamin E -7.5 IU/g
[5]Premix contained 330 mg/hd/d monensin
[6]Premix contains 8.8 g/ton tylosin.
[7]Based on analyzed nutrients for each ingredient.

Table 4.2. Effect of corn processing type on DGS use on growth performance and carcass characteristics of finishing cattle (Exp. 1)

	Treatment[1]						SEM	*P*-Value[2]		
	Control		DDGS		HiPro					
Item	DRC	SFC	DRC	SFC	DRC	SFC		Corn	Distiller	Int
Performance										
Initial BW, kg	288	288	288	288	288	287	0.6	0.26	0.73	0.69
Final BW, kg[3]	578	582	609	600	596	597	4.9	0.94	<0.01	0.22
DMI, kg/day	9.0	8.3	9.8	9.1	9.5	9.0	0.1	<0.01	<0.01	0.80
ADG, kg[3]	1.43	1.47	1.61	1.56	1.54	1.55	0.024	0.99	<0.01	0.22
Gain:Feed[3]	0.157[a]	0.175[c]	0.163[b]	0.171[c]	0.161[ab]	0.171[c]	0.002	<0.01	0.73	0.02
NEm, Mcal/kg	1.94	2.11	1.94	2.05	1.93	2.03	0.016	<0.01	0.03	0.07
NEg, Mcal/kg	1.29[a]	1.44[c]	1.29[a]	1.37[b]	1.28[a]	1.37[b]	0.011	<0.01	<0.01	<0.01
Carcass Characteristics										
HCW, kg	362	367	384	378	376	376	3.1	0.95	<0.01	0.22
LM Area, cm[2]	83.64[a]	87.99[c]	87.52[bc]	89.05[c]	86.33[bc]	85.03[ab]	0.99	0.06	0.02	0.02
Marbling Score[4]	513	505	499	490	533	515	16.7	0.40	0.20	0.95
Backfat Thickness, cm	1.21	1.23	1.28	1.34	1.42	1.33	0.057	0.90	0.03	0.37
Yield Grade[5]	3.003	2.840	3.065	2.997	3.193	3.170	0.079	0.19	<0.01	0.65
Liver Abscesses, %[6]	3.57	3.45	1.79	1.72	3.57	0.00	-	-	-	-

[1]Treatments were control (CON), regularly produced DDGS included in the diet at 30% (DDGS) or high protein DDGS included in the diet at 30% (HiPro), fed with either dry rolled corn (DRC) or steam flaked corn (SFC)

[2]Int = *P*-value for the interaction of corn processing method and DGS treatment. Corn = *P*-Value for the main effect of corn processing effect. Distiller = *P*-Value for the main effect of DGS treatment

[3]Calculated from hot carcass weight, adjusted to a common 63% dressing percentage

[4] Marbling Score 400-Small00, 500 = Modest00

[5] Calculated YG (yield grade) = [2.5 + (6.35 × fat thickness, cm) + (0.2 × 2.5% KPH) + (0.0017 × HCW, kg) – (2.06 × LM area, cm^2)]; (USDA, 2016).

[6]Did not converge

Table 4.3. Effect of high protein DGS and corn processing method on apparent total tract nutrient digestibility of dry rolled corn or steam flaked corn-based diets (Exp. 2)

	Treatment[1]							*P*-Value[2]		
	CON		DDGS		HiPro					
Item	DRC	SFC	DRC	SFC	DRC	SFC	SEM	Corn	Distiller	Int.
Dry Matter										
Intake, kg/day	7.94	5.80	8.62	8.37	8.97	8.56	0.96	0.07	0.01	0.26
Excreted, kg/day	1.96	1.32	2.53	2.36	3.11	2.57	0.37	0.04	0.01	0.60
Digestibility, %	76.1	77.6	71.3	72.1	66.0	70.1	1.91	0.13	0.01	0.56
Organic Matter										
Intake, kg/day	7.77	5.63	8.31	8.05	8.72	8.30	0.922	0.06	0.02	0.24
Excreted, kg/day	1.79	1.15	2.30	2.12	2.90	2.33	0.346	0.02	0.01	0.57
Digestibility, %	77.8	79.8	73.0	74.1	67.5	71.9	1.94	0.08	0.01	0.59
NDF										
Intake, kg/day	1.17	0.79	1.89	1.78	2.05	1.91	0.206	0.09	0.01	0.62
Excreted, kg/day	0.56	0.60	0.89	1.14	1.12	1.25	0.146	0.09	0.01	0.57
Digestibility, %	54.6	26.7	52.8	37.8	46.4	34.3	5.30	0.01	0.49	0.23
ADF										
Intake, kg/day	0.61	0.46	0.87	0.83	1.13	1.06	0.108	0.18	0.01	0.73
Excreted, kg/day	0.29	0.28	0.36	0.50	0.49	0.51	0.067	0.20	0.01	0.29
Digestibility, %	54.0	39.9	54.9	43.1	56.4	52.1	5.63	0.03	0.36	0.60
Starch										
Intake, kg/day	5.10	3.88	4.07	3.89	4.10	3.90	0.473	0.03	0.15	0.13
Excreted, kg/day	0.24^{ad}	0.09^{cd}	0.33^{a}	0.16^{d}	0.46^{b}	0.15^{cd}	0.042	0.01	0.01	0.04
Digestibility, %	95.1^{a}	97.8^{d}	92.0^{b}	96.1^{ad}	88.7^{c}	96.2^{ad}	0.71	0.01	0.01	0.01
Energy										
GE Intake, Mcal/d	36.35	25.35	41.17	39.16	43.28	40.39	4.238	0.04	0.01	0.27

DE Intake, Mcal/d	27.00	19.39	28.95	27.76	28.11	27.87	3.017	0.08	0.04	0.18
DEI, Mcal/kg	3.46	3.35	3.37	3.33	3.17	3.26	0.091	0.74	0.08	0.48
DE, % of GE	75.3	76.6	70.7	71.2	65.7	69.0	1.91	0.24	0.01	0.70
TDN[3]	78.58	76.04	76.68	75.68	72.00	74.02	2.057	0.74	0.08	0.48

[1]Treatments were control (CON), regularly produced DDGS included in the diet at 30% (DDGS) or high protein DDGS included in the diet at 30% (HiPro), fed with either dry rolled corn (DRC) or steam flaked corn (SFC)

[2]Int = *P*-value for the interaction of corn processing method and DGS treatment. Corn = *P*-Value for the main effect of corn processing effect. Distiller = *P*-Value for the main effect of DGS treatment

[3]TDN values calculated from DE of the diet

Table 4.4. Effect of high protein DGS on ruminal and duodenal nutrient digestibility of dry rolled corn or steam flaked corn-based diets (Exp. 2)

	Treatment[1]						SEM	*P*–Value[2]		
	Control		DDGS		HiPro			Corn	Distiller	Int.
Item	DRC	SFC	DRC	SFC	DRC	SFC				
Ruminal Digestibility, %										
Apparent OM	47.6	41.9	34.4	35.7	40.4	29.7	3.85	0.05	0.01	0.15
True OM	66.6	72.7	64.3	67.0	62.9	71.2	3.99	0.09	0.38	0.71
Apparent Starch	75.9	84.6	66.4	77.7	71.6	72.7	3.92	0.01	0.01	0.15
True Starch	76.9	86.8	68.6	83.0	75.6	85.3	3.60	0.01	0.11	0.67
Apparent NDF	56.4	11.7	47.4	31.1	52.0	22.7	7.00	0.01	0.80	0.13
Duodenal Flow, kg/d										
Bacterial OM	1.44	1.73	2.42	2.49	1.92	3.47	0.496	0.08	0.05	0.19
Feed OM	2.69	1.55	3.07	2.67	3.34	2.34	0.534	0.04	0.25	0.73
Total OM	3.97	3.28	5.49	5.16	5.27	5.81	0.661	0.63	0.01	0.31
NDF	0.52	0.72	0.97	1.25	0.99	1.46	0.162	0.01	0.01	0.51
Purine: N Ratio	0.143	0.152	0.147	0.168	0.151	0.159	0.011	0.08	0.50	0.68
Crude Protein	1.08	1.03	1.60	1.63	1.74	1.93	0.161	0.53	0.01	0.52
Microbial Nitrogen	0.121	0.108	0.179	0.140	0.139	0.197	0.031	0.93	0.12	0.16
Microbial CP	0.756	0.644	1.12	0.875	0.869	1.23	0.194	0.93	0.12	0.16
Microbial Efficiency, % TDN	12.55	15.64	17.60	14.83	13.63	18.88	2.532	0.34	0.59	0.21
Microbial Efficiency, % OM[3]	14.40	16.22	21.71	17.23	16.07	19.87	2.143	0.81	0.13	0.10
Microbial Starch	0.06[a]	0.09[a]	0.09[a]	0.21[b]	0.16[ab]	0.50[c]	0.045	0.01	0.01	0.02
Feed Starch	1.19	0.56	1.36	0.71	1.02	0.57	0.213	0.01	0.21	0.71
Total Starch	1.26	0.65	1.45	0.91	1.18	1.07	0.233	0.01	0.31	0.21

Post Ruminal Digestibility, % Entering										
OM	56.7^{b}	65.3^{c}	58.5^{bc}	59.5^{bc}	45.5^{a}	59.2^{bc}	2.75	0.01	0.01	0.05
Starch	77.6^{bc}	86.2^{a}	74.7^{c}	82.5^{ab}	59.3^{d}	83.5^{ab}	3.34	0.01	0.01	0.02

[1]Treatments were control (CON), regularly produced DDGS included in the diet at 30% (DDGS) or high protein DDGS included in the diet at 30% (HiPro), fed with either dry rolled corn (DRC) or steam flaked corn (SFC)

[2]Int = *P*-value for the interaction of corn processing method and DGS treatment. Corn = *P*-Value for the main effect of corn processing effect. Distiller = *P*-Value for the main effect of DGS treatment

[3]Microbial Efficiency, g N/kg of OM truly fermented

Table 4.5. Effect of HiPro and DDGS and corn processing method on ruminal VFA and ammonia concentration (Exp. 2)

	Treatment[1]							*P*–Value[2]		
	Control		DDGS		HiPro					
Item	DRC	SFC	DRC	SFC	DRC	SFC	SEM	Corn	Distiller	Int.
Ruminal VFA[3]										
Total, mM	138.07	129.14	145.10	119.82	150.90	108.53	15.09	0.03	0.96	0.50
Acetate[4]	38.64	48.39	33.95	38.93	33.97	41.19	2.051	0.01	0.01	0.47
Propionate[4]	42.40^{b}	28.48^{a}	40.34^{b}	42.02^{b}	39.26^{b}	38.15^{b}	1.720	0.01	0.01	0.01
Butyrate[4]	11.48^{a}	17.46^{ab}	16.01^{ab}	12.33^{a}	19.77^{b}	13.87^{a}	1.383	0.11	0.01	0.01
A:P[5]	0.95^{a}	1.89^{b}	0.88^{a}	0.92^{a}	0.91^{a}	1.12^{a}	0.083	0.01	0.01	0.01
Ammonia, mg/dL	19.99	14.01	10.25	6.15	8.80	3.93	1.449	0.01	0.01	0.73

[1]Treatments were control (CON), regularly produced DDGS included in the diet at 30% (DDGS) or high protein DDGS included in the diet at 30% (HiPro), fed with either dry rolled corn (DRC) or steam flaked corn (SFC)

[2]Int = *P*-value for the interaction of corn processing method and DGS treatment. Corn = *P*-Value for the main effect of corn processing effect. Distillers = *P*-Value for the main effect of DGS treatment

[3]Ruminal volatile fatty acids (VFA).

[4]VFA concentration in mol/100 mol

[5]Acetate:Propionate

Table 4.6. Effect of HiPro DDGS and corn processing method on ruminal pH parameters (Exp. 2)

	Treatment[1]							*P*–Value[2]		
	Control		DDGS		HiPro					
Item	DRC	SFC	DRC	SFC	DRC	SFC	SEM	Corn	Distiller	Int.
Ruminal pH										
Minimum pH	5.19	5.42	5.44	5.35	5.41	5.74	0.162	0.21	0.21	0.35
Maximum pH	6.78	6.76	6.67	6.61	6.54	6.78	0.213	0.75	0.78	0.70
Average pH	5.87	6.08	6.01	5.91	5.94	6.28	0.185	0.30	0.62	0.41
pH Variance	0.153	0.139	0.072	0.107	0.068	0.069	0.0276	0.73	0.01	0.63
Time < 5.6 min/d	534	352	435	422	195	58	157	0.40	0.08	0.86
Area < 5.6[3]	194	88	98	173	28	10	70	0.77	0.11	0.39
Time < 5.0 min/d	66	6	19	89	0	0	47	0.93	0.44	0.34
Area < 5.0[3]	14	0	4	9	0	0	7	0.63	0.59	0.48

[1]Treatments were control (CON), regularly produced DDGS included in the diet at 30% (DDGS) or high protein DDGS included in the diet at 30% (HiPro), fed with either dry rolled corn (DRC) or steam flaked corn (SFC)

[2]Int = *P*-value for the interaction of corn processing method and DGS treatment. Corn = *P*-Value for the main effect of corn processing effect. Distiller = *P*-Value for the main effect of DGS treatment

[3]Area < 5.6 and < 5.0 = ruminal pH units below 5.6 and 5.0 by minute

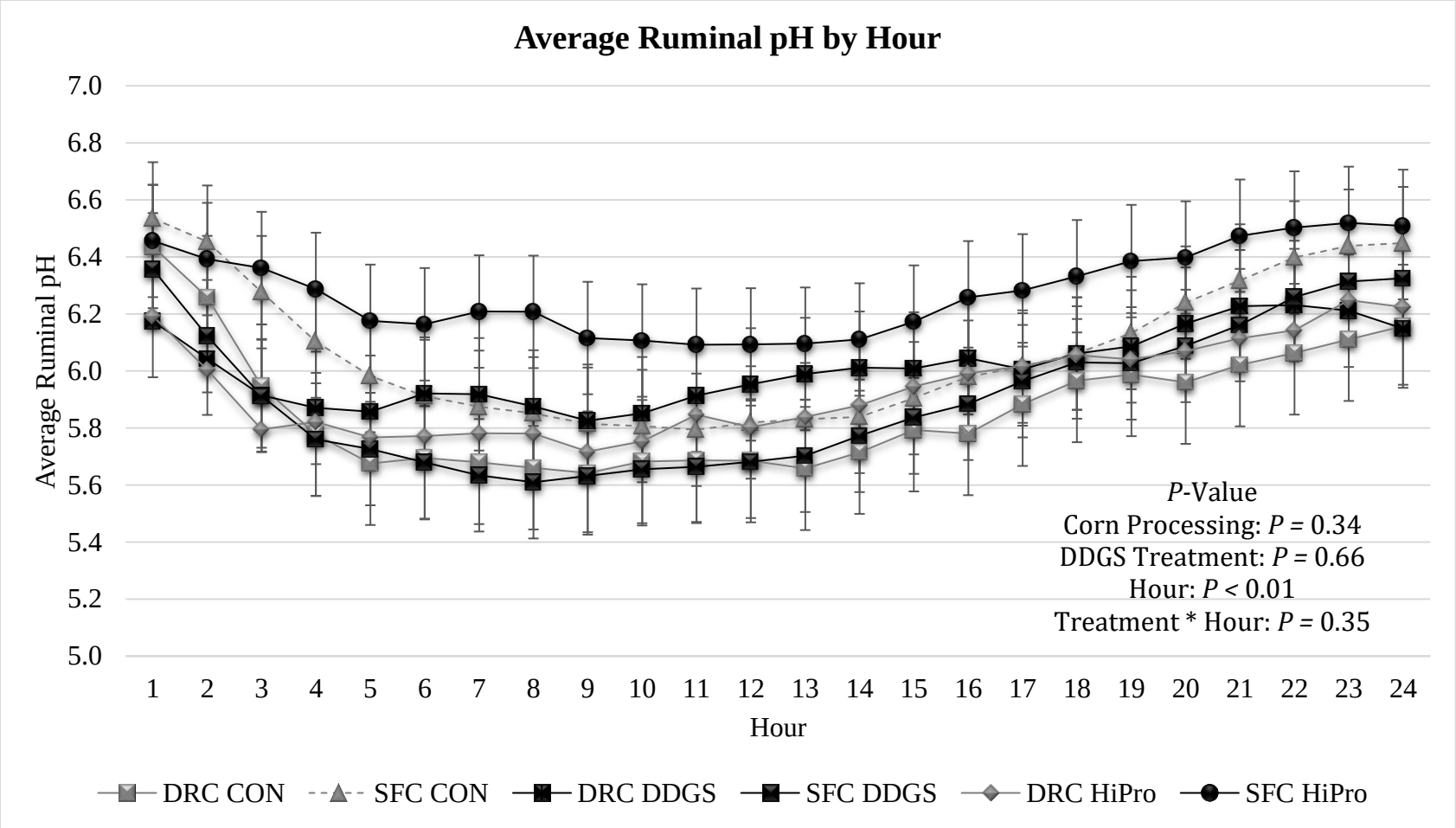

Figure 4.1. Average hourly ruminal pH in days 15-19 in Exp. 2. Treatments were control (CON), regularly produced DDGS included in the diet at 30% (DDGS) or high protein DDGS included in the diet at 30% (HiPro), fed with either dry rolled corn (DRC) or steam flaked corn (SFC).