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# Effect of corn silage harvest, hybrid, and concentration on performance in growing and finishing beef cattle

Fred H. Hilscher Jr
*University of Nebraska-Lincoln*, Henry_hilscher@yahoo.com

# EFFECT OF CORN SILAGE HARVEST, HYBRID, AND CONCENTRATION ON PERFORMANCE IN GROWING AND FINISHING BEEF CATTLE

by

F. Henry Hilscher Jr.

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EFFECT OF CORN SILAGE HARVEST, HYBRID, AND CONCENTRATION ON PERFORMANCE IN GROWING AND FINISHING BEEF CATTLE

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Six studies were conducted to evaluate effects of corn silage harvest, hybrid, and concentration in growing and finishing diets. Experiment 1, evaluated corn silage DM (37 or 43%) and replacing corn grain with silage (15 or 45% of diet DM) in finishing diets. Experiment 2, evaluated corn silage DM (37 or 43%) and response to rumen undegradable protein (RUP) supplementation in growing diets. Experiment 3, evaluated nutrient digestibility of 37 or 43% DM corn silage at two different intakes. Experiment 4, 5, and 6 evaluated three corn silage hybrids: a standard hybrid control (CON), a brown midrib (*bm3*) hybrid (BM3), and an experimental *bm3* hybrid (BM3-EXP) with a soft endosperm trait. Experiment 4 evaluated the three hybrids and concentration (15 or 45% of diet DM) in finishing diets, while Exp. 5 and 6, evaluated the same three silage hybrids in growing diets. In Exp. 1 with finishing cattle, as DM of silage increased from 37 to 43%, there were no differences ($P \geq 0.30$) in DMI, ADG, or G:F. In Exp. 2 with growing cattle, as DM of silage increased from 37 to 43%, ADG and G:F were reduced ($P \leq 0.04$). Increasing supplemental RUP in the diet increased ($P \leq 0.05$) ending BW, ADG, and G:F linearly. In Exp. 1 and 4, as concentration of silage in the finishing diet increased from 15 to 45%, ADG and G:F decreased ($P \leq 0.04$). In Exp 4, BMR-EXP had the greatest ADG and G:F at 15% silage. At 45% silage, both *bm3* hybrids had greater ($P \leq 0.05$) ADG than CON, but G:F was greatest for cattle fed BM3 ($P$<0.03). In Exp 5 with growing

cattle, ending BW, DMI, and ADG were greater ($P < 0.01$) for steers fed the BM3 and BM3-EXP compared to the CON. In Exp. 6, steers fed both *bm3* hybrids had greater ($P < 0.01$) NDF and ADF digestibility than the CON. Delayed silage harvest decreased performance in growing diets, but did not affect performance of finishing cattle. Silage hybrids containing the *bm3* trait improved performance, and improvement was most evident with large concentrations of silage.

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## Introduction

Corn silage production in the United States can be traced to the end of the 19th century, and has been used in beef production since the early 1900s (Hays, 1912). Corn silage allows cattle feeders to take advantage of the entire plant at a time of maximum quality and tonnage as well as secure substantial quantities of roughage/grain inventory (Burken et al., 2017b). It is a moderately high energy, low protein forage that allows for flexibility in growing and finishing cattle feeding programs and is a supplemental energy source in cow and calf production systems (Allen, 2003). It is well documented that when corn silage replaces corn in finishing diets, G:F decreases as corn silage increases in the diet (Goodrich et al., 1974; Erickson et al., 2001). Management decisions, such as silage harvest maturity and corn silage hybrid selection, can affect the quality and yield of corn silage and impact animal performance in growing and finishing cattle (Chamberlain et al., 1971; Keith et al., 1981)

While incorporating distillers grains and corn silage at higher concentrations in growing and finishing diet has shown to be more advantageous to corn silage alone in recent years (Felix et al., 2014; Burken et al., 2017a,b), researchers are still aiming to validate optimum harvest time and new hybrids to improve digestibility of corn silage in the diet. Companies have been evaluating hybrids of corn silage with lower lignin content that increase fiber digestibility, such as brown midrib hybrids. The objectives of the following studies were to provide enhanced knowledge of the value of corn silage by evaluating harvest time, hybrid selection, and concentration in the diet and their effects on animal performance in growing and finishing diets and carcass characteristics in finishing diets.

# CHAPTER I. Review of the Literature

## Fiber Digestion in Ruminants

Ruminant animals are a diverse group of mammals which have a symbiotic relationship with microorganisms that has allowed them to become herbivores and derive all of their required nutrients from forage plant materials. Ruminants have adapted to a variety of ecological niches because of diverse ruminal microbial populations, which consist primarily of bacteria, protozoa and fungi. Ruminant animals have the ability to convert low quality feeds into high quality protein and utilize feeds from land that is not suitable to grow crops for human consumption (Varga and Kolver, 1997). Forages are a highly utilized feed source in beef production systems. They account for roughly 84% of the feed inputs in beef production systems when the production and maintenance requirements of the cow are considered (NASEM, 2016). The energy that is acquired from forages comes from the fermentation of the plant cell wall by the microorganism within the rumen (Russell, 2002; Wilson, 1993). The ability of cattle to derive enough energy when consuming forages is highly influenced by the animals' ability to consume enough forage, as well as the microorganisms' ability to digest the cell wall of the forages the animals are consuming (Wilson, 1993). The ability of the rumen microorganism to adequately digest forage is determined by the structure of the plant cell wall, as well as the rate at which the masticated forage samples pass through the rumen (Wilson, 1993). Varga and Kolver (1997) summarized some of the major factors that regulate ruminant fiber digestion: plant structure and composition, nature and population densities of the

fiber digesting microorganisms, and animal factors that increase the availability of nutrients though mastication, salivation, and digesta kinetics.

When evaluating the nutritional content of fiber, it can be defined as much by its biological properties as its chemical properties (Van Soest et al., 1991). Fiber is defined as a complex of dietary nutrients composed of structural polysaccharides, wall proteins, and lignin that are somewhat resistant to digestion and are slowly and only partially degraded by ruminants (Moore and Jung, 2001). Plant cell wall material, measured as neutral detergent fiber (NDF), can account for 30 to 80% of the organic matter in forage crops with the remaining material consisting of cell solubles (Buxton and Redfearn, 1997). Plant cell walls are composed of polysaccharides in the form of cellulose, hemicellulose, and pectin, which cannot be degraded by mammalian enzymes. These polysaccharides must be fermented to volatile fatty acids (VFA) in the rumen or large intestine by microorganisms that synthesize and secrete the β-(1, 4) cleaving enzyme.

Cellulose consists of linear chains of D-glucopyranose residues linked by β-(1,4) bonds with alternate glucose residues in the same cellulose chain and bound to other parallel cellulose chains via hydrogen bonds that form microfibrils composed of 40 cellulose chains (NASEM, 2016). Cellulose accounts for 20-40 % of the DM in all plants and can vary in amount and structure depending on its location within the cell wall. Hemicellulose is a heterogeneous group of polysaccharides characterized by its complex combination of linear and branched β-(1, 4) linked backbones of hexoses and pentoses. Hemicellulose is bound to cellulose microfibrils through hydrogen bonding. Ester and ether bonds connect hemicellulose to lignin, and hemicellulose is more closely associated with lignin than any other polysaccharide (Van Soest, 1994). Pectin is an α-(1, 4) linked

backbone consisting of galacturonic acid with various hexose and pentose side chains. Pectin is found within the cell wall, however it is soluble in neutral detergent and is therefore considered neutral detergent soluble fiber. Although it has a similar linkage as starch α-(1, 4), it is not broken down by amylase but its coiled chain is fermented very rapidly in rumen (Van Soest, 1994). Cellulose, hemicellulose, and pectin form around 90% of the polysaccharides in plant wall material.

Lignin is a very generic term for complex polymers that are indigestible. Lignin is important to plant cell rigidity, structure, and resistance to diseases, insects, cold temperatures, and other biotic and abiotic stresses (Buxton and Redfearn, 1997). Lignin is the largest factor limiting the availability of cell wall material to anaerobic digestion and subsequently the animal (Van Soest, 1994). Lignin can be classified as core lignin or non-core lignin. Core lignin is comprised of highly condensed phenylpropanoid cell wall polymers consisting of ρ-hydroxyphenyl, guaiacyl, and syringyl core units in various proportions (NASEM, 2016). The ρ-hydroxyphenyl lignin is formed mainly from *ρ*-coumaryl alcohol, guaiacyl lignin is comprised of mainly coniferyl alcohol, and syringyl lignin is comprised of sinapyl alcohol (NASEM, 2016). These compounds polymerize into lignin via ether bonding and carbon-carbon bonding. The lignin polymerizes to fill the spaces between cellulose, hemicellulose, and pectin as the plant ages to give support, and it binds with hemicellulose (Undersander et al., 2009). Non-core lignin is made up of low-molecular weight phenolic compounds that are soluble by mild hydrolysis, consisting of coumaric, ferulic, sinapinic, and cinnamic acids. It can be present as ester- and ether- bond monomers or esterified dimers that can form bridges between core lignin and carbohydrates (NASEM, 2016). The lignin metabolic pathway is highly complex,

and there are a large number of ways to modify lignin concentration and composition (Allen et al., 2003). Interestingly, the brown midrib mutation is a gene that alters the enzyme activities which coverts 5-hydroxyferulic acid to a sinapinic acid. This occurs at a reduced rate resulting in a lower total lignin concentration and a greater amount of hydroxyguaiacyl lignin compared to syringyl lignin (Moore and Jung, 2001). The brown midrib trait is of particular interest in forages because it has been shown to increase fiber digestibility and improve animal performance. This will be discussed in more detail in later sections.

Lignification can impact digestibility of cell wall fiber. The largest factor affecting digestibility is that the lignin acts as a physical barrier to the microbial enzymes reaching and digesting carbohydrates within the cell wall (Moore and Jung, 2001). Other limiting factors to fiber digestion in ruminants have been proposed. The phenolic compounds that comprise non-core lignin may be toxic to fiber degrading bacteria, decreasing their ability to effectively metabolize the cell wall material. Lignin also creates a hydrophobic environment which limits the hydrophilic enzymes required to metabolize the cell wall material (Buxton and Redfern, 1997; Moore and Jung, 2001).

In order for maximal fiber digestion to occur, there must be a symbiotic relationship with rumen microorganisms. The animal must provide the right environmental conditions for this symbiotic relationship to occur: substrate for fermentation, removal of old substrate, absorption of waste products of fermentation, an anaerobic environment with a maintained temperature, moisture, and pH around 6.8. The microorganisms also need ammonia as a nitrogen source, and Hoover (1986) reported that proteins are superior to urea for maintenance of fiber digestion, partially due to a

requirement for the branched chain fatty acids isobutyrate, isovalerate, and 2-methylbutyrate that are formed from the deamination of valine, leucine, and isoleucine. The microorganisms in turn provide waste products of fermentation such as VFAs, which are used for energy, in addition to bacterial protein. Both of these products of microbial fiber digestion would otherwise not be utilized, as no mammal produces the necessary enzymes required to digest fiber components within the plant cell wall. The predominate fibrolytic bacteria involved in fiber digestion within the rumen are Fibrobacter succinogenenes, Ruminococcus flavefaciens, Butyrivibrio fibrisolvens, and Ruminococcus albus. Fungi make up roughly 8% of the rumen microbial community and are able to penetrate the cuticle and lignified cell wall allowing more bacterial access to cellulose and hemicellulose (Varga and Kolver, 1997). Additionally, protozoa can account for 19-28% of total cellulase activity and have a role in fiber digestion in ruminants as they have been shown to produce fibrolytic enzymes (Varga and Kolver, 1997).

The first step in fiber digestion is penetration by the microorganism through easily digested or damaged areas and digestion occurs from the inside out. The microbes then attach themselves to feed particles through the process of adhesion. Following attachment and adhesion, colonization occurs at which time the microbes release enzymes and digest the substrate until the nutrients are absorbed from the cell (Varga and Kolver, 1997). Plant, animal, and management all have an impact on fiber utilization in ruminants. As summarized by Varga and Kolver (1997) as well as NASEM (2016), fiber intake and fiber digestion can be altered and affected by: plant maturity, forage type, forage processing, environmental factors, and supplements. Rate and extent of fiber

digestion as well as fiber intake decrease as forage matures (Buxton and Redfearn, 1997). In terms of forage type, fiber intake will be less for legumes vs grasses, and ruminants grazing warm season grasses will have greater fiber intakes than those grazing cool season grasses when compared at the same maturity (NASEM, 2016). Rate of digestion is greater for legumes compared to grasses, however grasses will have a greater extent of fiber digestion compared to legumes. When processing forage either by pelleting or grinding, fiber intake is increased because of increase passage rate, but extent of fiber digestion is decreased. While fiber digestion is decreased, animal performance will increase as a result of increased energy intake and increased passage rate (Varga and Kolver, 1997). Chemical treatment of forages will result in an increase in fiber intake as well as rate of fiber digestion. Supplementing with protein can cause an increase in fiber intake with cattle consuming low-N forage; however, it has little effect on high-quality forages. The rate and extent of fiber digestion increases with low-N, high fiber forages and has shown variable effects on high quality forages. Lastly, supplementing with grain can decrease fiber intake as the amount of grain is increased in the diet, and when included at levels greater than 30%, grain fiber digestion decreases. The negative associative effect of increasing grain in fiber based diets occurs when readily fermentable carbohydrates in grain decrease the rate of intake and the rate of degradation of the forage NDF. This is likely caused by a decrease in pH below 6.2, which causes decreased growth and activity of fibrolytic bacteria (Kennington et al., 2005; NASEM, 2016).

## Negative Associative Effects of Starch and Fiber

Van Soest (1994) described an associative effect as observed differences that are greater or lesser that the predicted outcome from direct measurements of individual

ingredients. A negative associative effect occurs when actual measured digestibility or performance is less than predicted. Negative associative effects occur frequently in feedlot cattle fed high-grain diets mainly as a result of low ruminal pH (< 6.0) and suboptimal conditions for fiber digestion (NASEM, 2016). As described by Merchen and Bourquin (1994), the negative effect of starch on fiber digestion is thought to be a result of the combination of the microbial preference for starch rather than fiber, a decrease in ruminal pH caused by rapid degradation of starch, and preferential proliferation of starch digesting bacteria caused by competition of nutrients. As starch content of the diet increases, starch utilizing bacteria create an environment that maximizes starch digestion, creating a rumen pH environment less than 6. While some of the fiber digesting bacteria can utilize strach as a substrate for energy, they prefer that pH remains above 6.2. Increaseing the amount of starch in the diet, would cause the population of the starch utilizing bacteria to increase, which would decrease the pH and create an environment that limits fiber digestion. This creates a negative associative effect because fiber digestion is hindered due to a shift in microbial population that prefers starch and less microbes to digest the fiber in the diet. This phenomna can be measure by decreased intake and lower gains. Martin et. al. (2008) spectulated that a ration containing only corn silage as forage may limit intake and gain due to excess amounts of rapidly fermentable starch, low effective fiber, and/or slow rates of fiber digestion.

Joanning et al. (1981) evaluated corn silage and corn grain mixtures on nutrient digestibility in five diets containing either 90% corn silage, 90% dry rolled corn, or a 30:60 blend of corn silage and dry rolled corn. Steers fed the all silage diet had a DM digestibility of 67.8%, while the all corn diet had a DM digestibility of 84.4%. When a

blend of 30:60 silage to corn was fed, the expected DM digestibility was 78.6% but the observed DM digestibility was 69.8%, or an 11.3% decrease in DM digestibility. This resulted in a quadric response for DM digestibility. Starch digestibility decreased by 56% in the corn silage and corn grain mixture, and incomplete starch digestibility is a major contributor to the decrease in efficiency. Similar observations have been made by others comparing different levels of corn silage and corn grain mixtures (Gill et al., 1976; McEwen 2002a). Vance et al. (1972) evaluated the net energy of varying proportions of corn silage and corn grain and found that as corn silage increased in the diet from 0 to 65%, net energy of gain (NEg) values decreased linearly as corn grains decreased from 97 to 75% in the diet but remained relatively flat with no difference in NEg value when corn grain was decreased from 75 to 35% of the diet. It is important to remember that when harvesting corn silage, the goal is to achieve as much starch as possible with enough fiber to optimize rumen function to avoid low pH, which depresses microbial fermentation and fiber digestion (Jensen et al., 2005).

## Metabolizable Protein System

The ruminant animal's ability to capture value in digesting fiber from microbial fermentation also changes how we evaluate and understand how proteins and other nitrogenous compounds are digested. Protein nutrition in the ruminant animal is a complex, dynamic process because of pre-gastric fermentation. Ruminal microorganisms degrade some of the dietary nitrogen (N) using the products of their own metabolism, including protein synthesis (NASEM, 2016). The combination of microbial protein synthesis in the form of microbial crude protein (MCP) and dietary protein that escape the rumen are used to meet the animal's protein needs in the form of amino acids (AA).

The metabolizable protein system (MP) was developed to help better define the protein requirements of ruminant animals. The MP system takes into account rumen degradation of dietary protein and separates requirements into the protein needs of microorganisms and the protein needs of the animals (NASEM, 2016). Metabolizable protein is defined as all true protein absorbed by the intestine and it is comprised of MCP and rumen undegradable protein (RUP; NASEM, 2016). Endogenous proteins, including sloughed epithelial cells, do not contribute to the MP supply. With the adoption of the MP system from the crude protein (CP) system, increased research has explained how MCP synthesis and digestive kinetics of rumen degradable protein (RDP) allow for maximizing the supply of MCP to the host thereby improving formulations. Ruminally degradable protein is important to meet the needs of MCP synthesis as it provides peptides, AA, and ammonia. Sources of non-protein nitrogen (NPN) such as urea and ammonia can be supplemented to aid in MCP production which are also categorized as RDP. In order to determine MP supply, accurately predicting the RDP components of feed to predict MCP synthesis as well as accurately predicting the amount of RUP not degraded in the rumen are critical steps.

Depending on the RUP content of the diet, MCP synthesized in the rumen can supply anywhere from 50% to essentially all of the MP required by the animal (NASEM, 2016). Predicting the amount of MCP when formulating diets is critically important, and numerous models have been developed to predict MCP production using total digestible nutrients (TDN) and RDP (Watson et al., 2017). Burroughs et al. (1974) proposed a model where MCP production was 13.05% of TDN; however, the efficiency of 0.13 for MCP synthesis can vary across diet types and adjustments for RDP, ruminal pH, and

microbial turnover. The NRC (1996) model was developed from animal performance and uses a constant 13% microbial efficiency value for diets containing more than 40% forage (Watson et al., 2017). For diets containing less than 40% forage (20% NDF), Russell et al. (1992) suggested that microbial yield is reduced 2.5% for every 1% decrease in effective NDF.

Evaluating MCP production is very difficult, but it must be done to ensure that the animal's MP requirement are met. The NASEM (2016) estimates MCP based on TDN intake and CP of the diet and has lowered the MCP production efficiency from the previous NRC (1996). When comparing low quality forage diets and high grain based finishing diets, the NASEM (2016) and the NRC (1996) are in very close agreement, however in blended diets of fiber and grain like corn silage based diets, the models differ in MCP synthesis. Watson et al. (2017) compared three different equations for evaluating MCP synthesis in young growing calves on forage based diets. The authors compared the NRC (1996), Patterson et al. (2006), and Galyean and Tedeschi (2014), which is the basis for the NASEM (2016) nutritional requirements for beef cattle. When comparing forage based growing diets, the NASEM (2016) underestimated MP supply by 23% compared to NRC model (1996), discrepancies between models could cause an issue with the amount of RUP concentration when formulating diets to meet MP requirements. When predicting MP requirements for ruminants, it is important to know diet type and animal type as one size does not fit all. Overestimating or underestimating MCP synthesis can lead to changes in diet formulation that might lead to oversupply of protein, which could result in increased feed cost, or undersupplying protein, which could result in lower performance.

***RDP Rumen degradable protein***

Rumen degradable protein is the portion of crude protein of a feed that is available to the microorganism. The microorganisms first have a requirement for energy that allows them to grow and utilize the N that is being supplied in the form of RDP, which then allows for maximum MCP synthesis and supply to the animal. The NRC (1996) determined that the requirement for RDP, including NPN, is considered equal to MCP production, assuming the loss of ammonia due to absorption from the rumen or flow to the lower tract is equal to the amount of N recycled. The NASEM (2016) recognized that based on current research, the efficiency in which RDP is converted to MCP is less than 100%. However, there was a lack of certainty on the appropriate level of efficiency, so it maintained RDP to MCP at 100%.

In most grain based finishing diets, adding additional NPN in the form of urea can meet the ammonia needs for MCP synthesis. However, in diets with a high forage and grain similar to corn silage based growing diets or finishing diets high in corn silage, the fiber digesting organisms have an additional requirement for branched chain fatty acids isobutyrate, isovalerate, and 2-methylbutyrate that are formed from the deamination of valine, leucine, and isoleucine which would require RDP sources other than solely NPN (Hoover, 1986; Sindt et al., 1993). Additionally, the type of carbohydrate, processing method, forage to grain ratio, intake, passage rate, and ruminal pH can all affect MCP synthesis as these factors can shift microbial populations and their synchrony on how they digest feed (NASEM, 2016). Rumen degradable protein supplementation is needed to meet the microbial N requirements, and undersupplying N can lead to decreased MCP production and supply to the animal.

***RUP Rumen Undegradable Protein***

The portion of the CP that escapes ruminal fermentation and that is absorbed in the lower tract is considered RUP (Van Soest, 1994). The MCP and feed protein provide AA that are absorbed and utilized by the animal for maintenance and growth. The RUP required to meet MP demand is greatest in growing cattle and lactating cows (Klopfenstein, 1996). The sum of RDP and RUP is equal to CP. The supply of RUP to the lower tract can vary based on diet type and intake level. If intake is high and passage rate is fast, RDP that would be used by microorganisms for N requirements can bypass the rumen and be considered RUP. The RUP requirement for an animal can be estimated by subtracting MP supplied from MCP synthesis from the total MP requirement of the animal, however as previously mentioned, estimating MCP synthesis is very difficult. Overestimation of RUP can lead to an overestimation of total MP supply (NASEM, 2016). The NRC (1996) estimated that all RUP was 80% digestible, but current research has shown that this value can vary significantly depending on feed ingredient. Ingredients can vary in RUP content as well as RUP digestibility. Corn grain is the most commonly fed carbohydrate feed today, and the NASEM (2016) corn grain has a RUP value of 65.31%. Corn processing method can have a large impact on RUP %. Work by Benton et al. (2005) showed that when grain is harvested as high moisture corn (HMC), as the moisture content and length of ensiling period is increased, the RUP content of corn grain is decreased and it becomes more rumen degradable. This is an important consideration when discussing corn silage as the corn grain in silage is harvested earlier than HMC and would be even wetter, allowing for greater fermentation, which would lead to an increased RDP content of the corn grain in corn silage. The NASEM (2016)

lists the RUP content for corn silage as 25.38% (% of CP). When evaluating the RUP value of forages, work by Kononoff et al. (2007) found that the digestibility of forage RUP is much lower than the 80% suggested by the NRC (1996). Specifically looking at corn silage, Kononoff et al. (2007) estimated RUP (% of CP) to be 19.25%, but only had an intestinal RUP digestibility of 19.9%. Oney (2017) concluded that corn silage had a RUP (% of CP) content of 8.9% and an RUP digestibility of 32.3%. These differences could be explained by differences in basal diet as well as level of intake in lactating dairy cows compared to growing beef calves. When formulating diets that have fermented feed stuffs like corn silage that have high proportions of grain and fiber, it is important to note how that can influence MP supply to the animal.

## Corn Silage Production

Corn silage production in the United States can be traced to the end of the 19$^{th}$ century and has been used in beef production since the early 1900s (Hays, 1912). The USDA reported in 1910 that Nebraska ranked fourth in in the United States in total cattle production (Hays, 1912). According to 2016 USDA data, Nebraska is currently ranked first in number of cattle on feed, third in total corn grain production, and tenth in total silage production. Since the early 1900s, corn silage has become a staple in dairy operations as well as in beef growing and finishing operations. Based on the latest USDA data (2018), corn silage was grown on 210,000 acres in Nebraska with an average wet yield of 19.5 ton per acre for total corn silage production of just over four million tons. Corn silage production in Nebraska is produced on 2-3% of total acres planted for corn (USDA, 2018). Utilizing corn silage allows cattle feeders to take advantage of the entire corn plant at a time of maximum quality and tonnage as well as secure substantial

quantities of roughage/grain inventory (Burken et al., 2017b). Corn silage is a moderately high energy (67.7% TDN; NASEM. 2016), low protein (8.24% CP; NASEM, 2016) forage that allows for flexibility in growing and finishing cattle feeding programs and is a supplemental energy source in cow and calf production systems (Allen, 2003).

Corn silage is a fermented feed that is harvested in early fall in Nebraska once whole plant DM is around 35% DM (33.07 % DM; NASEM, 2016). This coincides with kernel milk line development from 1/2 to 2/3 milk line. At harvest, whole corn plants are chopped and placed into silos, horizontal bags, pits, or piles and packed to remove oxygen and allow anaerobic fermentation to occur. Corn silage quality and yield can be variable depending on corn plant characteristics, quantity of grain, quality of forage, maturity at harvest, and ensiling procedure and facility (Johnson et al., 1999; 2002a; 2003). On average, corn silage will contain approximately 50% grain and 50% stover.

Corn silage production has benefits and drawbacks that need to be considered to determine if it is a good fit for an individual operation. Advantages to corn silage production are firstly that it provides a large yield of a single harvested crop annually compared to other forages that require multiple harvests. Allen et al. (2003) reported that because of the large dry matter yields from corn silage compared to other forage crops, less land can be used for forage production, which allows for other crops to be grown or additional animals to be fed. Corn silage is harvested earlier than traditional corn grain harvest, so it can be grown in a shorter growing season and this allows for some flexibility in planting and harvesting dates. Silage harvest typically happens a few weeks before traditional corn grain harvest. This permits longer harvest windows as harvest can begin earlier with corn silage. This spreads out the labor and the risk of bad weather

inhibiting harvest. Another major advantage outlined by Allen et al. (2003) is that producers have some flexibility in harvesting corn for forage or grain. When market conditions are favorable for feeding cattle, crop producers can harvest more total yield of TDN through corn silage production and market their corn crop via feeding it to cattle. However, in reverse market conditions, crop producers may choose to sell the dry grain. In years when the crop is good, excess corn can be harvested for grain. However, if corn yields are low, most of the crop may need to be harvested for silage. Johnson et al. (2016) compared corn crop end points and profitability in feedlot steers and found only slight differences in whole crop value in terms of dollars returned per acre when fed as silage, earlage, HMC or DRC. While there were differences in DM yield with corn silage being the greatest and corn grain being the lowest, feed efficiency differences made up for lower yields in HMC and DRC. The authors found that when marketing corn crop though cattle compared to selling it at the local elevators, net returns were $114 per acre higher. While in this study, the authors fed corn crop at equal levels 75% of DM across diets, they concluded that with the flexibility to harvest corn silage and corn grain, the right combination of harvest endpoints could be used to maximize gross returns to corn acres (Johnson et al., 2016).

There are some disadvantages to corn silage production. From an agronomic perspective, Allen et al. (2003) reported that when taking all of the residue in corn silage, plant organic matter and nutrients, specifically N and phosphorus (P) that would normally be left on the field with corn grain harvest, are removed resulting in lower soil organic matter levels for subsequent crops. Additionally, corn silage harvest leaves little ground cover on crop surfaces allowing for increased potential for wind and water erosion.

However, the use of cover crops and application of livestock wastes to fields harvested for corn silage are ways of mitigating these agronomic issues (Allen et al., 2003). Some different management considerations need to be evaluated when producing corn silage in comparison to dry corn grain. Corn silage is a high moisture feedstuff that is usually harvested and ensiled at 35% DM. Shrink or loss of feed can be a large consequence of mismanaging corn silage during harvest and throughout ensiling and feeding. At relatively low DM content, there are increased transportation costs from field to bunker. Another limitation is that once harvested, corn silage essentially has to be marketed through cattle on-farm or to neighbors in close proximity to the storage area.

While there are advantages and disadvantages to corn silage production, if corn silage is a crop that fits the operation, proper ensiling of the corn silage is critical. Proper ensiling is the largest single factor to making sure DM and nutrient recovery is maximized and it ensures that the highest quality material is available for feed.

***Corn silage fermentation and nutritional changes***

The ensiling process is the rapid anerobic conversion of plant soluble sugars by microorganisms into organic acids, which in its final form is an acidic, fermented stored product (Wilkinson et al., 2003). Wilkinson et al. (2003) listed three important factors necessary for proper ensiling to commence: crop material, moisture, and most importantly, the exhaustion of oxygen inside the silo/bunker. Once these three criteria have been met, fermentation can occur. While these criteria sound simple to meet, there are a lot of factors that must occur in order for those three things to all happen in unison. Charley (2016) summarized silage harvest and proper fermentation as taking a high quality, stress-free, disease-free, insect and weather damage-free corn crop at the right

stage of maturity and moisture, chopping and processing it into a pile and sealing as quickly as possible while ensuring a proper pack density. In a review of corn silage fermentation by Pahlow et al. (2003), the process of fermentation can be broken down into four phases: 1) initial aerobic phase, 2) main fermentation phase, 3) stable phase, and 4) feed-out phase.

In the initial aerobic phase, which usually lasts 12-24 hours, the plant is chopped and is dead. This initiates the enzymatic process of breaking down plant material. By chopping/cutting the corn silage, all the microorganisms in the form of aerobic bacteria, yeasts, and molds that were living on the outside of the plant are distributed throughout the nutrient rich, oxygen exposed chopped material (Charley, 2016). Once in the bunker and sealed, the remaining oxygen allows for continued plant respiration and aerobic microbial growth generating heat. Additionally, proteases and carbohydrases (fiber and starch digesters) decompose proteins to amino acids and increase the amount of soluble carbohydrates available for fermentation (Pahlow et al., 2003).

The main fermentation phase technically begins once the last trace of oxygen has been depleted. Depleted anaerobic lactic acid bacteria continue to utilize water soluble carbohydrates to lactic acid, which causes a decrease in the pH of the silage (Der Bedrosian et al., 2012). While other anaerobic microorganism like bacteria, clostridia, and yeast can compete for nutrients, the decrease in pH is caused by the buildup of lactate which changes in the microbial community to one solely dominated by lactic acid bacteria in which other microorganisms enter a quiescence stage (Pahlow et al., 2003). During main fermentation chemical composition changes, the fermentable sugars are rapidly depleted and converted into lactic and acetic acid. In ideal fermentation 4 to 6%

of total DM is converted into lactic acid which can be then utilized as propionate in the rumen (NASEM, 2016). The lactic acid and acetic acid ratio should be 3:1 or greater for indication of proper fermentation, with ideal lactic acid comprising 65-70% of total organic acids. Whitlock et al. (2000) allowed silage to remain uncovered and exposed to oxygen and compared it to silage stored in Ag Bags fed in combinations of spoiled and non-spoiled silage. The authors reported that as spoiled silage concentration was increased in the diet up to 75%, DMI decreased linearly by 16% at the highest level, and steers feed non-spoiled silage had greater DM, OM, NDF, ADF, and CP digestibility than steers fed any diet with spoiled silage. Concentration of greater acetic acid indicates less than ideal fermentation and can result in decreases in DMI which can result in less milk production (Kung and Shaver, 2001). During main fermentation, the concentration of ammonia will increase as proteolysis is occurring. In ideal fermentation, this level should be kept below 10% of total CP (Kung and Shaver, 2001). The main fermentation phase can begin as few as 24 h after chopping and can occur for an additional 7 to 28 d after initial harvest. During this time, pH drops from 6.5 to 4 or below, and temperature rises to 80-100°F.

The stable phase follows main fermentation where little to nothing happens as long as the bunker remains free of oxygen exposure. Some microbial processes still occur. Acid tolerant enzymes cause degradation of hemicellulose increasing NDF digestibility, while proteases continue to degrade hydrophobic zein proteins in the starch-protein matrix of corn thereby increasing ruminal starch digestion (Pahlow et al., 2003; Der Bedrosian et al., 2012). Some losses are expected during silage fermentation as dry matter is lost due to the sugars within the corn being respired during the ensiling process

(Darby et al., 2002). In the stable phase, pH should be maintained at 4 or less and temperature should be stable.

The last and final stage is the feed out stage. During this phase, the silage bunker is opened and exposed to oxygen. Based on laboratory studies and fermentation analysis, oxygen can penetrate up to 1 meter causing microbial growth in the silage pile this is in part due to differences in gas pressure between fermentation gasses and ambient atmosphere (Pahlow et la., 2003). Once exposed to air, yeasts and bacteria can become reactivated and increase in population causing heating and mold spoilage on the face. This unwanted aerobic microbial growth can raise pH, increase potential for toxins from clostridia, and substantially decrease digestibility of the silage (Pahlow et al., 2003). Management recommendations are to remove 0.15 to 0.30 meters per day from the face of the pile in order to ensure limited microbial growth, heating, and spoilage (Charley, 2016). In the feed out stage, pH will rise to around 5 and depending on aerobic spoilage, the temperature should remain stable or rise. Increased pH and temperature are not preferred, so management practices should be in place to minimize both.

Ensiling corn silage properly is challenging. Management during harvest and feed out have the largest impacts on maintaining nutritional value. There are many management factors that have been studied for their effects on the quality of silage at feed out. These factors include: hybrid type, maturity, length of storage, inoculation, chop length, mechanical processing, and pack density (Johnson et al., 1999; 2002a; 2003). While these factors all have effects on corn silage nutritive value during feed out, the majority of this review will focus on harvest maturity and hybrid type.

## Effect of Maturity at Harvest

In corn silage production, timing of harvest is driven by the desire to produce the most DM tons of corn silage per hectare while simultaneously haveing the highest quality possible. Corn silage is unique from other forage crops as the maximum yield and quality are achieved at about the same time (Allen et al., 2003). Corn plants reach physiological maturity once the kernel is at black layer formation, indicating that sugar and other nutrients are no longer being transferred to the kernel. As the corn plant matures after dent, the milk line or the line that separates the milky liquid in kernels from solidified starch granules moves from top of the kernel down to the cob. Silage harvest has been recommended at 35% whole plant DM; however, determining whole plant DM or even grain DM requires chopping samples and DM analysis that will take multiple days. The adoption of using kernel milk line as a means to determine whole plant DM and maturity has been widely accepted as it can be done quickly in the field (Afuakwa and Crookston, 1984). Unfortunately, this method is not always precise. Wierma et al. (1993) observed up to a 7 percentage unit difference in DM concentration across years and across hybrids at the same kernel milk line. Allen et al. (2003) emphasized the need to measure whole plant dry matter as it is a better predictor of when to harvest corn silage as hybrids and environment can affect kernel milk line development. A combination of whole plant DM between 30-40% and kernel milk line at ½ to ¾ to indicate harvest is considered optimum for yield, quality, and proper ensiling (Hunt et al., 1989; Wiesma et al., 1993). Corn silage harvested outside of this range could lead to poor fermentation, reduced forage quality, and poor silage preservation (Darby and Lauer, 2002).

***Yield and nutrient content***

As corn silage reaches physiological maturity, there is usually an increase in the corn silage yield. As the plant matures, the grain fraction of the plant is increased as more nutrients are shuttled into the corn kernels in order for them to fully develop. Suazo et al. (1991) reported that across multiple hybrids, whole plant DM yield was maximized at black layer formation and grain yield in bushels per acre did not differ from black layer to corn grain harvest. Darby and Lauer (2002) reported that whole plant DM yield increased as the growing season was lengthened and more growing degree days occurred. Maximum DM yield was reported to occur at the latest date the researchers harvested, which was at 42% DM. Darby and Lauer (2002) also reported stover DM yield was maximized at the time of reproductive development around 35% DM, and as the harvest was delayed to 42% DM, stover quality decreased. Burken et al. (2017a) harvested corn plants at three different time points coinciding with traditional silage harvest, physiological maturity, and corn grain harvest. In year 1 of the experiment, stover yield and whole plant yields responded in a quadratic fashion with both stover and whole plant yields maximized at physiological maturity and decreasing at corn grain harvest. The author suggested that this could be due to senescence and abscission as the stover portion of the plant became dry and brittle after physiological maturity. In year two of the experiment, Burken et al. (2017a) noted linear increases in whole plant and stover yields as harvest was delayed from traditional silage harvest to corn grain harvest. Year-to-year variation will occur in corn silage yield because of management and environmental factors; however, Burken et al. (2017a) reported greater whole plant yield at

physiological maturity compared to traditional corn silage harvest in both years. These authors also reported that in year 1, residue TDN was maximized at black layer, but in year 2, residue TDN was linearly decreased as harvest was delayed. However in both years, whole plant TDN remained similar from traditional silage to black layer formation. These data would suggest that although residue is changing, these small changes are masked by increases in corn grain maintaining whole plant TDN. Daynard and Hunter (1975) reported that whole plant yield was maximized at 39% DM while stover yield was lowest at 39% DM. This is in agreement with Burken et al. (2017a). Filya (2004) also reported DM yield in t/ha were maximized at black layer formation which coincided with 42% DM. Additionally, Hunt et al. (1989) reported that as harvest was delayed, whole plant yield and TDN in tons/acre was increased.

While total yield and TDN increase by delaying harvest, the nutrient location and quality changes. Allen et al. (2003) summarized these changes as grain development occurring largely at the expense of stover quality. As previously shown by Burken et al. (2017a), the amount of corn grain increases as the plant matures. This increase in starch content has been documented many times (Andrae et al., 2001; Di Marco et al., 2002; Jensen et al., 2005). Total starch plus sugars increase as harvest is delayed (Hunt et al., 1989; Bal et al., 1997), suggesting that plant photosynthesis is continually adding to net sugar production. Since starch provides more than 50% of the energy in corn silage (Owens, 2008), this increase in starch content represents a large increase in total energy yields by harvesting corn silage with more maturity.

As corn silage is harvested later in the harvest season with advanced maturity, whole plant NDF decreases (Bal et al., 1997; Di Marco et al., 2002; Owens 2008).

Owens (2008) suggested that NDF is being lost by the plant during this maturation process possibly in the form of hemicellulose. Harvesting corn silage later in the season has decreased (Johnson and McClure, 1968; Wiersma et al., 1993; Filya, 2004) or had no effect (Jensen et al., 2005) on crude protein content.

***Digestibility***

Delaying corn silage harvest to black layer causes a change of the nutrient profile of the corn plant as the plant continues to age, and because of this, nutrient digestion can also be affected by delaying corn silage harvest. As previously mentioned, as the corn plant matures, the NDF content of the corn plant decreases, and the digestibility of the NDF (NDFD) has also been shown to decrease by 3% (Johnson et al. 1999; Andrea et al., 2001; Owens, 2008). Joanning et al. (1981) fed either 90% silage on a DM basis or 30% silage 60% corn grain blend on a DM basis and found that as harvest was delayed, there was a decrease in NDFD of 14.6 percentage units in the 90% silage diet and 15.7 percentage unit decrease in NDFD at the 30-60 blend of corn silage and corn grain. In this study, the authors found that delaying corn silage harvest decreased NDFD but increasing the amount of grain in the diet further hurt NDFD compared to straight silage diets. In a summary by Owens (2008), there was a decrease in NDFD of only 3 percentage points within the harvest window of 30% and 40% whole plant DM, but decreased by 10 percentage units from 21 to 45% whole plant DM. Joanning et al. (1981) compared corn silage with DM of 22% vs. 35% which could account for such large differences in NDFD. When evaluating corn silage harvested at ½ milk line (28.4% DM) or black layer (42.5% DM), Andrea et al. (2001) reported decreases in total tract NDFD and ADF digestibility (ADFD) by 5.9 and 7.5 percentage units, respectively. The

authors concluded that NDFD and ADFD were decreased due to increased lignification, but also the possibility of increased starch from the more mature corn silage caused an unfavorable rumen environment with lower pH that hindered fiber digestion.

As the plant continues to mature, the starch concentration in the plant continues to increase (Burken et al., 2017a). While the amount of corn grain and starch content increases, starch digestibility has been shown to decrease as harvest DM increases. Total tract starch digestibility has decreased as harvesting of corn silage has been delayed (Bal et al., 1997; Johnson et al., 1999; Jensen et al., 2005; Ferraretto and Shaver, 2012). However, in these studies, researchers conducted trials with lactating dairy cattle and varying concentration of corn silage. In some cases, less than half of dietary starch came from corn silage. Additionally, in these studies, while there were decreases in total tract starch digestion, digestibility was still greater than 90%. In a meta-analysis, Ferraretto and Shaver (2012) reported that as starch digestibly decreased, 4% fat corrected milk (kg/d) was also decreased. Limited work has been done in beef cattle on harvest maturity. In two studies, total tract starch digestion was unchanged as harvest was delayed to black layer (Joanning et al., 1981; Mc Geough et al., 2010), but both studies had corn silage concentrations of 77 or 90%. Joanning et al. (1981) did report that when feeding a 30% silage and 60% grain mix, starch digestibility was decreased compared to a 90% corn silage based diet, but starch digestion was not different between harvest maturities. Andrae et al. (2001) fed growing diets with corn silage and reported that total tract starch digestion was decreased from ½ milk line corn silage to black layer harvested corn silage from 97.5% to 91.1%, respectively.

Interestingly, management can have an impact on harvest maturity and digestibly. Kernel processing is a strategy used by some silage producers with an on board roller mill that damages and disrupts the kernel, cob and stover portions of corn silage. This can lead to increased digestion (Johnson et al., 1999). Andrae et al. (2001) compared two harvest maturities with and without kernel processing and reported that starch digestibly decreased as corn silage was harvested later. When kernel processed, the higher DM later harvested silage had equal starch digestibility as earlier harvested corn silage. The authors indicated that with kernel processing, it could be possible to maximize total corn silage yield and have starch digestibility of earlier harvested corn silage. Owens (2008) also summarized data and concluded that starch digestibility is greater for processed corn silage with benefits being greater for corn silage harvested later and drier. Kernel processing has led to decreased (Andrae et al., 2001) or no difference in fiber digestion (Rojas-Bourrillon et al., 1987). When measured in lab settings, kernel processing aided in proper wet silage pack densities in corn silage harvested at higher DM which would aid in proper fermentation and allow for greater DM recovered. (Johnson et al., 2002a).

Length of storage can also impact starch digestion in corn silage that is harvested at higher DM. Benton (2005) reported that ruminal starch digestion was increased in HMC with increased moisture and longer days in storage prior to feeding. Almost all of the corn grain in corn silage is at greater moisture than in corn samples reported by Benton (2005) and increasing the amount of time in storage prior to feeding will increase ruminal starch digestion. De Bedrosian et al. (2012) reported that due to continued proteolysis after fermentation, in vitro starch digestion continued to increase as length of

storage increased. The length of ensiling has little to no effect on fiber digestion across different harvest maturities of corn silage (De Bedrosian et al., 2012).

In summary, as harvest of corn silage is delayed, there is an increase in total DM yield of whole plant corn silage and an increase in the amount of grain harvested, while at the same time NDF and ADF content are decreased. Furthermore, NDFD and starch digestibility are decreased. In reviews by Owens (2008) and meta-analysis by Ferraretto and Shaver (2012), both found the ideal range for harvesting corn silage to be 36 to 40% whole plant DM, as corn silage in this range benefits from increased yield compared to lower DM silage while maintaining milk yield and enough moisture for proper fermentation.

## Effect of Corn Hybrid

Over the last 80 years, corn breeders have focused breeding programs around increasing grain yield and related traits. While this produced new hybrids with higher whole plant yields, the effects on corn silage yield and quality were mostly unintentional (Allen et al., 2003). Owens (2008) summarized corn yield from 1940 to 2008 and found grain yield has increased an average of 1.9% per year. Based on this summary, maximizing DM yield appears to maximize both grain and stover yield, benefitting both the grain and silage grower. Maximizing corn silage yield is beneficial, but maximizing quality will also benefit the silage grower. Allen et al. (2003) suggested that breeders could increase the forage quality of hybrids by focusing more on the quality attributes of corn stover. Today, growers must consider many factors when choosing the right hybrid. Growers must determine if the end goal is corn grain, silage, or a possible combination of both. There are grain hybrids, dual purpose hybrids, and silage specific hybrids, such as

leafy varieties, waxy varieties, high oil varieties, varieties with hard or soft kernels, and varieties with reduced lignin content. For the purpose of this review on hybrids, focus will be directed to silage varieties that have the brown midrib trait for reduced lignin content and various kernel traits.

The brown midrib trait (*bm1*) was first discovered at the University of Minnesota in 1924 and derives its name from the brownish red coloring in the leaf midrib and stalk (Allen, et al. 2003). Since the initial discovery, three other brown midrib traits have been found: *bm2* in 1932, *bm3* in 1935, and *bm4* in 1947. The brown midrib traits all originated from natural populations and were all found independently as recessive traits (Allen et al., 2003). The most commonly used and most researched brown midrib trait is the *bm3*. The remainder of this discussion will be focused on the *bm3* trait and any use of brown midrib (BM3) will refer to the *bm3* trait.

***Yield and nutrient content***

From an agronomic perspective, BM3 corn hybrids have shown poor results compared to non BM3 corn silages. In a review, Barrière and Argillier (1993) concluded that BM3 was inferior to normal isogenic corn plants, as the BM3 delayed silking up to a week and DM yield were decreased 10 - 20%. Eastridge (1999) reported an average decrease in yield of 10.4 % with a range of 2.8 to 16.9% lower DM yield for BM3 compared to non-BM3. Furthermore, the author concluded that BM3 should only be used for corn silage as delaying for grain harvest will increase the chance of lodging. Cox and Cherney (2001) also saw that over three years, BM3 varieties had 18 – 20% less DM yield as the BM3 hybrids had lower early season growth rates and lower grain content compared to non-BM3 hybrids. McEwen and Buchanan-Smith (1996) reported

11.5 t/ha vs 14.9 t/ha when comparing a BM3 to non-BM3 varieties, respectively. Allen et al. (2003) summarized that the BM3 varieties often have lower growth rates, poorer early season-vigor, increased lodging, delayed flowering, and poor grain yields. While yield data has been shown to be lower, when calculating milk yield, Cox and Cherney (2001) reported that some BM3 hybrids in certain years had the highest milk yield and were able to offset lower DM yield, but this was not consistent across multiple years. BM3 hybrid breeding programs were not commercially developed outside of universities until the early 1990s and most of the agronomic data were reviewed in the early 2000s. Very little yield data have been reviewed since. Interestingly, all of the reviews (Barrière and Argillier, 1993; Cox and Cherney, 2001; Allen et al., 2003) indicated that because of the low lignin and increased fiber digestibility, plant breeders will continue to develop better BM3 hybrids with higher yield and forage quality. More recently, two years of yield trial were collected on BM1, BM3, and non-BM3 control silage in 2015 and 2016 (Young et al, 2016). When comparing brown midrib silage vs non-BM3 control, there were no consistent differences in yield. The BM3 hybrids had an average yield of 16.08 t/ha while controls averaged 16.47 t/ha on a DM basis (Young et al. 2016).

The BM3 trait has little effect on CP, NDF, and ADF in corn plants (Eastridge, 1999; Ferraretto and Shaver, 2015). There have been decreases in NDF and ADF percentages in BM3 compared to non-BM3 hybrids, but results vary from trial to trial (Oba and Allen, 2000; Taylor and Allen, 2005). The consistent difference in BM3 hybrids compared to non-BM3 hybrids is reduced lignin concentration (Barrière and Argillier, 1993; Allen et al., 2003, Ferraretto and Shaver, 2015). Eastridge (1999) reported a 33.9% decrease in lignin content when comparing a BM3 to non-BM3 hybrid.

As previously mentioned in the fiber digestion section of this review, lignin is the largest factor limiting the availability of cell wall material to the animal and anaerobic digestion (Van Soest, 1994). Lignin is a complex of phenolic aromatic ring polymers that are indigestible in the rumen. Lignification can impact digestibility of cell wall fiber by acting as a physical barrier to the microbial enzymes from attaching and metabolizing carbohydrates within the cell wall (Moore and Jung, 2001). Lignin is cross linked with plant wall polysaccharides and this cross linking provides a rigid backbone to plant cell structures. The BM3 trait changes the lignin content of the plant because of a stop coding or deletion of the genes that code for caffeic acid-O-methyltransferase. Without O-methyltransferase, less total lignin accumulation occurs and there is an increase in the proportion of 5-hydroxyguaiacyl concentration in lignin polymers compared to syringyl lignin (Allen et al., 2003).

Updated research would indicate that breeding improvements have been made in the last 20 years, and increased yields and maintained advantages in lower lignin content could make BM3 competitive with non-BM3 hybrids in silage feeding operations.

***Digestibility***

Changing the physical components of the fiber portion of the corn silage has the potential to change fiber digestibility of the plant in beef cattle diets (Tjardes et al., 2000). The lower lignin content of BM3 hybrids is of great interest to cattle fed high forage diets, and improving NDF digestibility would be of great benefit. As NDF of BM3 silage has been shown to be more digestible in the rumen, increased passage rate and reduced rumen fill could support greater DMI compared to conventional corn silage hybrids (Oba and Allen, 2000).

In a meta-analysis, Ferraretto and Shaver (2015) compared different hybrid types on lactation performance and total tract digestibility in dairy cows. These authors reported that BM3 hybrids had greater DMI than dual purpose and leafy hybrids and similar DMI to high fiber digestibility hybrids that did not have the brown midrib trait. Additionally, the BM3 hybrids had the greatest milk production in kg/d as well as 3.5% fat corrected milk production per day. This increased productivity did not translate into greater efficiency on a kg of milk/kg of DMI and had a tendency for the lowest efficiency on a kg of 3.5% FCM/kg of DMI compared to the 3 other hybrid types (Ferraretto and Shaver, 2015). The authors reported no differences in DM or OM total tract digestibility between all four hybrids evaluated, however, the BM3 and the high fiber digestibility hybrids had the greatest total tract NDF digestibility and the lowest total tract starch digestibility when compared to dual purpose and leafy hybrids. Intake can impact passage rate and in turn, passage rate can affect total tract digestibility. Oba and Allen (2000) reported that cows fed BM3 hybrids had greater DMI when fed at low (33.9% of diet DM) and high (53.2% of diet DM) concentrations compared to an isogenic control, but there were no differences in total tract NDFD. The authors did measure rumen passage and digestion rates, and while total tract NDFD was not different, NDF passage rate were greater and digestion rate were lower compared to controls. Dry matter intake in this study as well as lower pH were likely causes of lower NDFD. Ferraretto et al. (2015b) reported greater DMI and milk production (kg/d) in dairy cows fed BM3 vs leafy hybrids but reported no differences in NDFD. Barlow et al. (2012) compared BM3 to waxy hybrids and reported no difference in DMI but greater milk kg/d for the BM3 hybrids. Barlow et al. (2012) reported no differences in DM or OM total tract

digestibility for BM3 hybrids but did report greater NDF and ADF total tract digestibility for BM3 hybrids compared to control and waxy hybrids. Weller and Phipps (1986) utilized sheep feed at maintenance and reported that sheep fed a BM3 vs a conventional silage hybrid had greater DM, OM, NDF and ADF digestibility. Lim et al. (2015) compared BM3 fed at a low (35% DM) and high (50% DM) concentrations to isogenic controls (35% DM) and reported no differences in DMI but greater milk production in kg/d in both BM3 treatments. Additionally, these authors reported greater feed efficiency on a milk/day basis for BM3 hybrids of 2.8% compared to the control and a 2.1% improvement in FCM/DMI for the BM3 hybrids compared to the control. With no difference in DMI, passage rate was unaffected, resulting in greater total tract DM, OM, NDF and starch digestibility than that of the control (Lim et al. 2015). Muller et al. (1972) compared just the stover fraction (ears removed prior to ensiling) of BM3 and non-BM3 hybrids in sheep fed ad libitum and restricted to 90% of ad libitum. When comparing ad libitum, DMI, DM, NDF and ADF digestibility were greater for the BM3 hybrids, and when restricted to 90% of ad libitum, DM, NDF, and ADF digestibility were greater for BM3 fed lambs than the controls. Tjardes et al. (2000) fed steers BM3 or isogenic controls at ad libitum and restricted to 80% of ad libitum. These authors reported greater DMI and increases of 10.5 and 9.4 percentage unit improvements in total tract digestibility of NDF and ADF, respectively, for the BM3 hybrid compared to the control. When fed at 80% of ad libitum and DMI was constant, BM3 hybrids had 15.8 and 15.4 percentage unit improvements in total tract digestibility of NDF and ADF, respectively. These data suggest that increased passage rate as a result of increased DMI can explain differences in digestibility and efficiency.

BM3 studies have mixed results for total tract starch digestion. In some research, it has been shown to decrease in BM3 hybrid diets (Oba and Allen, 2000; Ferraretto et al., 2015b; Hassanat et al., 2017), some show no difference between silage hybrids (Weiss and Wyatt, 2006; Barlow et al., 2012) and BM3 hybrid diets have greater starch digestion in one study (Lim et al., 2015). The results greatly depend on DMI response. Oba and Allen (2000) suggested increased passage rate out of the rumen could decrease starch digestibility in the rumen. In meta-analysis by Ferraretto and Shaver (2015), total tract starch digestibility was reduced in diets with BMR compared to dual purpose and leafy hybrids.

Kernel type and kernel processing can impact digestibility of the silage hybrid. Kernel type of endosperm type is measured in terms of kernel vitreousness, which is the ratio of vitreous (hard) to floury (soft) endosperm (Lopes et al., 2009). While endosperm vitreousness can have an impact when harvested as dry corn on starch digestibility (Taylor and Allen, 2005; Corona et al., 2006), little work has been done with silage and flinty vs floury endosperm. Ferraretto and Shaver (2015) compared conventional, high oil, NutriDense (a higher oil and CP corn hybrid), and waxy hybrids and reported no differences total tract DM, OM, NDF, or starch digestibility.

Johnson et al. (2002b) compared corn silages with low or high vitreousness at varied maturities and processing settings. The authors found that at earlier maturities, the floury hybrids had greater total tract starch digestion, but as the plant matured, the hybrids also increased the total amount of vitreousness in the kernels, causing a decrease in starch digestion. Kernel processing, as previously mentioned, increased starch digestion in both hybrids as the plant matured. Fanning (2002) compared flinty and

floury endosperm hybrids as corn silage harvested at black layer that was either kernel processed or not in dairy cows. The floury trait in corn silage had greater DM, OM, and starch total tract digestibility. Endosperm type had no effect on NDF digestibility. Fanning (2002) reported no differences between endosperm type in DMI and 4% FCM in kg/d statistically. There was, however, a tendency for greater FCM/DMI efficiency with the floury endosperm compared to the flinty. Kernel processing of both floury and flinty grains improved milk production, efficiency, and total tract DM, OM, NDF, and starch digestibility. In HMC, vitreousness of grain did not affect animal performance when compared to dry rolled corn (Szasz et al., 2007). With the addition of moisture and fermentation, the proteins are solubilized and increase digestibility of the starch in HMC (Owens, 2008). As corn grain in corn silage is harvested wetter than HMC, this may not impact corn silage harvested prior to black layer as the kernel are immature, but this could be a factor when harvested at later maturities (Fanning 2002).

Despite calling it, kernel processing, all of the plant material goes though the roller mill and is subjected to grinding. Effects of processing on fiber digestion have been variable with reports of decreased fiber digestion (Johnson et al., 2003) or increased fiber digestion (Rojas-Bourrilon et al., 1987), however, little to no work has been done with BM3 hybrids and kernel processing. Ebling and Kung (2004) compared processed BM3 and unprocessed BM3 hybrids to a processed isogenic control in dairy cows. The processed BM3 had the greatest DMI and 3.5% FCM production. The processed control had the lowest DMI, and the unprocessed BM3 was the intermediate of the two. The authors reported no differences in FCM/DMI efficiency between the three treatments. Total tract NDF and ADF digestibility were greatest for the processed BM3, but there

were no differences between the processed control and unprocessed BM3. With processing, BM3 fiber digestion was improved, but starch digestibility was also improved over unprocessed BM3 as processing allowed for equal total tract starch digestion compared to the control (Ebling and Kung, 2004). Length of ensiling can change the fermentation profile and starch digestibility but has minimal impact on fiber digestion, regardless of the hybrids used (Der Dedrosian et al., 2012; Ferraretto et al., 2015a)

Recently a new silage hybrid that combines the BM3 trait with a floury endosperm trait has been developed. The new hybrid combines the positive attributes of BM3 with potential for increased starch digestibility from the floury trait. To the author’s knowledge, there is only one report on the use of these combined traits. Grant et al. (2017) compared an isogenic control to a BM3 hybrid and a BM3 hybrid with a softer endosperm (BM3-EXP) fed to dairy cows. All silages were kernel processed. The authors reported that DMI was greatest for the BM3 hybrid and lowest for the control, while the BM3-EXP was intermediate. While total milk yield and 3.5% FCM yield were greater for both BM3 hybrids compared to the control, the BM3-EXP had greater FCM/DMI efficiency compared to both the BM3 and the control. However, total tract digestibility was not different for OM, NDF, and starch between all three treatments. Increased DMI, increased passage rate and resulted in greater milk production (cows) or weight gain (growing cattle), however with no difference in digestibility, efficiency should remain the same. As this is a new hybrid combination and only one study has been done to evaluate it in dairy cattle, opportunities for use in beef cattle diets may prove worthy of research.

In summary, BM3 hybrids specifically can have a negative impact on DM yield. However, more recent data has shown that the negative DM yield associated with BM3 hybrids has possibly been alleviated with improvements in breeding programs while at the same time maintaining low lignin concentrations. Furthermore, NDFD is increased when feeding BM3 hybrids while starch digestibility has been shown to decrease. With improvements in breeding programs and the introduction of kernel traits, there may be continued opportunities to utilize BM3 hybrids and maintain fiber digestion and improve starch digestion.

## Inclusion of Corn Silage in Beef Cattle Diets

Inclusion of corn silage in finishing diets is not a novel concept, and silage has been used to finish cattle since the early 1900s (Hays, 1912). With the increase in corn grain production in the United States, corn grain became more widely available and cattle feeding was not confined to certain geographic locations. Corn grain could be transported cheaply and was a more efficient way to feed livestock. The NASEM (2016) reports TDN value of dry rolled corn as 87.6% while corn silage is reported as 67.7% TDN. As corn silage is added to a diet replacing corn grain, energy density decreases and less energy is available for gain. Preston (1975) summarized experiments feeding corn silage replacing corn grain up to 64% of the diet and reported decreases in NEm values from 2.12 Mcal per kg to 1.84 Mcal per kg. While there was a linear decrease in NEm, NEg values decreased from 1.55 Mcal per kg to 1.29 Mcal per kg (Preston, 1975). This is in alignment with Vance et al. (1972) who noted possible negative associative effects of starch and fiber when corn silage is fed at 20 to 50% of the diet DM. Increasing concentration of corn silage in turn can be seen in cattle performance with lower ADG

and poorer feed efficiencies (Hammes et al., 1964; Klosterman et al., 1965; Jesse et al., 1976; Brennan et al., 1987; DiCostanzo et al., 1997; Erickson, 2001; McEwen, 2002a,b). More recently, Owens (2018) summarized that corn silage fed up to 21% had no effect on ADG and up to 29% had no effect on DMI. At concentrations greater than 21%, ADG decreased due decreased energy content and DMI increased to compensate for lower dietary energy.

***Corn silage in finishing diets***

In times when corn grain price is high relative to corn silage, it is economical to finish cattle with elevated concentrations of corn silage. Goodrich et al. (1974) summarized published university trials on the effect of the corn silage concentration in finishing diets on cattle performance. Across 17 studies, corn silage concentration was increased from 10% to 80% of the diet DM in increments of 10 percentage units. Daily gain decreased from 1.14 kg/d at 10% concentration to 0.86 kg/d at 80% concentration. The decrease in ADG was much greater as concentration of corn silage increased. From 10 to 40% concentration, ADG decreased by 0.02 kg/d, but from 50 to 80% concentration, ADG decreased by 0.06 kg/d. Efficiency of gain also decreased linearly from 0.165 at 10% to 0.126 at 80% concentration of corn silage in the diet which increased feed usage by 11.8 kg for every 45.4 kg of gain for each 10 percentage unit increase in corn silage. With increasing corn silage in the finishing diet, days on feed to gain 272 kg was increased by an additional 76 d when silage concentration was increased from 10 to 80%. As silage was increased from 10 to 40% concentration, average DOF increased by 5 days for every 10 percentage unit increase in corn silage. From 50 to 80%

concentration, an additional 17 DOF was required for every 10 percentage unit increase in corn silage.

Gill et al. (1976) fed diets containing 14, 30 or 75% corn silage. Cattle on the 75% corn silage diet were fed for 28 d longer compared to all other cattle due to lower ADG of 1.10 kg/d compared to 1.30 and 1.26 kg/d for cattle fed 30 and 14% corn silage, respectively. Efficiency of gain followed a similar trend. For cattle fed 75% corn silage, the G:F was 0.141 compared to 0.179 and 0.188 for cattle fed 30 and 14% corn silage, respectively. This is in agreement with Brennn et al. (1987) who also reported that cattle had similar performance when fed corn silage up to 37%, but performance decreased as corn silage concentration increased due to possible negative associative effects of forage and grain, a transition from chemostatic regulation to gut fill, and decreased energy intake.

When cattle are fed elevated concentrations of corn silage (or roughage), dressing percentage is decreased due to increased gut fill. Peterson et al. (1973) reported that as corn silage concentration was increased from 0 to 85.71%, dressing percentage linearly decreased (64.36 to 62.61%). Similarly, Gill et al. (1976), reported cattle fed 75, 30, or 14% corn silage had dressing percentages of 62.8, 65.9, and 65.3%, respectively.

More recent data, from trials conducted by DiConstanzo et al. (1997) and Erickson (2001) evaluated finishing diets containing up to 48% corn silage on a DM basis. DiCostanzo et al. (1997) fed finishing diets containing 12, 24, 36, or 48% corn silage. These researchers reported no differences in gains, however, there was a linear increase in DMI as corn silage concentration increased in the diet. Efficiency of gain linearly decreased as corn silage concentration increased in the diet and were 0.148,

0.141, 0.134, and 0.122 for the four corn silage concentrations. Erickson (2001) evaluated corn silage in finishing diets at 15, 30, or 45% of diet on a DM basis. In two trials with yearling cattle, DMI was not affected by treatment, but ADG and G:F decreased as corn silage concentration increased from 15 to 45% of the diet. In a trial with calf feds, Erickson (2001) reported DMI increased as corn silage concentration increased; however, ADG and G:F both linearly decreased with increased corn silage.

***Corn silage in growing diets***

While it could be argued that some of the earlier finishing work could encompass both growing and finishing diets, the more recent research evaluating corn silage in finishing diets from DiCostanzo et al (1997) and Erickson (2001) do not have concentrations greater than 45% as increased corn silage results in slower growth rate and efficiencies of gain. While high concentrations of corn silage compared to low concentrations of corn silage or grain results in poorer performance, the forage in corn silage plus the grain make it a high energy feed stuff compared to grass hay.

Nelson et al. (1980) compared cattle fed ad libitum access of corn silage or alfalfa-orchard grass hay over a 114 d growing trial over two consecutive years. The authors reported that ADG increased by 0.4 kg/d during the growing phase. Feeding corn silage during the growing phase also resulted in greater G:F compared to steers grown on a hay based diet and total G:F was greater throughout the growing and finishing phases. The increased ADG and G:F resulted in 35 less DOF in the finishing phase (Nelson et al., 1980). In similar studies comparing corn silage to grass hay (Merchen et al., 1987) or to rice straw (Nazli et al., 2018), corn silage based growing diets had greater ADG and G:F.

Increasing the energy density of the growing diet will result in greater performance by changing the proportion of corn silage concentration (Rojas-Bourrillon et al., 1987).

As previously discussed, corn silage has a very low (8.9%) amount of RUP as a percent of total CP, and the digestibility of that RUP is very low (32.3%; Oney, 2017). Much of the protein in silage is fermented to soluble protein in the bunker and to ammonia in the rumen; and such degradation reduces the amount of intact protein and amino acids available in the small intestine as RUP (Owens, 2018). The concentration and source of protein can have a large impact on growing steer performance. Byers and Moxon (1980) fed corn silage based growing diets (55% of diet DM) and three concentrations of protein, either 11.6, 14.1 or 16.5%, to growing steers (average initial BW = 233 kg). The additional CP in these supplements came from increased soybean meal (44% RUP; NASEM, 2016) and linseed meal (32% RUP; NASEM, 2016). As CP increased from 11.6 to 16.5, DMI, ADG and G:F all linearly increased. This indicated that calves fed 11.6% CP were not meeting their MP requirements, therefore limiting growth. Perry et al. (1983) fed corn silage (92% of diet DM) to growing steers (average initial BW 213 kg) with supplemental soybean meal to achieve CP concentrations of 9, 11, or 13% of DM. Increasing the concentration of CP in the diet increased DMI, ADG, and G:F of these growing calves. While Byers and Moxon (1980) and Perry et al. (1983) concluded that increased dietary protein in silage based growing diets improves performance; however, not all protein is created equal. The RUP content of the supplemental CP that had a significant impact on performance because the addition of urea (100% RDP) does not have the same effect as the RUP supplements that were used in those trials. Felix et al. (2014) compared corn silage based (90% of DM) diets with

increased levels of CP at 11, 12, and 13%, and only urea was used to increase CP. When increasing the CP through increased urea in silage diets fed to growing calves (In BW = 198 kg), the authors reported a linear decrease in ending BW, ADG, and G:F and increasing the amount of RDP may not provide enough MP to meet the needs of growing cattle.

***Harvest maturity effect in growing and finishing diets***

As harvest is delayed and corn plant maturity increases, both NDFD and starch digestibly decrease; however, there are limited data outside of digestion trials showing performance in growing and finishing trials. In growing diets, Worley et al. (1986) fed silage harvested at 31 or 44% whole plant DM to growing heifers. The authors reported decreased ADG and poorer feed conversion in the first 28 DOF. While overall performance from d 0 to d 70 was not statistically different, the 44% DM silage had numerically lower ADG and G:F. Chamberlain et al. (1971) fed corn silage harvested at different maturities in growing diets (70% of diet DM): late milk (62% grain moisture), early dent (49% grain moisture), late dough (43% grain moisture), and when the endosperm was mealy (35% grain moisture). These grain moistures correspond to roughly 25, 30, 36.5, and 44% whole plant DM based on research by Daynard and Hunter (1974). There were no differences in ADG between the first three stages of maturity, but the latest maturity had the lowest ADG. Intake was lowest for latest harvested corn silage and G:F decreased as harvest was delayed. Chamberlain et al. (1971) compared corn silage in finishing diets (27% of diet DM) harvested from 25 to 44% whole plant DM, and as harvest maturity was increased, there were no differences in final BW, DMI, ADG or G:F in the finishing period across all corn silages. Buchanan-Smith (1982)

compared corn silage harvested at 28 or 42% whole plant DM in finishing steers and reported that steers fed 42% DM silage had a 5% increase in DMI but there was no difference in ADG between steers fed 28 or 42% DM silage. Browne et al. (2005) compared silages harvested at 29.1, 33.9 and 39.3% whole plant DM in European style finishing systems with 89% corn silage included in the finishing diet. The authors found that as harvest was delayed, DMI increased; however, final BW, HCW, and ADG were not different as harvested was delayed.

Limited research has been done with harvest maturity in growing and finishing cattle, and more research is warranted to evaluate delayed corn silage harvest. Based on the limited data, growing cattle may have decreased performance as corn silage harvest is delayed but finishing cattle are not as affected by harvest maturity.

***Hybrid effect in growing and finishing diets***

Hybrids like BM3 have been shown to have greater NDF digestibility, which could be advantageous for increasing animal performance in beef cattle diets. However, research trials on comparing BM3 varieties to conventional hybrids are limited for growing diets and non-existent for finishing diets with less than 25% corn silage concentration. Furthermore, all of the digestibility data have been done with high concentrations of silage in growing cattle or high-producing lactating dairy cows, which have greater DMI and faster passage rates than finishing cattle on a feedlot diet. With decreased intakes and passage rates, different responses could occur in ruminal and total tract digestion of fiber and starch in feedlot cattle.

Colenbrander et al. (1972, 1973, 1975) presented the first growing trial utilizing beef heifers in which the BM3 hybrid was compared to isogenic controls. These studies

showed BM3 silages had greater DMI, ADG and G:F compared to controls. Unfortunately, these trials were side by side comparisons and not replicated. Additionally, ears were removed, comparing only the forage portion of *bm3,* but it did show a potential for use in beef cattle. Weller and Phipps (1986) compared BM3 corn silage to non-BM3 control fed to weaned heifer calves for 56 d. The authors reported that DMI was not different between BM3 and non-BM3, but the calves fed BM3 had 11 % greater ADG which translated into improved G:F.

More recently, Tjardes et al. (2000) evaluated a BM3 hybrid to isogenic control in a 112-d growing trial with steers. During the growing phase, silage was fed at 86 % of the diet DM. The authors reported that during the growing phase, DMI was greater for steers fed BM3 than non-BM3, but there were no differences in ADG between the two treatments. Subsequently, G:F was lesser for steers fed BM3 during the growing phase. Tjardes et al. (2000) finished the steers on a common finishing diet of 15% non-BM3 corn silage. Steers fed BM3 during the growing phase maintained greater DMI, but the G:F response in the growing phase for non-BM3 silage was not maintained. Saunders et al. (2015) compared a BM3 hybrid to an isogenic control silage using individually fed crossbred beef steers. The authors reported that final BW had a tendency to be greater at the end of the 84-d growing period. Steers fed BM3 silage had a tendency for greater ADG and G:F compared to non-BM3 silage, with no difference in DMI between silage treatments.

Keith et al. (1981) compared the performance of feedlot cattle fed either BM3 or non-BM3 silage at concentrations of 88, 60, 27% on DM basis in the finishing diet. Cattle fed BM3 at both 88 and 60% of diet DM had greater total gain, DMI, and ADG

compared to the non-BM3 fed cattle. Cattle fed BM3 at the higher concentration also had a tendency for an improvement in G:F compared to non-BM3 fed cattle. As the concentration of corn silage decreased in the finishing diet to 27%, no differences in feedlot performance were reported between the BM3 and non-BM3 fed cattle. This suggests fiber digestion was reduced and had no advantage at the lower concentration (Keith et al., 1981). A more recent evaluation of the BM3 with other commercial hybrids was done by McEwen and Buchanan-Smith (1996) and these authors reported that cattle fed BM3 silage had lower intakes and greater G:F with no difference in ADG compared to other commercial hybrids.

Increasing the concentration of corn silage has been shown to decrease performance; however, the extent of the decrease depends on silage concentration. In growing diets, delayed harvest maturity could lead to slight impacts in performance, but in a finishing diet, performance differences are negligible. Brown midrib silages in growing and finishing diet performance have varied with increases in performance to no differences in performance. In summary, recent data are limited for silage growing and finishing diets with elevated concentrations of corn silage. Research with harvest maturity and hybrid differences is very limited and needed to better evaluate enhancements in corn silage breeding programs.

## Inclusion of Distillers Grains in Beef Cattle Diets

Ethanol production from the fermentation of cereal grains has been used for millennia and utilizing the byproducts or distillers grains from this process as livestock feed has been around just as long. With the creation of the Renewable Fuels Standard in 2005, ethanol production for use in fuel has increased dramatically and so has the

production of distillers grains. In 1999, biorefineries produced roughly 2.3 million metric tons of distillers grains. This increased to 39.0 million metric tons in 2011 (RFA, 2016). The most common byproduct of the ethanol industry today is distillers grains plus solubles (DGS) derived from corn grain. The combination of 80% distillers grains and 20% distillers solubles on a DM basis is the most common combination used today (Corrigan et al., 2009). In the fermentation process, the starch in grain is converted to sugar for the production of ethanol. As corn grain is approximately 2/3 starch, the remaining fiber, protein, fat, and minerals become concentrated 3-fold (Klopfenstein et al. 2008). Three forms of distillers grains are available to cattle feeders today: dry DGS (DDGS; 89.9% DM), modified DGS (MDGS; 47.8% DM), or wet DGS (WDGS; 31.2% DM). All of these have a CP content of approximately 30.2% and a NDF content of 34% (NASEM, 2016). Fat content of DGS has changed due to fractionation in ethanol plants with centrifuges. Fat content should be 11 to 13%, but plants with centrifuges decrease fat to 7 to 9% (Jolly, 2013). Including distillers grains plus solubles in beef cattle diets as either a protein (inclusion level of 15-20%, DM basis) or energy source (inclusion levels >20% DM basis) has become common over the past decade (Klopfenstein et al, 2008).

***Distillers grains in forage based diets***

As previously mentioned, starch can have a negative associative effects on fiber digestion in the rumen, and supplying grain at high rates can hinder performance in grazing cattle (Chase and Hibberd, 1987). With the starch removed in DGS, energy comes from protein, fat, and highly digestible NDF that does not limit fiber digesting bacteria by competing with starch digesting bacteria. With increasing concentrations of DRC supplementation in forage diets, Loy et al. (2008) reported that the TDN of DRC

decreased from 90% at low concentrations to 81% when high concentrations of corn were fed. The authors attributed this decrease in TDN to increased starch and decreased pH affecting cellulolytic activity and decreasing fiber digestibility. Loy et al. (2008) calculated a TDN of DDGS that was 118-130% the value of corn in this experiment. Ahern et al. (2016) compiled data from four experiments that compared DRC, DDGS, and WDGS as energy sources in high forage diets. The authors concluded that WDGS was 137% the value of DRC when fed at 15% of the diet and 136% the value of corn when fed at 30% of the diet. Furthermore, the authors found no differences in the feeding value of WDGS or DDGS. As previously mentioned, the MP requirements of growing animals are important in maximizing growth and DGS can help meet this protein requirement with high CP (30.2%) and high RUP (63%) as % of CP (Castillo-Lopez et al., 2013). Digestibility of RUP in DGS is relatively high (Kononoff et al., 2007). In forage based diets, total tract CP digestibility of DDGS was 94.1% and intestinal RUP digestibility (% of RUP) of DDGS was 86.1%. As mentioned, Oney (2017) concluded that corn silage had a RUP (% of CP) content of 8.9% and a RUP digestibility of 32.3%. Additional DGS supplementation greater than 20% of DM can provide excess MP beyond recycling RDP to the rumen and can be deaminated and used as an energy source (NASEM, 2016).

With high digestible NDF and low starch, increased concentrations of DGS in silage based growing diets could be beneficial in counteracting the negative associative effects of starch and fiber. Additionally, with the high CP and RUP value of DGS, supplementation has been shown to meet the MP requirements of growing calves. The

protein in DGS fits well into a silage growing program that is lacking in RUP, which could benefit from additional RUP and maximizing performance.

***Distillers grains in finishing diets***

Distillers grains are a very palatable, high energy feed that, with the expansion of the ethanol industry, have been commonly used to replace corn in finishing diets. Bremer et al. (2011) conducted a meta-analysis of feedlot finishing diets where DGS replaced DRC, HMC, or a combination of DRC and HMC. DMI increased quadratically at a decreasing rate as DGS increased in the diet. ADG and G:F increased quadratically in MDGS and WDGS diets, with maximum ADG occurring at 30% of diet DM and maximum G:F occurring at 40% of the diet DM. In DDGS diets, ADG and G:F linearly increased as DDGS increased in the diet (Bremer et al., 2011). The authors' calculated feeding values were 150, 143, 136, and 130% that of corn for WDGS fed at 10, 20, 30, and 40% of the diet DM, respectively. For MDGS, the calculated feeding values were 128, 124, 120, and 117% that of corn for MDGS fed at 10, 20, 30, and 40% of the diet DM, respectively. G:F values did not decrease at the higher concentrations, but feeding values decreased due to increased DGS concentration in the feeding value calculation. The feeding value of DDGS did not change with increases in concentration and was 112% that of corn when fed at 10 to 40% of the diet DM (Bremer et al., 2011). Watson et al. (2014) evaluated WDGS and MDGS replacing DRC and HMC in finishing diets on animal performance. The authors reported that when feeding WDGS, maximum gain was achieved at 30% concentration on a DM basis and maximum G:F was achieved at 40% concentration. When feeding MDGS, maximum ADG and G:F were achieved when fed at 20 and 50%, respectively, and both types of distillers grains had greater feeding

value than corn. Research comparing different DGS types validated this drying effect on feedlot performance by comparing WDGS, MDGS, and DDGS in a corn-based finishing diet (Nuttelman et al., 2011). Bremer et al. (2011) attributed increased performance to feeding value, as it supplies moisture to the diet, which could help reduce sorting and improve palatability, rather than energy content as increased fat, protein, and fiber content cannot account for all of the increased energy value.

Distillers grains with solubles have been shown to be an excellent source of protein and energy for feedlot cattle and subsequently have been widely adopted in present-day feedlot diets. Distillers grains in combination with corn silage in growing and finishing diets could benefit from high protein as well as replacement of starch with highly digestible NDF, however little work has been done evaluating corn silage in combination with DGS at higher concentrations.

## Corn Silage and Distillers Grains

In growing cattle, corn silage has been used as a way to grow calves in fall and winter prior to finishing (Folmer et al., 2002). With the increase in use of DGS in feeding operations, cattle feeders have incorporated DGS into their corn silage based growing programs. Prior to the expansion of the ethanol industry, Folmer et al. (2002) evaluated corn silage hybrids with 90% corn silage concentration and 10% supplement consisting of soybean meal and urea combination (75:25% N basis). This resulted in an average ADG of 1.34 kg/d and G:F of 0.158 over 110 d growing trial. Post ethanol expansion, Weber et al. (2011) fed similar corn hybrids with 80% corn silage concentration and 15% WDGS that resulted in an average ADG of 1.64 kg/d and G:F of 0.174 over 86 days. While these two trials cannot be compared directly, comparison of

trial averages suggests a synergistic effects of WDGS in a silage based growing diet. Segers et al. (2013) compared silage based (75% on DM basis) with either 25% corn gluten feed, DDGS or a 60:40% blend of ground ear corn and soy bean meal (SBM). The authors reported no difference in final BW after an 84 d growing period, however DDGS and SBM had 10 kg heavier final BW. Daily gain and G:F were greatest for DDGS and SBM compared to corn gluten feed. While DDGS and SBM had similar performance, total costs were lower for the calves fed DDGS compared to those fed the ground corn/SBM mix as DDGS cost less per kg (Segers et al., 2013) Felix et al. (2014) compared silage based (79% on DM basis) growing diets with sources of supplemental protein on animal performance. The authors compared silage growing and formulated diets to be iso-nitrogenous with a CP of 10.8, however the source of supplemental protein, either urea, DDGS or SBM, was different. The DDGS and SBM supplemented treatments had similar performance, and both treatments had greater final BW, DMI, ADG and G:F compared to the urea treatment. As corn silage is lacking in the protein necessary to meet MP requirements in growing calves, supplementing with high quality protein like DDGS or SBM that is higher in RUP benefited these growing calves compared to increased RDP in the urea treatment. While DDGS and SBM had similar performance, total costs were lower for the calves fed DDGS compared to those fed SBM as DDGS was half the cost of SBM per kg (Felix et al., 2014). Feeding DGS in silage growing diets can improve the quality of the protein fed at a reduced price.

Corn silage has been used as a roughage source in finishing cattle, and when fed at concentrations < 15% (Uwituze et al., 2011), there are no observed differences in performance between finishing cattle fed 0 or 25% DDGS in the diet. Burken et al.

(2017a) fed corn silage at 15, 30, 45, and 55% with MDGS concentration of 40% (DM basis) and an additional diet of 45% corn silage and no distillers in finishing diets to evaluate animal performance. As corn silage concentration increased from 15 to 45%, ADG and G:F decreased linearly, but when comparing diets with 45% corn silage, the diet with 40% MDGS had greater ADG and G:F compared to 0 % MDGS. While performance was reduced when feeding high concentrations of corn silage and DGS, the decreased in performance is less with DGS in the diet compared to previous studies without DGS. With 40% MDGS in the diet, increasing the amount of corn silage in the diet from 15 to 45% resulted in a 5% reduction in G:F, however without DGS in the diet, both Goodrich et al. (1974) and Erickson (2001) reported a 15% reduction in G:F when increasing silage concentration from 15 to 45% (Burken et al., 2017a). Additionally, Burken et al. (2017b) conducted two more feeding trials comparing the concentration of silage (15 or 45%) and DGS (20 or 40%) concentration with a non-silage control. In the first experiment, there were no differences in DMI across treatments, but feeding elevated concentrations of corn silage decreased ADG and G:F. As DGS concentration increased, cattle fed 40% had no difference in ADG or G:F when silage was increased from 15 to 45%. However, at 20% concentration of MDGS, ADG and G:F were significantly lower as silage concentration increased (Burken et al., 2017b). In the second trial, increasing the silage from 15 to 45% increased DMI and decreased ADG regardless of MDGS concentration, which resulted in decreased G:F for steers fed 45% corn silage. In Exp. 1, Burken et al. (2017b) reported that the feeding value of corn silage relative to a 1:1 blend of DRC:HMC was 56% in diets with 20% MDGS and 88% in diets with 40% MDGS. In Exp. 2, the feeding value of corn silage was 85% of the corn blend in 20% MDGS diets

and 83% in 40% MDGS diets. While the authors cited differences in cattle type and season of feeding, feeding values in both Exp. 1 and 2 were similar at 40% MDGS concentration and to the feeding value of 83% reported by Burken et al. (2017a), but could not explain the difference in feeding value at 20% MDGS concentration.

Ramirez et al. (2012) compared the effects of feeding a dual purpose control to a BM3 hybrid with or without 30% DDGS in dairy cows. The authors concluded that BM3 with DDGS increased DMI and improved NDF digestibility, but total milk yield was not improved. Unfortunately, there is no peer review data available on the effect of BM3 hybrid and DGS concentration in growing and finishing cattle. Nestor (2011) filed for a patent application for the use of BM3 hybrids replacing corn in beef cattle diets and presented two studies comparing hybrids fed at 15% of the diet with 25% WDGS in Exp.1 and 25% corn silage concentration with 20% WDGS and 20% wet corn gluten feed (WCGF). In Exp 1, Nestor (2011) reported no difference in DMI, ADG, or G:F between a dual purpose and BM3 hybrid. In Exp 2. with increased corn silage concentration (25%) and increased concentrations of WDGS and WCGF, the BM3 hybrid had a tendency for greater ADG and a significant increase in G:F compared to the dual purpose control. Nestor (2011) suggested greater fiber digestibility and this is in agreement with previous BM3 studies. When BM3 concentration is increased, performance response is greater compared to lower concentration (Keith et al., 1981). Unfortunately, there are no data available on the effects of harvest maturity and DGS concentration in growing and finishing cattle.

## Conclusion

Due to increased corn grain prices in recent years, there has been a resurgence in the interest of feeding corn silage among cattle feeders. Although G:F is decreased with high concentrations of corn silage, opportunities may exist for cattle feeders with the incorporation of distillers grains as an excellent source of protein and energy for feedlot cattle. Additionally, different management practices such as harvesting corn silage at later maturities and selection of different hybrids could impact performance in growing and finishing diets.

Limited work has been done evaluating increasing concentrations of corn silage in feedlot diets containing distillers grains with solubles. Additionally, limited work has been done evaluating distillers grains in silage growing diets. Lastly, there is a need for research on the effects of corn hybrid and harvest maturity on corn silage quality and yield. Therefore, more research is needed to evaluate production practices on nutrient metabolism, cattle performance, and carcass characteristics when cattle are fed increased concentrations of corn silage in finishing diets containing distillers grains with solubles.

The objectives of the following studies were to provide enhanced knowledge of the value of corn silage by evaluating harvest time, hybrid selection, and concentration in the diet and their effects on animal performance in growing and finishing diets and carcass characteristics in finishing diets.

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# Chapter II. Impact of corn silage moisture at harvest on performance of growing steers with supplemental RUP, finishing steer performance, and nutrient digestibility by lambs[1]

F. H. Hilscher, D. B. Burken, C. J. Bittner, J. L. Gramkow, R. G. Bondurant, M. L. Jolly-Breithaupt, A. K. Watson, J. C. MacDonald, T. J. Klopfenstein, and G. E. Erickson[2].

Department of Animal Science, University of Nebraska, Lincoln, NE, 68583

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[2]Correspond author: gerickson4@unl.edu.

## Abstract

Three experiments evaluated the effects of delayed corn silage harvest, silage concentration, and source of supplemental protein on performance and effect of nutrient digestibility in growing and finishing diets. Experiment 1 utilized 180 crossbred yearling steers (BW = 428; SD = 39 kg) to evaluate corn silage DM (37 or 43%) and replacing corn with silage (15 or 45% of diet DM) in finishing diets containing 40% modified distillers grains with solubles. Experiment 2 utilized 60 crossbred steers (BW = 271; SD = 32 kg) to evaluate corn silage harvest DM (37 or 43%) and response to rumen undegradable protein (RUP) supplementation (0.5, 1.4, 2.4, 3.3, or 4.2% of diet DM) in high silage growing diets. Experiment 3 utilized 9 crossbred lambs (BW = 30.1; SD = 4.1 kg) to evaluate nutrient digestibility of 37 or 43% DM corn silage in high silage growing diets at two different intakes. Previous data suggests DM yield and grain content may be increased if silage harvest is delayed which results in the silage being drier. In Exp. 1, as corn silage concentration increased from 15 to 45%, ADG and G:F decreased ($P \leq 0.04$). Carcass-adjusted final BW and HCW were lower ($P \leq 0.04$) for steers fed 45% corn silage compared to 15% when fed for equal DOF. As DM of corn silage was increased from 37 to 43%, no differences ($P \geq 0.30$) in DMI, ADG, G:F, or HCW were observed. In Exp. 2, as DM of corn silage increased from 37 to 43%, ADG and G:F decreased ($P \leq 0.04$). Increasing supplemental RUP in the diet increased ($P \leq 0.05$) ending BW, DMI, ADG, and G:F linearly as supplemental RUP increased from 0.5 to 4.2%. In Exp. 3, there were no differences ($P \geq 0.56$) in DM digestibility and OM digestibility between silage harvest DM or intake level. NDF intake was lesser ($P <$ 0.01) for lambs fed the delayed harvest corn silage compared to earlier corn silage

harvest. As silage harvest was delayed from 37% to 43% DM, NDF digestibility decreased ($P < 0.01$) from 64.39 to 53.41%. While increasing corn silage concentration in place of corn in finishing diets reduced ADG and G:F, delayed silage harvest did not affect performance of finishing cattle. Delayed silage harvest in growing cattle resulted in lower ADG and G:F, possibly due to increased grain yield and in turn decreased NDF digestibility. The addition of RUP to silage-based, growing diets improves performance by supplying more metabolizable protein and suggests RUP of corn silage is limiting.

**Key words**: Corn silage, distillers grains, dry matter, finishing cattle, growing cattle, rumen undegradable protein

## Introduction

Feeding corn silage allows cattle feeders to take advantage of the entire corn plant at a time of maximum quality and tonnage as well as secure substantial quantities of roughage/grain inventory (Burken et al., 2017b). Corn silage is a moderately high energy, low protein forage that allows for flexibility in growing and finishing cattle feeding programs (Allen, 2003). Corn silage typically contains 6.5 to 8.5% CP, most of which is in the form of rumen degradable protein (RDP) and is utilized for microbial protein synthesis. The NASEM (2016) lists the rumen undegradable protein (RUP) content for corn silage as 25.38% (% of CP). When evaluating the RUP value of forages, Kononoff et al. (2007) estimated RUP of corn silage to be 19.25% of CP, but of that, intestinal RUP digestibility was only 19.9%. An inadequate supply of metabolizable protein requires supplemental RUP to meet requirements (NASEM, 2016). Thus, source and amount of supplemental protein are important factors affecting growth because supplemental protein provides a significant amount of the total dietary protein (Felix et

al., 2014). When corn silage replaces corn in finishing diets, G:F decreases as corn silage increases in the diet (Goodrich et al., 1974; Burken et al., 2017a). Management decisions, such as silage harvest maturity, can affect the quality and yield of corn silage and impact performance in growing and finishing cattle (Chamberlain et al., 1971). Hunt et al. (1989) reported that as silage harvest is delayed whole plant yield and TDN in Mg/ha were increased. Allen et al. (2003) summarized these changes as, grain development occurring largely at the expense of stover quality. The total amount of starch increases as the plant matures (Andrae et al., 2001). Since starch provides more than 50% of the energy in corn silage (Owens, 2008), this increase in starch content represents a large increase in total energy yield by harvesting corn silage with more maturity. However, as corn silage is harvested later in the harvest season with advanced maturity, whole plant NDF decreases as well as NDF digestibility (Andrae et al, 2001; Owens, 2008). While incorporating distillers grains and corn silage at greater concentrations in growing and finishing diets has been shown to improve animal performance compared to corn silage alone (Felix et al., 2014; Burken et al., 2017a,b), optimum harvest time to maximize yield and quality and the effects on animal performance have not been evaluated with distillers grains and additional RUP supplementation.

The objectives of the following studies were to 1) evaluate harvest time and concentration of silage in finishing cattle diets containing distillers grains, 2) determine the effects of delaying corn silage harvest on growing steer performance with additional RUP, and 3) determine nutrient digestibility of 37 or 43% DM corn silage at two intakes.

## Materials and Methods

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

***Corn cultivation, harvest and chemical composition***

A single corn hybrid (P1498AM; Du Pont Pioneer, Johnston, IA) was planted in a single irrigated field at the Eastern Nebraska Research and Extension Center (ENREC) located near Ithaca, NE in 2014. Target planting density was 84,015 seeds/ha. The field was managed in a corn and soybean rotation every year for the previous 6 years. Corn silage was harvested using a self-propelled forage harvester (JD 5400, John Deere, Moline, IL) set for a 1.27-cm theoretical length of chop, without a kernel processing unit.

Harvest DM was targeted to mimic traditional corn silage harvest at 37% DM or a delayed harvest at 43% DM. Harvest for 37% DM corn silage was harvested all on September 4, 2014 when the corn was at approximately ¾ milkline and whole plant corn silage samples were greater than 35% DM as determined by a moisture tester (Koster Crop Tester, Inc., Brunswick, OH) prior to harvest. Silage harvest for 43% DM corn silage occurred two wk later on September 16, 2014 and all occurred on one day. This coincided with black layer formation and moisture tester samples were greater than 42% DM prior to harvest. Corn silage was harvested in 4 replications of 0.72 ha each, and within replication, the total weight of silage harvested was recorded for silage yield determination. Additionally, high moisture corn (kernel DM 32%) and dry corn (kernel DM 15%) yield strips were harvested within the same field on September 18, 2014 and November 4, 2014, respectively. Both, 37% DM and 43% DM silages were stored in

separate side-by-side 3-m diameter by 61-m long plastic silos (AgBag, St. Nazianz, WI) and allowed to ferment for 28 d before commencing the feeding trials.

Corn silage was sampled weekly during the feeding trial for DM determination in a 60° C forced air oven for 48 h (Table 1). Weekly samples (n = 19) within a month were composited (n = 4) and analyzed by a commercial laboratory (Dairyland Laoratories, Inc., Arcadia, WI) for fermentation analysis, starch, and water soluble carbohydrates. Silage samples were analyzed for CP, NDF, and ADF by monthly composites (n = 4) at a commercial laboratory (Ward Laboratories, Inc., Kearney, NE).

Harvest data were analyzed using the GLIMMIX procedure of SAS (SAS Inst. Inc., Cary, NC). Silage harvest data were analyzed as a completely randomized design with silage strips serving as the experimental unit. There were 4 replications per silage DM harvested, as well as 4 replications per DRC and HMC yield. Significance was declared at $P \leq 0.05$.

***Exp. 1 - Cattle Finishing Experiment***

Crossbred yearling steers (n=180; initial BW = 428; SD = 39kg) were sorted into 3 BW blocks and assigned randomly to one of 20 pens (9 steers/pen; 1 replication in heavy BW block, 3 replications in middle BW block, and 1 replication in light BW block). Prior to the initiation of the experiment, all steers were individually identified and processed at arrival at the research feedlot with: a modified live viral vaccine for infectious bovine rhinotracheitis, bovine viral diarrhea types I and II, parainfluenza3, bovine respiratory syncytial virus, *Mannheimia haemolytica* toxoid (Bovi-Shield Gold One Shot, Zoetis Inc., Kalamazoo, MI), *Histophilus somnus* bacterin (Zoetis Inc.), and an injectable anthelmintic (Dectomax, Zoetis Inc.). All steers were revaccinated

approximately 14 to 28 d after initial processing with a modified live viral vaccine for infectious bovine rhinotracheitis, bovine viral diarrhea types I and II, parainfluenza3, bovine respiratory syncytial virus (Bovi-Shield Gold 5, Zoetis Inc.), and a killed viral vaccine for clostridial infections (Ultrabac 7, Zoetis Inc.). Prior to the start of the experiment, steers were limit fed (Watson et al., 2013) a diet containing 50% wet corn gluten feed (Sweet Bran, Cargill Inc., Blair, NE) and 50% alfalfa hay (DM basis) at 2.0% of projected BW for 5 d to equalize gastro-intestinal fill prior to weighing on d 0 and d 1 for initial BW determination (Stock et al., 1983). Treatments (Table 2) were designed as a 2 X 2 factorial arrangement that consisted of harvested corn silage DM (37% DM or 43% DM) and concentration of corn silage in the finishing diet (15% or 45% DM basis). Corn silage replaced high moisture corn (HMC) on a dry basis. All steers were fed a supplement formulated for 33 g / ton monensin (Elanco Animal Health, Greenfield, IN) and a targeted intake of 90 mg/steer daily of tylosin (Elanco Animal Health). Pens were fed once daily at approximately 0830 h. Steers were implanted with Revalor-200 (200mg of trenbolone acetate and 20mg estradiol; Merck Animal Health, Summit, NJ) on d 1. Feed bunks were assessed at approximately 0530 h with the goal of trace amounts of feed at time of feeding. All diets were fed once daily, and feed refusals were removed from feed bunks when needed, weighed, and subsampled. All feed refusals were subsampled and dried for 48h in a 60ºC forced-air oven for determination of DM and calculation of refusal DM weight (AOAC, 1999 method 4.1.03). Dietary ingredients were sampled weekly for determination of DM content. Dietary as-fed ingredient proportions were adjusted weekly. Steers were on feed for an average of 108 d (97 d block 1, 111 d block 2 and 3) and were harvested at a commercial abattoir (Greater Omaha Packing, Omaha,

NE). On the day of shipping to the commercial abattoir, pens of steers were fed 50% of the previous day's DM offering at regular feeding time. Pens of steers were weighed on 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 calculation of dressing percentage (HCW / shrunk live final BW). Hot carcass weight and liver scores were obtained the d of harvest. Liver abscesses were categorized as 0 (no abscesses), A-, A, or A+ (severely abscessed) according to the procedures outlined by Brink et al. (1990). Liver abscess categories were combined to calculate the proportion of steers with abscessed livers in each pen. Carcass-adjusted final BW, used in the calculation of ADG and G:F, was calculated from HCW and a 63% common dressing percentage. Marbling score, 12th rib fat thickness, and LM area were recorded after a 48 h carcass chill. The energy value of the diets was calculated by utilizing pen data in the Galyean (2009) Net Energy calculator based on NRC (1996) net energy equations. The calculator utilizes initial BW, final BW, DMI, ADG, and a target endpoint (assuming choice quality grade).

Performance and carcass data were analyzed using the GLIMMIX procedure of SAS (SAS Inst. Inc.) with pen serving as the experimental unit (n = 5 per treatment) and block (n = 3) as a fixed effect. Data were analyzed as a randomized block design with BW sort as block. Initial BW was significantly different between silage DM treatments (1.7 kg), therefore initial BW was included as a covariate in the model if significant. Inclusion of initial BW was not significant for any variables and was removed from the model. Significance of effects was determined at $P \leq 0.05$.

***Exp. 2 - Cattle Growing Experiment***

An 83 day growing study was conducted at the Eastern Nebraska Research and

Extension Center (ENREC) near Mead, NE using 60 crossbred steers (BW = 271; SD = 32 kg). Steers were individually fed using Calan gate feeders (American Calan Inc., Northwood, NH). Upon arrival and prior to initiation of the experiment, steers were identified and processed as previously described. Cattle were limit-fed a diet of 50% Sweet Bran and 50% alfalfa hay at 2.0% of projected BW for 5 d prior to trial initiation to equalize gut fill (Watson et al., 2012). Steers were weighed 3 consecutive days, with the average of the 3 days used as initial BW (Stock et al., 1983). A randomized block experimental design was used with treatments arranged in an unbalanced 2 x 5 factorial arrangement. The first factor was the base corn silage growing diet fed at 88% of the diet DM which consisted of either corn silage harvested at 37% or 43% DM (Table 3). The second factor was response to RUP supplementation at 0.5, 1.4, 2.4, 3.3 or 4.2% of the diet DM. The RUP supplementation consisted of top dressing a blend of 0/100, 25/75, 50/50, 75/25, or 100/0 combination of a RDP and RUP supplement (Table 3). The supplement included RUP source, urea, minerals, vitamins A-D-E, and soybean hulls. Soybean hulls was the carrier that was replaced with the RUP sources. The supplement also included monensin (Elanco Animal Health) and was formulated to provided 200 mg/steer daily. The RUP supplement consisted of 52% SoyPass (50% CP; 75% RUP as % CP; Borregaard Lignotech, Rothschild, WI) and 34.7% Empyreal (75% CP; 65% RUP as % of CP; Cargill Inc.) and provided RUP in a blend of amino acids from soybean meal and corn gluten meal. SoyPass is an enzymatically browned soybean meal and Empyreal is a concentrated corn gluten meal. Steers were stratified by day -1 and day 0 BW, and assigned randomly to 1 of 10 treatments arranged in a 2 x 5 factorial arrangement. Steers per level of RUP supplementation included n = 8 for 0.5% RUP; n = 5 for 1.4% and 2.4

% RUP; n = 6 for 3.3% and 4.2% RUP treatments. With a limited number of bunks, a greater number of animals were fed at 0.5% RUP concentration to better compare the effect of delaying corn silage harvest. Additionally, a greater number of animals were fed at 3.3% and 4.2% RUP concentration as it was hypothesized the steers metabolizable protein needs would be met at greater levels of RUP concentration. Steers were treated for external parasites (StandGuard, Elanco Animal Health) and were implanted with Ralgro (36 mg zeranol, Merck) on d 1. Feed bunks were assessed at approximately 0600 h and managed to allow for trace amounts of feed to remain at time of feeding. Steers were fed ad libitum once daily at 0800 h. Feed refusals were collected weekly, weighed, and then dried in a 60°C forced air oven for 48 hours to calculate an accurate DMI for individual steers. Feed ingredients were sampled weekly and analyzed in the same manner for DM, with as-fed ingredient proportions adjusted weekly. At the conclusion of the study, steers were again limit-fed for 5 d as described above and weighed 3 consecutive days to determine ending BW. The energy value of the diets was calculated by utilizing pen data in the Galyean (2009) Net Energy calculator based on NRC (1996) net energy equations. The calculator utilizes initial BW, final BW, DMI, ADG, and target endpoint (assuming choice quality grade).

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc.) as a randomized block design in a 2 x 5 factorial arrangement testing for linear and quadratic interactions between silage DM and RUP level with steer serving as the experimental unit and weight block (n = 5) as a fixed effect. If no interactions were detected, the main effects of silage DM and RUP concentration were evaluated. To evaluate RUP level,

linear and quadratic contrasts were developed to evaluate the effect of increasing RUP level. Significance was declared at $P \leq 0.05$.

***Exp. 3 - Lamb Digestion Experiment***

An 85-d metabolism study utilizing 9 crossbreed wether lambs (BW = 30.1; SD = 4.1 kg) was conducted to determine the extent of nutrient digestibility in corn silage at two different levels of DM and intake. Lambs were blocked into 2 blocks based on BW and arranged in a 4 × 5 Latin rectangle. The metabolism study was 5 periods in length with treatments assigned randomly to lambs within each period, allowing each lamb to receive each treatment at least once. Treatments were arranged in a 2 x 2 factorial arrangement. Factors included corn silage harvested at either 37% or 43% DM and intake of corn silage ad libitum or restricted to 1.5% of BW. Basel diet consisted of 92% corn silage and 8% supplement (Table 4).

The periods were 17 d in length allowing for 10 d of adaptation and 7 d for total fecal collection. Intake restriction to 1.5% of BW began on d 8 of the period 3 d prior to collection. Body weight was determined by weighing two consecutive days at the end of a period for subsequent restriction calculations in the next period. During the adaptation period, lambs were housed in individual pens with grate floors, individual feed bunks, and automatic waterers. Feeding occurred twice daily at approximately 0800 and 1500, and orts were collected, weighed, and fed back during the adaptation period.

At the end of adaptation, lambs were placed in individual metabolism crates and fitted with harnesses and fecal collection bags on the evening of d 10. Total fecal output was collected twice daily beginning on d 10 at 0800 h and 1600 h, weighed, and retained individually in a cooler until the end of the period. Orts were collected at feeding,

weighed, and retained individually until the end of the period. At the end of each period, feces and orts were individually composited and mixed on an as-is basis. Three 100 g sub-samples were taken and dried in a 60°C forced air oven for 48 h for orts and 72 h for feces. Dried samples were ground through a 1 -mm screen of a Wiley mill. Samples of individual feedstuffs were taken on d 10 and d 14 and dried to correct for DM of each period. Feedstuff samples were ground first through a 2 -mm screen of a Wiley mill, composited by period, and a subset of period composites were ground through a 1-mm screen of a Wiley mill. Diet and fecal samples were analyzed for DM, OM, and NDF. Ground feed and fecal samples were dried in a 100℃ oven for 24 h to determine lab-adjusted DM, and then incinerated in a muffle furnace at 600℃ for 6 h to determine the ash content to calculate OM. Neutral detergent fiber was determined by refluxing samples in beakers for 1 h (Van Soest and Marcus, 1964; Van Soest et al., 1991). Total tract apparent digestibility was calculated using DM, OM, and NDF disappearance.

Total tract digestibility data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc.) with period and block as fixed effects. Lamb was included as a random effect. Lamb served as the experimental unit, and the model included silage DM, intake, and silage DM by intake interaction. Significance was declared at $P \leq 0.05$.

## Results and Discussion

### ***Corn silage and grain harvest***

There was a significant increase ($P < 0.01$) in yield of DM tons per acre comparing 37% DM to 43% DM corn silage with yields of 21.41 and 22.58 Mg/ha (DM), respectively (Table 5). There was no difference ($P = 0.64$) in yield between high moisture corn and dry corn grain with 13.72 and 13.80 Mg/ha DM yields, respectively

(data not presented). The increase in DM yield is the result of increased grain development, as the plant matures, the grain fraction of the plant is increased as more nutrients are shuttled into the corn kernels in order for them to fully develop. Suazo et al. (1991) reported that across multiple hybrids, whole plant DM yield was maximized at black layer formation and grain yield in Mg per hectare did not differ from black layer to corn grain harvest. Darby and Lauer (2002) reported that whole plant DM yield increased as the growing season was lengthened and more growing degree days occurred. Maximum DM yield was acchived when whole plant DM reached 42% DM, which occurred at the latest date the researchers harvested. Burken et al. (2017a) harvested corn plants at three different time points coinciding with traditional silage harvest with a whole plant DM of 35.8 %, physiological maturity with a whole plant DM of 42.4 %, and corn grain harvest. In year 1 of the experiment, stover yield and whole plant yields responded in a quadratic fashion with both stover and whole plant yields maximized at physiological maturity and decreased at corn grain harvest. The authors suggested that this could be due to senescence and abscission as the stover portion of the plant became dry and brittle after physiological maturity. In year two of the experiment, Burken et al. (2017a) noted linear increases in whole plant and stover yields as harvest was delayed from traditional silage harvest to corn grain harvest. Year to year variation will occur in corn silage yield because of management and environmental factors; however, Burken et al. (2017a) reported greater whole plant yield at physiological maturity compared to traditional corn silage harvest in both years. Filya (2004) also reported DM yield in Mg/ha were maximized at black layer formation which coincided with 42% whole plant DM. Additionally, Hunt et al. (1989) reported that as harvest was delayed, whole plant

yield and TDN in Mg/ha increased. These data suggest that grain yield was maximized when delaying corn silage harvest until black layer formation. Additionally, high-moisture corn was harvested 3 d after the 43% DM silage was harvested further suggesting grain yield was maximized. No further yield increase for grain was observed between this time point and dry grain harvest.

***Exp. 1 - Cattle Finishing Experiment***

There were no interactions between corn silage DM and concentration of corn silage concentration ($P \geq 0.47$) for feedlot performance or carcass characteristics; therefore, main effects will be discussed (Table 6). As concentration of corn silage in the finishing diet increased from 15 to 45%, ADG decreased ($P = 0.04$) while DMI did not differ ($P = 0.15$), and this in turn led to a decrease in G:F ($P < 0.01$). Prior to the expansion and adoption of distiller grains use in finishing cattle, Goodrich et al. (1974) reported linear decreases in ADG and G:F as corn silage was increased in the finishing diet. Similarly, Gill et al. (1976) observed decreased G:F as corn silage was increased in the finishing diet. Brennan et al. (1987) reported no difference in DMI, ADG, or G:F between cattle fed 41 or 23% corn silage in finishing diets. Erickson (2001) evaluated corn silage in finishing diets at 15, 30, or 45% of diet on a DM basis. In two trials with yearling cattle, DMI was not affected by treatment, but ADG and G:F decreased as corn silage concentration increased from 15 to 45% of the diet. In a trial with calf feds, Erickson (2001) reported that DMI increased as corn silage concentration increased; however, ADG and G:F both linearly decreased with increased corn silage. Recently, Burken et al. (2017a) fed increased concentrations of corn silage at 15, 30, 45, and 55% with MDGS concentration of 40% (DM basis) and an additional diet of 45% corn silage

and no distillers in finishing diets to evaluate animal performance. As corn silage concentration increased from 15 to 45%, DMI, ADG, and G:F decreased linearly, but when comparing diets with 45% corn silage, the diet with 40% MDGS had greater ADG and G:F compared to 45% silage with 0 % MDGS. While performance was reduced when feeding greater concentrations of corn silage and DGS, the decrease in performance is less with DGS in the diet compared to in previous studies without DGS.

Calculated NEm and NEg values were significantly decreased ($P < 0.01$) as corn silage concentration increased from 15 to 45% of the diet DM. Preston (1975) summarized experiments where corn silage replaced corn grain up to 64% of the diet and reported linear decreases in NEm and NEg values as concentration of corn silage increased. Similarly, Burken et al. (2017a) reported linear decreases in NEm by 4% (2.00 to 1.92) and NEg by 4.5% (1.34 to 1.28) values as corn silage concentration increased from 15 to 55% of the diet DM. While performance was reduced when feeding high levels of corn silage and DGS, the decrease in performance is less with DGS in the diet compared to previous studies without DGS. Burken et al. (2017a) fed 40% MDGS in the diet, and increased the amount of corn silage in the diet from 15 to 45% which resulted in a 5% reduction in G:F. However without DGS in the diet, both Goodrich et al. (1974) and Erickson (2001) reported a 15% reduction in G:F when increasing silage concentration from 15 to 45%. As corn silage concentration increased from 15 to 45%, ADG and G:F decreased because the decrease in dietary energy content as the corn silage is lower in net energy compared to the corn gain it replaced in the finishing diet.

Carcass-adjusted final BW and HCW were reduced ($P \leq 0.04$) for steers fed 45% corn silage compared to 15%. Burken et al. (2017a) reported a linear decrease in final

BW and HCW as corn silage was increased in finishing diets. Additional studies by Burken et al. (2017b) reported a tendency for decreased final BW and HCW in Exp. 1 and a significant decrease in final BW and HCW in Exp. 2 as concentration of corn silage increased from 15 to 45% of the diet. Dressing percentage decreased ($P = 0.05$) as concentration of corn silage was increased from 15 to 45% in the finishing diet. When cattle are fed elevated concentrations of corn silage, dressing percentage decreases due to increased gut fill. Peterson et al. (1973) reported that as corn silage concentration increased, dressing percentage linearly decreased. Similarly, Brennan et al. (1987), reported cattle fed increased concentrations of corn silage had decreased dressing percentages. Burken et al. (2017a) reported a linear decrease in dressing percentage as corn silage concentration increased. There were no differences ($P \geq 0.31$) in LM area, 12$^{th}$ rib fat, and marbling score as concentration of corn silage concentration increased. Burken et al. (2017b) also reported no differences in carcass characteristics when silage was fed at 15 or 45% of the diet.

As DM of corn silage increased from 37 to 43% due to delaying harvest, there were no differences ($P \geq 0.30$) in DMI, ADG, or G:F . Additionally, there were no differences ($P = 0.68$) in carcass adjusted final BW or HCW as corn silage DM was increased. Chamberlain et al. (1971) compared corn silage in finishing diets (27% of diet DM) harvested from 25 to 44% whole plant DM, and as harvest maturity increased, there were no differences in final BW, DMI, ADG or G:F in the finishing period across all corn silages. Buchanan-Smith (1982) compared corn silage harvested at 28 or 42% whole plant DM in finishing steers and reported that steers fed 42% DM silage had a 5% increase in DMI. There was no difference in ADG between steers fed 28 or 42% DM

silage; however there was a numerical increase in ADG and G:F for steers fed 42% DM silage. Browne et al. (2005) compared silages harvested at 29.1, 33.9, and 39.3% whole plant DM in European style finishing systems with 89% corn silage included in the finishing diet. The authors found that as harvest was delayed, DMI increased and G:F decreased; however, final BW, HCW, and ADG were not different. In the current study, no differences ($P \geq 0.27$) in dressing percent, 12$^{th}$ rib fat, or marbling scores were observed as DM of corn silage was increased.

***Exp. 2 - Cattle Growing Experiment***

There were no linear ($P \geq 0.33$) or quadratic ($P \geq 0.36$) interactions between corn silage DM and level of RUP supplementation for growing performance; therefore, main effects will be discussed. As DM of corn silage increased from 37 to 43%, there was a significant decrease ($P = 0.04$) in ending BW (Table 7). There was no difference ($P = 0.93$) in DMI between 37 or 43% DM corn silage, and ADG was reduced ($P = 0.01$) as DM of silage increased, which led to a significant decrease ($P < 0.01$) in G:F. Worley et al. (1986) fed silage harvested at 31 or 44% whole plant DM to growing heifers. The authors reported decreased ADG and G:F in the first 28 DOF when feeding drier silage. While overall performance from d 0 to d 70 was not statistically different, the 44% DM silage had numerically lower ADG and G:F. Chamberlain et al. (1971) compared corn silage in growing diets (70% of diet DM) harvested from 25 to 44% whole plant DM. There were no differences in ADG in between the first three stages of maturity harvested at 25, 30, and 36.5% DM, but the latest maturity harvested at 44% DM had the lowest ADG. Intake was lowest for latest harvested corn silage and G:F decreased as harvest was delayed. When evaluating corn silage harvested at ½ milk line (28.4% DM) or black

layer (42.5% DM), Andrea et al. (2001) reported decreases in total tract starch, NDF digestibility (NDFD), and ADF digestibility (ADFD) by 6.5, 5.9 and 7.5 percentage units, respectively. The authors concluded that NDFD and ADFD decreased due to increased lignification, and also the increased starch content from the more mature corn silage caused an unfavorable rumen environment with lower pH that hindered fiber digestion. Calculated NEm and NEg values were significantly lower ($P = 0.03$) for 43% DM compared to 37% DM corn silage.

As supplemental RUP in the growing diet increased from 0.5 to 4.2% of total diet, ending BW increased linearly ($P < 0.01$) with steers receiving 4.2% RUP as a % of total diet having the heaviest ending BW and steers receiving 0.5% supplemental RUP having the lowest ending BW (Table 8). There was a linear increase ($P = 0.05$) in DMI as RUP concentration increased in the growing diet. Daily gain improved as RUP concentration increased in the growing diet, with ADG increasing ($P < 0.01$) linearly from 0.5 to 4.2% RUP concentration. With both an increase in DMI and ADG, G:F increased ($P < 0.01$) linearly as RUP concentration increased, with the steers on the 4.2% treatment being 19.9, 14.5, 5.9, and 2.7% more efficient than steers supplemented with 0.5, 1.4, 2.4, or 3.3 % RUP, respectively. Ingredients can vary in RUP content as well as RUP digestibility. Corn grain is the most commonly fed grain in the United States, and dry corn grain has a RUP value of 65.31% (NASEM, 2016). Corn processing method impacts RUP %. Work by Benton et al. (2005) showed that when grain is harvested as high moisture corn (HMC), the RUP content of corn grain decreases, and it becomes more rumen degradable as the moisture content and length of ensiling period increases. The corn grain in silage is harvested earlier than HMC and wetter, suggesting a further

increase in RDP content of the corn grain in corn silage. The NASEM (2016) lists the RUP content for corn silage as 25.38% (% of CP). When evaluating the RUP value of forages, work by Kononoff et al. (2007) found that the digestibility of forage RUP is much lower than the 80% suggested by the NRC (1996). Specifically looking at corn silage, Kononoff et al. (2007) estimated RUP (% of CP) to be 19.25%, but with an intestinal RUP digestibility of only 19.9%. Much of the protein in silage is fermented to soluble protein in the bunker and to ammonia in the rumen. Such degradation reduces the amount of intact protein and amino acids available in the small intestine as RUP (Owens, 2018). The level and degradability in the rumen of protein can have a large impact on growing steer performance. Byers and Moxon (1980) fed corn silage based growing diets (55% of diet DM) and three levels of protein, either 11.6, 14.1 or 16.5%, to growing steers (average initial BW = 233 kg). The additional CP in these supplements came from increased soybean meal (44% RUP; NASEM, 2016) and linseed meal (32% RUP; NASEM, 2016). As CP increased from 11.6 to 16.5, DMI, ADG and G:F all significantly increased. This indicated that calves fed 11.6% CP were not meeting their MP requirements, therefore limiting growth. Perry et al. (1983) fed corn silage (92% of diet DM) to growing steers (average initial BW 213 kg) with supplemental soybean meal to achieve CP levels of 9, 11, or 13% of DM. Increasing the level of CP in the diet increased DMI, ADG, and G:F of these growing calves. While Byers and Moxon (1980) and Perry et al. (1983) concluded that increased dietary protein in silage based growing diets improves performance, it is actually RUP of supplemental CP that had a significant impact on performance because the addition of urea (100% RDP) does not have the same effect as the RUP supplements that were used in those trials. Felix et al. (2014)

compared corn silage based (90% of DM) diets with increased levels of CP at 11, 12, and 13%, and only urea was used to increase CP. When increasing the CP through increased urea in silage diets fed to growing calves (In BW = 198 kg), the authors reported a linear decrease in ending BW, ADG, and G:F and increasing the amount of RDP did not increase the MCP supply enough to maximize growth. Felix et al. (2014) compared silage based (79% on DM basis) growing diets with sources of supplemental protein on animal performance. The authors compared silage growing and formulated diets to be iso-nitrogenous with a CP of 10.8, however the source of supplemental protein, either urea, DDGS or SBM, was different. The DDGS and SBM supplemented treatments had greater final BW, DMI, ADG, and G:F As corn silage is lacking in the protein necessary to meet MP requirements in growing calves, supplementing with high quality protein like DDGS or SBM that is higher in RUP benefited these growing calves compared to increased RDP in the urea treatment.

***Exp. 3 - Lamb Digestion Experiment***

There was no interaction between corn silage DM and intake level for DM and OM intake and digestibility, and therefore the main effects will be presented. Due to intake restriction between ad libitum and lambs held at 1.5% of BW, there was a significant ($P < 0.01$) decrease in DMI and OMI as intake for restricted lambs as designed (Table 9). There were no differences ($P = 0.56$) in DM digestibility and OM digestibility between silage harvest or intake level. Worley et al. (1986) fed silage harvested at 31 or 44% whole plant DM either ad libitum or restricted to growing lambs. The authors reported greater DMI for 44% DM corn silage when fed ad libitum but there were no differences in DM digestibility between silage DM when fed ab libitum or

restricted. Johnson and McClure (1968) reported greater DMI as whole plant DM increased to 33.9% DM and remained constant up to 46% when fed to growing lambs. The authors reported DM and OM digestibility were significantly impacted by harvest DM over a broad range of harvest DM. Between 33.9 and 42.6% DM, DM digestibility changes were minimal: 68.2 vs 68.9% for 33.9 and 42.6% DM silages, respectively. When feeding beef steers, Joanning et al. (1981) reported no difference in DM digestibility between corn silage harvested at 22 or 35% DM. Similarly, Mc Geough et al. (2010) reported no differences in DMI or DM digestibility between silage harvested at four different maturities.

There was an intake × harvest time interaction for NDF intake and therefore the simple effects will be discussed. Intake of NDF was reduced ($P < 0.01$) when intake was restricted from ad libitum to 1.5% BW. Intake of NDF was lower ($P < 0.01$) for lambs fed 43% DM corn silage compared to 37% DM corn silage as NDF content of the silage was decreased and starch content increased as corn silage harvest was delayed. As silage harvest was delayed from 37% to 43% DM, there was a significant decrease ($P < 0.01$) in NDFD from 64.39 to 53.41%. Worley et al. (1986) reported greater NDF intake in 44% DM corn silage compared to 31% DM, but reported no difference in NDFD when lambs were fed ab lib or had intake restricted. The corn silage used by Worley et al. (1986) increased in NDF content as corn silage harvest was delayed, this is not in agreement with previous work that shows NDF content decreases as corn silage harvest is delayed, and could explain why these authors reported increased NDF intake. Jensen et al. (2005) reported NDF intake decreased as whole plant DM increased from 35 to 40% DM. As corn silage is harvested later in the harvest season with advanced maturity, whole plant

NDF decreases (Bal et al., 1997; Di Marco et al., 2002; Ferratetto and Shaver, 2012). Andrea et al. (2001) reported that as the corn plant matures, the NDF content of the corn plant decreased from 43.67 to 38.43% NDF when harvested at 28.4 and 42.4% DM, respectively. These authors also reported digestibility of the NDF has also been shown to decrease from 39.11 to 33.21% when corn silage harvest is delayed. Fiber digestibility significantly decreased as corn silage harvest was delayed in growing lambs (Johnson and McClure, 1968). Joanning et al. (1981) reported that as silage DM increased from 22 to 35% DM, there was a decrease in NDFD of 14.6 percentage units in a 90% silage diet. Jensen et al. (2005) reported decreased NDFD as harvest DM increased from 35 to 40% DM. Delaying silage harvest allows for increased grain yield as a percentage of whole plant yield, with no impact on OM digestion, but delaying silage harvest decreases NDF content and this could explain the reduction of NDFI and NDFD between 37 and 43% DM corn silage.

Delaying corn silage harvest increased corn silage yield and maximized grain yield. While increasing corn silage concentration from 15 to 45% in place of corn in finishing diets reduced ADG and G:F, there were no differences in performance when corn silage harvest was delayed from 37% to 43% DM. However, delayed corn silage harvest in growing diets indicates that 37% DM silage would result in greater ADG and G:F compared to 43% corn silage. As corn silage harvest is delayed, plant NDF decreases at the expense of corn grain being maximized and NDF intake and digestibility decrease. Increasing the amount of RUP in silage growing diets resulted in linear increases in DMI, ADG, and G:F. These results indicate that the addition of RUP into silage diets will improve performance by supplying more metabolizable protein. When

formulating diets that have fermented feedstuffs like corn silage that have high proportions of grain and fiber, it is important to note how that can influence MP supply to the animal.

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**Table 2.1. Nutrient and fermentation analysis of 37 and 43 % DM silage (DM Basis)**

| | 37% DM | | 43% DM | |
|---|---|---|---|---|
| Item | Mean | C.V.[1] | Mean | C.V.[1] |
| DM, %[2] | 37.3 | 3.2 | 42.7 | 3.9 |
| CP, % of DM | 7.51 | 3.6 | 7.50 | 1.2 |
| NDF, % of DM | 31.6 | 17.5 | 28.9 | 5.7 |
| ADF, % of DM | 21.4 | 15.8 | 18.6 | 17.9 |
| Starch, % of DM | 35.4 | 16.7 | 40.8 | 5.0 |
| Sugar, % of DM | 2.6 | 19.6 | 2.5 | 8.7 |
| pH | 3.88 | 1.3 | 3.85 | 1.5 |
| Lactic acid, % of DM | 3.11 | 26.9 | 4.14 | 28.1 |
| Acetic acid, % of DM | 3.98 | 21.5 | 2.81 | 27.1 |
| Propionic acid, % of DM | 0.51 | 26.8 | 0.28 | 54.3 |
| Butyric acid, % of DM | < 0.01 | 0.0 | < 0.01 | 0.0 |
| Total acids, % of DM | 7.61 | 10.5 | 7.22 | 3.3 |

[1] C.V. = coefficient of variation and is calculated by dividing the standard deviation by the mean and is expressed as a percentage.
[2] DM was calculated using weekly samples and oven dried for 48 h at $60^0$ C.
[3] All other samples are based on monthly composites (n = 4) of weekly (n = 19) samples taken during the finishing trial, and analyzed at Dairyland Labs (St. Cloud, MN) and Ward Labs (Kearney, NE).

**Table 2.2. Diet composition (% DM basis) for cattle finishing experiment (Exp.1)**

| | Treatment[1] | | | |
|---|---|---|---|---|
| | 15% corn silage | | 45% corn silage | |
| | 37% DM | 43% DM | 37% DM | 43% DM |
| High moisture corn | 41.0 | 41.0 | 11.0 | 11.0 |
| Modified distillers grains plus solubles | 40.0 | 40.0 | 40.0 | 40.0 |
| 37% DM corn silage | 15.0 | - | 45.0 | - |
| 43% DM corn silage | - | 15.0 | - | 45.0 |
| Supplement[2] | 4.0 | 4.0 | 4.0 | 4.0 |
| Fine ground corn | 1.8048 | 1.8048 | 1.8048 | 1.8048 |
| Limestone | 1.7050 | 1.7050 | 1.7050 | 1.7050 |
| Tallow | 0.1000 | 0.1000 | 0.1000 | 0.1000 |
| Salt | 0.3000 | 0.3000 | 0.3000 | 0.3000 |
| Trace Mineral premix[3] | 0.0500 | 0.0500 | 0.0500 | 0.0500 |
| Vitamin A-D-E premix[4] | 0.0150 | 0.0150 | 0.0150 | 0.0150 |
| Monensin[5] | 0.0165 | 0.0165 | 0.0165 | 0.0165 |
| Tylosin[6] | 0.0087 | 0.0087 | 0.0087 | 0.0087 |

1. Treatments: 15% silage 37 % DM = 15% concentration of 37% DM silage, 15% silage 43% DM = 15 % concentration of 43 % DM silage, 45% silage 37% DM = 45 % concentration of 37% DM silage, 45% silage 43% DM = 45 % concentration of 43% DM silage; all diets contained 40% MDGS.
2. Supplement was formulated to be fed at 4% of diet DM
3 Trace mineral premix contained 6% Zn, 5.0% Fe, 4.0% Mn, 2.00% Cu, 0.29% Mg, 0.2% I, and 0.05% Co
4 Vitamin A-D-E premix contained 30,000 IU of vit A, 6,000 IU of vit D, 7.5 IU of vit E per gram.
5 Monensin (Rumensin-90; Elanco Animal Health, Indianapolis, IN) premix contained 198 g/kg monensin.
6 Tylosin (Tylan-40; Elanco Animal Health, Indianapolis, IN) premix contained 88 g/kg tylosin.

**Table 2.3. Diet composition (% DM basis) for cattle growing experiment (Exp 2.)**

| | Treatment[1] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 37% DM | | | | | 43% corn silage | | | | |
| Ingredient | 0.5% | 1.4% | 2.4% | 3.3% | 4.2% | 0.5% | 1.4% | 2.4% | 3.3% | 4.2% |
| 37% DM corn silage | 88.0 | 88.0 | 88.0 | 88.0 | 88.0 | - | - | - | - | - |
| 43% DM corn silage | - | - | - | - | - | 88.0 | 88.0 | 88.0 | 88.0 | 88.0 |
| Rumen degradable protein supplement[2] | 12.0 | 9.0 | 6.0 | 3.0 | 0.0 | 12.0 | 9.0 | 6.0 | 3.0 | 0.0 |
| Rumen undegradable protein supplement[2] | 0.0 | 3.0 | 6.0 | 9.0 | 12.0 | 0.0 | 3.0 | 6.0 | 9.0 | 12.0 |
| Soybean hulls | 9.3552 | 7.1225 | 4.8897 | 2.6570 | 0.4242 | 9.3552 | 7.1225 | 4.8897 | 2.6570 | 0.4242 |
| Limestone | 0.2120 | 0.2583 | 0.3045 | 0.3508 | 0.3970 | 0.2120 | 0.2583 | 0.3045 | 0.3508 | 0.3970 |
| Salt | 0.4000 | 0.3750 | 0.3500 | 0.3250 | 0.3000 | 0.4000 | 0.3750 | 0.3500 | 0.3250 | 0.3000 |
| Urea | 1.2000 | 0.9750 | 0.7500 | 0.5250 | 0.3000 | 1.2000 | 0.9750 | 0.7500 | 0.5250 | 0.3000 |
| Tallow | 0.3000 | 0.3000 | 0.3000 | 0.3000 | 0.3000 | 0.3000 | 0.3000 | 0.3000 | 0.3000 | 0.3000 |
| Dicalcium phosphate | 0.4540 | 0.3905 | 0.3270 | 0.2635 | 0.2000 | 0.4540 | 0.3905 | 0.3270 | 0.2635 | 0.2000 |
| Trace mineral premix[3] | 0.0500 | 0.1625 | 0.2750 | 0.3875 | 0.5000 | 0.0500 | 0.1625 | 0.2750 | 0.3875 | 0.5000 |
| Vitamin A-D-E premix[4] | 0.0150 | 0.0488 | 0.0825 | 0.1163 | 0.1500 | 0.0150 | 0.0488 | 0.0825 | 0.1163 | 0.1500 |
| Monensin[5] | 0.0138 | 0.0138 | 0.0138 | 0.0138 | 0.0138 | 0.0138 | 0.0138 | 0.0138 | 0.0138 | 0.0138 |
| Bypass soy[6] | - | 1.5000 | 3.0000 | 4.5000 | 6.0000 | - | 1.5000 | 3.0000 | 4.5000 | 6.0000 |
| Concentrated corn gluten meal[7] | - | 1.0000 | 2.0000 | 3.0000 | 4.0000 | - | 1.0000 | 2.0000 | 3.0000 | 4.0000 |

[1.] Treatments: Diets contained 88% of either 37 or 43% DM corn silage and formulated to contain 0.5, 1.4, 2.4, 3.3, or 4.2 % RUP % of total diet.
[2.] RDP and RUP supplement: was formulated for a target concentration of 12%. Combinations of both were used to achieve desired RUP % of the diet DM.
[3] Trace mineral premix contained 6% Zn, 5.0% Fe, 4.0% Mn, 2.00% Cu, 0.29% Mg, 0.2% I, and 0.05% Co
[4] Vitamin A-D-E premix contained 30,000 IU of vit A, 6,000 IU of vit D, 7.5 IU of vit E per gram.
[5] Monensin (Rumensin-90; Elanco Animal Health, Indianapolis, IN) premix contained 198 g/kg monensin .
[6] Enzymatically browned soybean meal 50% CP; 75% RUP as % CP (SoyPass; Borregaard Lignotech, Rothschild, WI)
[7] Concentrated corn gluten meal 75% CP; 65% RUP as % of CP (Cargill Inc., Blair, NE)

**Table 2.4. Diet composition (% DM basis) for lamb digestion experiment (Exp 3.)**

| | Treatment[1] | |
|---|---|---|
| Ingredient | 37% DM | 43% corn silage |
| 37% DM corn silage | 92.140 | - |
| 43% DM corn silage | - | 92.140 |
| Bypass soy[2] | 3.000 | 3.000 |
| Concentrated corn gluten meal[3] | 2.000 | 2.000 |
| Urea | 0.750 | 0.750 |
| Limestone | 0.100 | 0.100 |
| Trace mineral premix[4] | 2.000 | 2.000 |
| Vitamin A-D-E premix[5] | 0.015 | 0.015 |

[1]Treatments: Diets contained 92.14% of either 37 or 43% DM corn silage and fed at ad libitum or restricted at 1.5% of BW.
[2]Enzymatically browned soybean meal 50% CP; 75% RUP as % CP (SoyPass; Borregaard Lignotech, Rothschild, WI)
[3]Concentrated corn gluten meal 75% CP; 65% RUP as % of CP (Cargill Inc., Blair, NE)
[4]Trace mineral premix contained 6% Zn, 5.0% Fe, 4.0% Mn, 0.29% Mg, 0.2% I, and 0.05% Co
[5] Vitamin A-D-E premix contained 30,000 IU of vit A, 6,000 IU of vit D, 7.5 IU of vit E per gram.

**Table 2.5. Delayed silage dry matter and yield**

| | Treatments[1] | | | | | |
|---|---|---|---|---|---|---|
| | Early Harvest | | Late Harvest | | SEM | *P*-value |
| Item | Mean | SD | Mean | SD | | |
| Silage DM, %[2] | 37.3 | 1.18 | 42.7 | 1.68 | | |
| Silage yield, DM Mg/ha[3] | 21.41 | 0.52 | 22.58 | 0.13 | 0.19 | <0.01 |

[1]Early harvest corn silage harvested at whole plant DM = 37.3% DM and kernel milk = ¾ harvested on September, 4, 2014. Late harvest corn silage harvested at whole plant DM = 42.7% DM and kernel black layer formation harvested on September 16, 2014.
[2] DM was calculated using weekly (n = 19) samples and oven dried for 48 h at $60^0$ C. Coefficient of variation was 3.2 for early harvest and 3.9 for late harvest based on weekly DM samples.
[3]Silage yield = total DM kg/ha at 100% DM

**Table 2.6. The effects of delayed silage harvest and increased concentrations of silage on feedlot performance and carcass characteristics on cross bred yearling steers (Exp. 1)**

| | Treatments[1] | | | | | *P*-value | | |
|---|---|---|---|---|---|---|---|---|
| | 15 % corn silage | | 45% corn silage | | | | | |
| Variable | 37% DM | 43% DM | 37% DM | 43% DM | SEM | Int.[2] | Concentration[3] | DM[4] |
| Feedlot performance | | | | | | | | |
| Initial BW, kg | 426 | 427 | 426 | 427 | 0.5 | 0.77 | 0.87 | < 0.01 |
| Final BW[5], kg | 621 | 626 | 608 | 608 | 7.0 | 0.71 | 0.04 | 0.68 |
| Live Final BW, kg | 638 | 649 | 635 | 640 | 9.7 | 0.76 | 0.54 | 0.44 |
| DMI, kg/d | 13.0 | 13.2 | 13.3 | 13.5 | 0.2 | 0.82 | 0.15 | 0.30 |
| ADG, kg | 1.85 | 1.87 | 1.72 | 1.71 | 0.07 | 0.79 | 0.04 | 0.90 |
| G:F | 0.142 | 0.142 | 0.129 | 0.126 | 0.003 | 0.79 | <0.01 | 0.64 |
| NEm, Mcal/kg DM[6] | 1.81 | 1.80 | 1.68 | 1.66 | 0.03 | 0.88 | <0.01 | 0.62 |
| NEg, Mcal/kg DM[6] | 1.17 | 1.16 | 1.06 | 1.04 | 0.02 | 0.83 | <0.01 | 0.53 |
| Carcass characteristics | | | | | | | | |
| Hot carcass weight, kg | 391 | 394 | 383 | 383 | 4.4 | 0.71 | 0.04 | 0.68 |
| Dressing percentage, % | 61.1 | 60.8 | 60.2 | 59.8 | 0.56 | 0.93 | 0.05 | 0.68 |
| Longissimus area, $cm^2$ | 84.38 | 82.63 | 84.78 | 83.36 | 0.89 | 0.85 | 0.52 | 0.08 |
| $12^{th}$-rib fat, cm | 1.28 | 1.40 | 1.26 | 1.28 | 0.08 | 0.47 | 0.26 | 0.27 |
| Marbling score[7] | 514 | 498 | 489 | 493 | 14.0 | 0.48 | 0.29 | 0.67 |

[a,b,c] Means with different superscripts differ ($P < 0.05$).
[1.] Treatments: 15% silage 37 % DM = 15% concentration of 37% DM silage, 15% silage 43% DM = 15 % concentration of 43 % DM silage, 45% silage 37% DM = 45 % concentration of 37% DM silage, 45% silage 43% DM = 45 % concentration of 43% DM silage; all diets contained 40% MDGS
[2.] Silage Concentration X Silage DM interaction
[3.] Fixed effect of silage concentration
[4.] Fixed effect of silage DM
[5.] Final BW, were calculated based on HCW / common dressing percent of 63%
[6.] NEm and NEg were calculated using methodology of NRC (1996) using a tool developed by Galyean (2009) assuming a 625 kg target endpoint
[7.] Marbling score 400 = small00, 500 = modest00

**Table 2.7. Effects of delayed silage harvest on growing steer performance (Exp. 2)**

| Item | Treatments[1] | | SEM | *P* - value |
|---|---|---|---|---|
| | 37% DM | 43% DM | | |
| Initial BW, kg | 271 | 271 | 1.8 | 0.92 |
| Ending BW, kg | 384 | 375 | 3.0 | 0.04 |
| DMI, kg/d | 8.2 | 8.1 | 0.1 | 0.93 |
| ADG, kg | 1.45 | 1.33 | 0.03 | 0.01 |
| G:F | 0.177 | 0.164 | 0.001 | <0.01 |
| NEm, Mcal/kg DM [2] | 1.73 | 1.65 | 0.02 | <0.01 |
| NEg, Mcal/kg DM [2] | 1.11 | 1.04 | 0.02 | <0.01 |

[1]Treatments: steers were fed 88% of either 37 or 43% DM corn silage.
[2] NEm and NEg were calculated using methodology of NRC (1996) using a tool developed by Galyean (2009) assuming a 625 kg target endpoint

**Table 2.8. The effects of increased concentration of RUP in silage based growing diets on performance of cross bred steers (Exp 2).**

| | Treatments[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | 0.5% | 1.4% | 2.4% | 3.3% | 4.2% | SEM | Lin. | Quad. |
| Initial BW, kg | 270 | 271 | 271 | 270 | 272 | 2.4 | 0.98 | 0.60 |
| Ending BW, kg | 359 | 374 | 388 | 382 | 394 | 4.1 | <0.01 | 0.88 |
| DMI, kg/d | 7.7 | 8.3 | 8.6 | 7.9 | 8.3 | 0.2 | 0.05 | 0.84 |
| ADG, kg | 1.14 | 1.32 | 1.50 | 1.43 | 1.56 | 0.04 | <0.01 | 0.82 |
| G:F | 0.149 | 0.159 | 0.175 | 0.181 | 0.186 | 0.002 | <0.01 | 0.57 |
| NEm, Mcal/kg DM[2] | 1.58 | 1.63 | 1.71 | 1.77 | 1.79 | 0.04 | <0.01 | 0.57 |
| NEg, Mcal/kg DM[2] | 0.97 | 1.02 | 1.09 | 1.14 | 1.16 | 0.03 | <0.01 | 0.57 |

[1]Treatments: Diets contained 88% of either 37 or 43% DM corn silage and formulated to contain 0.5, 1.4, 2.4, 3.3, or 4.2 % RUP % of total diet.

[2] NEm and NEg were calculated using methodology of NRC (1996) using a tool developed by Galyean (2009) assuming a 625 kg target endpoint

**Table 2.9. Effect of delayed silage harvest and intake restriction on digestibility of lambs (Exp. 3)**

| | Treatments[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Ad libitum | | Limited | | | *P*-value | | |
| Item | 37% DM | 43% DM | 37% DM | 43% DM | SEM | Int.[2] | Intake[3] | DM[4] |
| DM | | | | | | | | |
| Intake, kg/d | 2.14 | 1.99 | 1.16 | 1.15 | 0.08 | 0.28 | <0.01 | 0.23 |
| Digestibility, % | 70.8 | 71.5 | 71.9 | 71.1 | 1.3 | 0.56 | 0.76 | 0.97 |
| OM | | | | | | | | |
| Intake, kg/d | 2.01 | 1.89 | 1.09 | 1.09 | 0.08 | 0.33 | <0.01 | 0.39 |
| Digestibility, % | 72.6 | 73.3 | 73.7 | 73.1 | 1.3 | 0.56 | 0.67 | 0.99 |
| NDF | | | | | | | | |
| Intake, kg/d | 1.07 | 0.77 | 0.58 | 0.45 | 0.03 | <0.01 | <0.01 | <0.01 |
| Digestibility, % | 63.4 | 53.3 | 65.4 | 53.5 | 0.02 | 0.67 | 0.60 | <0.01 |

[1]Treatments: Diets contained 92.14% of either 37 or 43% DM corn silage and fed at ad libitum or restricted at 1.5% of BW.
[2]. Silage Intake X Silage DM interaction
[3]. Fixed effect of silage intake
[4]. Fixed effect of silage DM

# Chapter III. The effect of corn silage hybrid and concentration on performance of finishing steers and silage hybrid effects on digestibility and performance of growing steers[3]

F. H. Hilscher, * C. J. Bittner, * J. L. Gramkow, * M. L. Jolly-Breithaupt, * H. C. Wilson, * M. M. Norman, * A. K. Watson, * J. C. MacDonald, * T. J. Klopfenstein, * J. N. Anderson, † and G. E. Erickson*[4].

*Department of Animal Science, University of Nebraska, Lincoln, NE 68583
†Dow AgroSciences, Mycogen Seeds, Indianapolis, IN 46268

[3] A contribution of the University of Nebraska Agricultural Research Division, supported in part by funds provided through the Hatch Act.
[4]Correspond author: gerickson4@unl.edu.

## Abstract

Three experiments evaluated the effects of 3 corn silage hybrids, concentration, and nutrient digestibility in growing and finishing diets. The 3 hybrids tested included a standard hybrid, which served as the control (CON), a hybrid containing the brown midrib (*bm3*) trait (BM3), and an experimental *bm3* hybrid (BM3-EXP) with soft endosperm trait. Exp. 4 utilized 360 crossbred steers (BW = 334; SD = 25 kg) to evaluate concentration of silage in the finishing diet at (15 or 45% of diet DM) and silage hybrid (CON, BM3, or BM3-EXP). Exp. 5 and 6 utilized 216 crossbred steers (BW = 324; SD = 10 kg) and 6 ruminally fistulated steers (BW = 274; SD = 27 kg ) to evaluate effects of either CON, BM3, or BM3-EXP silage hybrids on performance and nutrient digestibility in silage-based growing diets. In Exp. 4, there was a silage concentration × hybrid interaction for ADG and G:F. All treatments with 15% silage had greater ($P \leq$ 0.04) ADG and G:F compared with 45% silage, but ADG and G:F response due to hybrid was different depending on concentration. Cattle fed BM3-EXP had greater ADG and G:F than cattle fed CON or BM3 when silage was included at 15% of the diet. When silage was fed at 45% of the diet DM, ADG did not differ between cattle fed BM3 and BM3-EXP; however, BM3 had the greatest ($P < 0.01$) G:F, with no difference between BM3-EXP and CON. At 15% silage concentration, HCW was greater ($P < 0.01$) for cattle fed BM3-EXP compared with cattle fed CON and BM3 but did not differ between cattle fed BM3 and CON. At 45% silage concentration, steers fed BM3-EXP and BM3 did not differ in HCW but were both heavier ($P < 0.01$) compared with cattle fed CON. Cattle fed 15% silage had greater ($P < 0.01$) fat thickness and marbling score compared to steers fed 45% silage in the finishing diet when fed equal days on feed. In Exp. 5,

ending BW, DMI, and ADG were greater ($P < 0.01$) for steers fed the BM3 and BM3-EXP compared to steers fed the CON, but not different between steers fed the *bm3* varieties. There were no differences ($P = 0.26$) in G:F between the silage hybrids. In Exp. 6, steers fed BM3 and BM3-EXP had greater ($P < 0.01$) NDF and ADF digestibility than steers fed the CON. Ruminal pH was lower ($P < 0.01$), and total VFA concentration was greater ($P < 0.01$) for steers fed *bm3* hybrids compared to steers fed CON. Feeding silage with the *bm3* trait improved fiber digestibility, which increased DMI and subsequent ADG in high forage growing diets. Feeding corn silage with the *bm3* trait improved performance compared to non-*bm3* corn silage when fed at 45% but was variable between the *bm3* traits when fed at 15% concentration.

**Key words:** brown midrib, corn silage, digestibility, feedlot, growing cattle

## Introduction

Changing the lignin content of the fiber portion of corn silage has the potential to change fiber digestibility of the plant in beef cattle diets (Tjardes et al., 2000). The lower lignin content of the brown midrib (*bm3*) mutation could be valuable to cattle fed high forage diets as improving NDF digestibility should increase DMI and ADG. The NDF of *bm3* silage has been shown to be more digestible in the rumen, have increased passage rate, and reduced rumen fill which could support greater DMI compared to conventional corn silage hybrids (Oba and Allen, 2000). When conventional corn silage hybrids replace corn in finishing diets, G:F decreases as corn silage increases in the diet (Goodrich et al., 1974; Burken et al., 2017a). While incorporating distillers grains and corn silage at higher concentrations in growing and finishing diets has shown to be more advantageous to corn silage alone (Felix et al., 2014; Burken et al., 2017ab), little research has been

done in beef finishing and growing diets with corn silage incorporating the *bm3* trait and distillers grains. We hypothesize that feeding *bm3* silage may enhance animal performance by increasing fiber digestion and DMI in growing cattle and offset the negative effects of feeding greater concentrations of corn silage compared to traditional concentrations as a roughage in finishing cattle.

The objective of the following studies was to 1) evaluate two corn silage hybrids containing the *bm3* trait compared to a control silage fed at either 15 or 45% of diet DM with 20% distillers grains, 2) determine the effect of feeding two *bm3* corn silage hybrids on growing steer performance, and 3) determine digestibility and ruminal fermentation characteristics for two *bm3* corn silage hybrids in growing steers.

## Material and Methods

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

### *Corn cultivation, harvest, and chemical composition*

Three hybrids of corn silage were grown in a single irrigated field at the Eastern Nebraska Research and Extension Center (ENREC) near Mead, NE. The three hybrids (Mycogen Seeds, Indianapolis, IN) were a standard corn silage hybrid which served as the control (CON; hybrid-TMF2R720), a *bm3* hybrid (BM3; hybrid-F15579S2), and an experimental *bm3* hybrid (BM3-EXP; hybrid-F15578XT; Unified) with a softer endosperm trait SilaSoft (Mycogen Seeds). Planting density was targeted at 84,015 seeds/ha, and all seeds were grown under the same growing conditions. The field was managed as a corn, soybean, and wheat rotation for the previous 6 years. Corn silage was

harvested using a self-propelled forage harvester (JD 5400, John Deere, Moline, IL) set for a 1.27-cm theoretical length of chop, without a kernel processing unit.

Corn silage harvest initiation occurred on September 11, 2015 when the corn silage was at approximately ¾ milkline and whole plant corn silage samples were 35% DM determined by a moisture tester (Koster Crop Tester, Inc., Brunswick, OH) prior to harvest. Silage was harvested from 9/11/15 through 9/16/15. Silage was stored in concrete wall bunkers and covered first with a sheet of oxygen barrier film (SiloStop; Bruni Rimini Ltd., London, UK), and then a sheet of black and white plastic (Up North Plastics, Cottage Grove, MN) until the initiation of the trial. Bunker samples were tested for DM and fermentation analysis 28 d after harvesting to ensure proper ensiling by taking core samples of 1 m in depth every 15 m across the length of the bunker. Corn silage was sampled weekly (n = 27) during the feeding trial for DM determination in a 60° C forced air oven for 48 h (Table 1). Composited weekly samples by month (n = 7) were analyzed by a commercial laboratory (DairyOne, Inc., Ithaca, NY) for fermentation analysis, starch, and water soluble carbohydrates. Silage samples were also analyzed for CP, NDF, ADF, and lignin by monthly composites (n = 7) at a commercial laboratory (DairyOne, Inc.). Total metric tons of DM harvested per hectare were 19.9, 17.6 and 16.6 from CON, BMR and BMR-EXP, respectively; however, as corn was not grown in replicated field plots, statistical evaluation of corn silage yield was not analyzed.

***Exp. 4 - Cattle Finishing Experiment***

Crossbred steers (n = 360; initial BW = 334; SD = 25 kg) were sorted into 3 BW blocks and assigned randomly to one of 36 pens (10 steers / pen). The light block contained 3 replications, the middle BW block contained 2 replications, and the heaviest

BW block contained 1 replication. Prior to the initiation of the experiment, all steers were individually identified and processed at arrival at the research feedlot with: a modified live viral vaccine for infectious bovine rhinotracheitis , bovine viral diarrhea types I and II, parainfluenza3, bovine respiratory syncytial virus, a *Mannheimia haemolytica-Pasteurella multocida* bacterin-toxoid (Titanium 5 PH-M, Elanco Animal Health., Greenfield, IN), and a *Haemophilus somnus* vaccine (Somnu Shield; Elanco Animal Health) administered at 2ml/steer. They were treated for internal and external parasites with an injectable wormer (Dectomax; Zoetis Animal Health, Kalamazoo, MI) administered at 1ml/45.4kg of BW. All steers were revaccinated 28 d after initial processing with modified live viral vaccines for infectious bovine rhinotracheitis, bovine viral diarrhea types I and II, parainfluenza3, bovine respiratory syncytial virus (Titanium 5, Elanco Animal Health.), and a killed viral vaccine for clostridial infections (Ultrabac 7, Zoetis Inc.).

Prior to the start of the experiment, all steers were fed limit-fed (Watson et al., 2013) a common diet consisting of 50% alfalfa hay and 50% wet corn gluten feed (Sweet Bran, Cargill, Blair, NE) at 2.0% of projected BW for 5 d to equalize gastro-intestinal fill prior to weighing on d 0 and d 1 for initial BW determination (Stock et al., 1983). Treatments were designed as a 2 × 3 factorial arrangement that consisted of concentration of corn silage in the finishing diet (15% or 45% silage on a DM basis) and silage hybrid (CON, BM3, or BM3-EXP; Table 2). Corn silage fed at 45% of diet DM in the finishing diet replaced a 50:50 blend of dry-rolled and high-moisture corn compared to 15% silage treatments. All steers were fed a supplement formulated for 30 g / ton of monensin (Elanco Animal Health, DM basis) and a targeted intake of 90 mg / steer daily of tylosin

(Elanco Animal Health). Steers were implanted with Component TE-IS (80 mg trenbolone acetate and 16 mg estradiol; Elanco Animal Health) on d 1, and re-implanted with Component TE-200 (200 mg of trenbolone acetate and 20 mg estradiol; Elanco Animal Health) on d 91. Pens were fed once daily at approximately 0730 h. Feed bunks were assessed at approximately 0530 h with the goal of trace amounts of feed at the time of feeding. All diets were fed once daily, and feed refusals were removed from feedbunks when needed, weighed, and subsampled. All feed refusals were subsampled and dried for 48h in a 60ºC forced-air oven for determination of DM and calculation of refusal DM weight (AOAC, 1999 method 935.29). Dietary ingredients were sampled weekly for determination of DM content. Dietary as-fed ingredient proportions were adjusted weekly. Steers were fed for 181 d and were harvested at a commercial abattoir (Greater Omaha Packing, Omaha, NE). On the day of shipping to the commercial abattoir, pens of steers were fed 50% of the previous day's DM offering at regular feeding time. Pens of steers were then weighed on 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 calculation of dressing percentage (HCW / shrunk live final BW).

Hot carcass weight and liver scores were obtained the d of harvest. Liver abscesses were categorized from 0 (no abscesses), A-, A, or A+ (severely abscessed) according to the procedures outlined by Brink et al. (1990). Liver abscess categories were then combined to calculate the proportion of steers with abscessed livers in each pen. Carcass-adjusted final BW, used in calculation of ADG and G:F, was calculated from HCW and a 63.8% common dressing percentage. Marbling score, 12th rib fat thickness, and LM area were recorded after a 48 h carcass chill. The energy value of the

diets was calculated by utilizing pen data in the Galyean (2009) Net Energy calculator based on NRC (1996) net energy equations. The calculator utilizes initial BW, final BW, DMI, ADG, and target endpoint (assuming choice quality grade).

Performance and carcass data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, N.C.) with pen serving as the experimental unit and block as a fixed effect. The treatment design was a 2 × 3 factorial; therefore, data were first evaluated for an interaction between hybrid and concentration. If a significant interaction was observed for performance variables, then simple effects of hybrid within either 15 or 45% concentration were evaluated. Significance of effects was determined at $P \leq 0.05$.

***Exp. 5 - Cattle Growing Experiment***

A 76-day growing study was conducted utilizing 216 yearling crossbred steers (BW = 324; SD = 10 kg). Upon arrival and prior to initiation of the experiment, steers were identified and processed as previously described. Cattle were limit-fed a diet of 50% Sweet Bran and 50% alfalfa hay at 2.0% of projected BW for 5 d prior to trial initiation to equalize gut fill (Watson et al., 2013). Steers were weighed 2 consecutive days, with the average of the first 2 days used as initial BW (Stock et al., 1983). Initial BW was calculated by averaging the two-day weights. Cattle were stratified by BW and assigned randomly to pens with 12 head per pen. Pens were assigned randomly to one of three treatments, with 6 replications per treatment. The three treatments (Table 3) were set up in a generalized randomized design. All diets included 15% modified distillers grains plus solubles (MDGS) and 5% supplement. Monesin (Elanco Animal Health) was added in the supplement to supply 200 mg / steer daily. The remainder of the diet consisted of 80% corn silage of 1 of the three hybrids (CON, BM3 or BM3-EXP). Steers

were treated for external parasites (StandGuard, Elanco Animal Health) and were implanted with Ralgro (36 mg zeranol, Merck Animal Health) on d 1. Feed bunks were assessed at approximately 0530 h and managed to allow for trace amounts of feed to remain at time of feeding. Steers were fed ad libitum once daily at 0930 h. All feed refusals were subsampled and dried for 48h in a 60ºC forced-air oven for determination of DM and calculation of refusal DM weight. Dietary ingredients were sampled weekly for determination of DM content. Dietary as-fed ingredient proportions were adjusted weekly. Ending BW was collected similar to initial BW with steers limit-fed at 2% of BW for five days and weighed for two consecutive days. The energy value of the diets was calculated by utilizing pen data in the Galyean (2009) Net Energy calculator based on NRC (1996) net energy equations. The calculator utilizes initial BW, final BW, DMI, ADG, and target endpoint (assuming choice quality grade).

Performance data (BW, DMI, ADG, and G:F) were analyzed using the MIXED procedure of SAS (SAS Institute, Inc.) with pen serving as the experimental unit. Significance was declared at $P \leq 0.05$.

***Exp. 6 - Steer Digestion Experiment***

Six ruminally fistulated steers (BW = 290; SD = 27 kg) were used in a 3 × 6 Latin rectangle experiment to determine diet digestibility used in the steer growing experiment. Steers were assigned randomly to the same 3 growing diets as described in Exp. 5 (CON, BM3, BM3-EXP). Using six steers in a 3 × 6 design allowed for 12 observations per treatment. The study consisted of six periods that were 21 d in length with a 16 d adaptation period and a 5 d collection period. Steers were housed in individual slatted

floor pens that were 3.70 m wide and 2.14 m in length. The study was conducted over 126 d.

Diets were mixed twice weekly and stored in a cooler held at 4°C to ensure fresh feed was maintained. Steers were fed once daily at 0800 h. Feed refusals were removed daily prior to feeding. Refusals collected on d 17 to 21 were saved and dried in a forced air oven at 60°C for 48 h (AOAC, 1999, Method 935.29) to determine DM content. Individual feed ingredients were collected and dried in a 60°C forced air oven weekly to ensure that accurate DM were used when mixing dietary treatments. Feeds offered and refused were analyzed for NDF (Van Soest and Marcus, 1964; Van Soest et al., 1991), ADF, ADL (Van Soest, 1963), starch (AOAC, 2007, Method 996.11), and organic matter (OM; 600°C for 6 hr).

Titanium dioxide was ruminally dosed at 5 g/steer twice daily at 0700 and 1500 hours on d 10-20. Fecal grab samples (approximately 300 g) were collected at 0700, 1100, 1500, and 1900 hours during day 17-20 of each period. Fecal samples were composited on a wet basis into daily composites by steer, lyophilized (Virtis Freezemobile 25ES, Life Scientific, Inc., St. Louis, MO), and ground through a 1-mm screen using a Wiley mill (No. 4, Thomas Scientific, Swedesboro, New Jersey). The lyophilized and ground daily composites were then composited on a dry weight basis by steer within collection period. Fecal samples were subsequently analyzed for OM, NDF, ADF, ADL and starch concentration using the procedures mentioned above. Titanium dioxide concentration of fecal samples was determined as described by Myers et al. (2004). Concentration of $TiO_2$ was then used to calculate fecal DM output using the following equation (Cochran and Galyean, 1994): [(g marker dosed per d) ÷

(concentration of marker in feces)]. Total tract digestibility was calculated using the following equation (Cochran and Galyean, 1994): [(kg of nutrient fed – kg of nutrient refused – kg of nutrient in feces) ÷ (kg of nutrient fed – kg of nutrient refused)] × 100.

Rumen pH was recorded every minute using weighted wireless pH probes (Dascor, Inc., Escondido, CA) from day 17 to 20 of the collection period. Whole rumen contents were collected on d 21 of each period at 1400 (6 hours post feeding). A sample of 250 mL of contents (in duplicate) was frozen for volatile fatty acids (VFA; Trace 1300, Thermo Fisher Scientific Inc., Waltham, MA) using the procedures outlined by Ehrlich et al. (1981). Additional, rumen samples were incubated and stirred for 2, 4, and 6 hrs post collection in a 39°C incubated orbital shaker (Model 4730, Queue Systems, Parkersburg, WV) to determine VFA production. At the end of the designated time point, contents were removed from the incubator and frozen for VFA analysis. The difference of VFA concentration at 0, 2, 4 and 6 h was used to determine the rate of VFA production. At the time of analysis, rumen fluid samples were thawed in a cooler (4°C) to ensure that no additional fermentation occurred. Each sample collected was analyzed twice for VFA concentration to ensure an accurate value was obtained. Additionally, from the whole rumen samples, a 150 g (as-is basis) sample of contents was placed into 250 mL glass bottles (in duplicate) and fitted with a gas production module (Ankom Technologies, Macedon, NY). The bottles were incubated in a 39 ºC water bath where the modules recorded cumulative pressure (PSI) every 30 minutes for 20 h to determine rate of gas production. Gas production (mL) was determined using the Ideal gas law ($n = p[V/RT]$) and Avagadros Law (1 psi=6.89 kilopascal) as described in the Ankom RF Gas Production System Operator's Manual (Ankom Technologies, Macedon, NY).

Digestibility data were analyzed as a Latin rectangle using the MIXED procedure of SAS (SAS Inst. Inc.) with period and treatment as fixed effects and steer as a random effect. Ruminal pH data were analyzed as repeated measures using the GLIMMIX procedure of SAS (SAS Inst. Inc.) with day as the repeated measure, treatment as a fixed effect, and steer as a random effect. Rumen VFA data were analyzed using the MIXED procedure of SAS, with fixed effects of period, treatment, hour, and interaction of hour by treatment, and steer as a random effect. Gas production data were analyzed using the MIXED procedure of SAS. Response variables were total gas production and gas production rate. Bottle served as the experimental unit. Rate of gas production was generated by analyzing the gas production data in a modified Gompertz model (Schofield et al., 1994; Huhtanen et al., 2008) using the NLIN procedure of SAS (SAS Int. Inc.). Significance of effects was determined at ($P \leq 0.10$).

## Results and Discussion

### *Corn silage*

Corn silage was targeted to be harvested at 35% DM (Table 1). The fermentation analysis of the three corn silage hybrids indicated that proper fermentation did occur as pH was below 3.9, as well as having total acids greater than 7.3%. The starch percentage and the sugar (water soluble carbohydrates) percentage remained consistent across all three silage hybrids. The ADF and lignin concentrations were numerically lower in both the BM3 and BM3-EXP compared to the CON, as expected.

### *Exp. 4 - Cattle Finishing Experiment*

There was a silage concentration by hybrid interaction ($P \leq 0.05$); therefore, simple effects will be presented (Table 4). No interaction was observed between hybrid

and concentration for DMI. Cattle fed 45% silage averaged across hybrids had greater DMI ($P < 0.01$) compared to steers fed 15% silage. Corn silage hybrid did not significantly affect ($P = 0.11$) DMI. Keith et al. (1981) reported that as silage concentration increased in finishing diets, DMI increased. The authors also reported that at greater concentrations of corn silage, cattle fed *bm3* corn silage had greater DMI than cattle fed non-*bm3* corn silage, but at low concentration there was no difference in DMI between *bm3* and non-*bm3* corn silage. DiCostanzo et al. (1997) fed finishing diets containing 12, 24, 36, or 48% corn silage. These researchers reported that there was a linear increase in DMI as corn silage concentration increased in the diet. Burken et al. (2017b) conducted two feeding trials comparing the silage concentration of 15 or 45% in finishing cattle. In the first experiment, there were no differences in DMI across treatments, while in the second trial, increasing the silage from 15 to 45% increased DMI. Cattle fed BM3-EXP had greater ADG than CON or BM3 when silage was included at 15% of the diet. When silage was fed at 45% of the diet DM, cattle fed BM3 and BM3-EXP did not differ in ADG, but both were greater than CON ($P < 0.05$). Interestingly, steers fed BM3 and BM3-EXP at 45% of the diet did not differ in ADG to steers fed either 15% CON or 15% BM3 suggesting the *bm3* trait allowed for more silage to be fed without compromising ADG if the silage contains the *bm3* trait. All treatments with 15% corn silage concentration had greater ($P \leq 0.04$) G:F compared to 45% corn silage concentration, but G:F response due to hybrid was different depending on concentration. For steers fed 15% silage, G:F was greatest for BM3-EXP, lowest for BM3, and intermediate for CON. The range in G:F across the hybrids was 0.174 to 0.166. For steers fed 45% silage, G:F was greatest for cattle fed BM3 while CON and BM3-EXP

were not different. The range in G:F was 0.162 to 0.154. Similar to G:F, dietary NEm and NEg values were greater ($P \leq 0.01$) for cattle fed 15% corn silage compared to 45% corn silage concentration, but differed between hybrid depending on concentration. At 15% corn silage, NEm and NEg were greatest for the BM3-EXP and lowest for the BM3 hybrid, while at 45% corn silage BM3 had the greatest NEm and NEg with CON being the lowest. Keith et al. (1981) compared the performance of feedlot cattle fed either *bm3* or non-*bm3* silage at concentrations of 88, 60, and 27% on DM basis in finishing diets. Cattle fed *bm3* at both 88 and 60% of diet DM had greater total gain and ADG compared to the non-*bm3* fed cattle. Cattle fed *bm3* at the greater concentration also had a tendency for an improvement in G:F compared to non-*bm3* fed cattle. As concentration of corn silage decreased in the finishing diet to 27%, no differences in feedlot performance were reported between the *bm3* and non-*bm3* fed cattle. McEwen and Buchanan-Smith (1996) compared a *bm3* hybrid with other commercial hybrids and these authors reported that cattle fed *bm3* silage did not differ in ADG and had greater G:F compared to other commercial hybrids.

At 15% concentration, BM3-EXP had greater ADG and G:F compared to BM3; however at 45% concentration both treatments did not differ in ADG while BM3-EXP had greater G:F. In comparing kernel type, Jaeger et al. (2006) reported that corn with softer endosperm had greater G:F compared to corn with harder endosperm when fed as dry rolled corn (DRC) to finishing cattle; however kernel moisture can impact performance. Macken et al. (2003) compared floury and flinty hybrids in finishing diets as DRC or high moisture corn (HMC). When fed as DRC, corn with floury endosperm had greater G:F, but when fed as HMC there were no differences in G:F between floury

and flinty hybrids. Szasz et al. (2007) reported no differences in ruminal or total tract starch digestibility between floury and flinty corn when fed as HMC. Utilizing silage hybrids similar to the current experiment, Grant et al. (2017) compared an isogenic control to a *bm3* hybrid and a *bm3* hybrid with a softer endosperm (*bm3-E*) fed to dairy cows fed 49% of the diet. These authors reported that the *bm3* and *bm3-E* had greater milk yield and fat corrected milk yield when compared to the control. Efficiency of milk production was greatest for *bm3-E* with the control having the lowest and the *bm3* being intermediate (Grant et al., 2017). Burken et al. (2017a) reported a linear decrease in NEm and NEg as corn silage concentration increased in finishing diets.

At 15% corn silage concentration, carcass-adjusted final BW and HCW were greater ($P < 0.01$) for BM3-EXP compared to CON and BM3, but did not differ between BM3 and CON. At 45% corn silage concentration, steers fed BM3-EXP and BM3 did not differ in carcass-adjusted final BW and HCW but were both heavier ($P < 0.01$) compared to CON. Steers fed 15% silage had heavier ($P < 0.01$) carcass-adjusted final BW and HCW compared to steers fed 45% concentration across hybrids. No significant interaction was observed for final live BW ($P = 0.49$). When CON silage was fed at 45% of diet DM, live final BW was reduced 7 kg compared to feeding CON at 15% concentration. However, HCW was reduced by 12 kg when CON silage was fed at 45% compared to 15%. This relative change in HCW compared to final live BW illustrates the negative effect of increasing silage concentration from 15 to 45% of diet DM on dressing percentage and gut fill. Dressing percentage at 15% concentration was greatest ($P < 0.03$) for BM3-EXP and lowest for CON with BM3 being intermediate. However, at 45% silage concentration, steers fed both BM3-EXP and BM3 had dramatically greater

($P < 0.01$) dressing percentages than CON suggesting less gut fill. All cattle fed 15% silage had greater ($P < 0.01$) dressing percentages compared to cattle fed 45% corn silage. When cattle are fed elevated concentrations of corn silage, dressing percentage decreases due to increased gut fill.

Burken et al. (2017a) reported a linear decrease in final BW and HCW as corn silage was increased in finishing diets. Additional studies by Burken et al. (2017b) reported a tendency for decreased final BW and HCW in Exp. 1 and a significant decrease in final BW and HCW in Exp. 2 as concentration of corn silage increased from 15 to 45% of the diet. Peterson et al. (1973) reported that as corn silage concentration increased, dressing percentage linearly decreased. Similarly, Brennan et al. (1987), reported cattle fed increased concentrations of corn silage had decreased dressing percentages. Cattle fed 15% corn silage had greater ($P$ <0.01) fat thickness over the 12$^{th}$ rib and marbling score compared to steers fed 45% corn silage in the finishing diet. Burken et al. (2017a) reported a linear decrease in dressing percentage and 12$^{th}$ rib fat thickness as corn silage concentration increased. Tjardes et al. (2000) reported no differences in final BW, HCW, or any other carcass characteristics between cattle fed *bm3* compared to non-*bm3* corn silage over a 112 d growing period followed by finishing on a common diet. Keith et al. (1981) also reported no differences in yield and quality grade between cattle fed *bm3* and non-*bm3* corn silage when fed at high and low concentrations of silage. Replacing corn grain with corn silage in finishing diets resulted in decreased animal performance as energy content of the diet decreased. Intake increased as a result of this decrease in dietary energy to increase total energy intake. With the incorporation of *bm3* hybrids that are lower in lignin content, increased ruminal

NDF digestion and passage rate allows for greater DMI, which could allow for greater energy intake, that minimizes the decrease in ADG, and G:F as silage concentration increased from 15 to 45% compared to control silage.

***Exp. 5 - Cattle Growing Experiment***

Ending BW was greater ($P < 0.01$) for steers fed the BM3 and BM3-EXP compared to the CON, but not different between the two *bm3* varieties (Table 5). Steers fed both BM3 and BM3-EXP had greater ($P < 0.01$) DMI and ADG compared to the steers on the CON treatment, but DMI and ADG were not different between steers on the BM3 or BM3-EXP treatments. While BM3 and BM3-EXP had greater DMI and ADG, there were no differences ($P = 0.26$) in G:F among the three silage treatments. Calculated NEm and NEg values were not different ($P \geq 0.82$) across all three treatments. Weller and Phipps (1986) compared *bm3* corn silage to non- *bm3* control fed to weaned heifer calves for 56 d. The authors reported that DMI was not different between *bm3* and non- *bm3*, but the calves fed *bm3* had 11 % greater ADG which translated into improved G:F. Tjardes et al. (2000) evaluated a *bm3* hybrid to isogenic control in a 112 d growing trial with steers. During the growing phase, silage was fed at 86% of the diet DM. The authors reported that during the growing phase, DMI was greater for steers fed *bm3* than non- *bm3*, but there were no differences in ADG between the two treatments. Subsequently, G:F was greater for steers fed *bm3* during the growing phase. Tjardes et al. (2000) reported no differences in NEm and NEg values in silage growing diets between *bm3* and non-*bm3* hybrids. Saunders et al. (2015) compared a *bm3* hybrid to an isogenic control silage using individually fed cross bred beef steers. The authors reported that final BW had a tendency to be greater at the end of the 84 d growing period. Steers

fed *bm3* silage had a tendency for greater ADG and G:F compared to non- *bm3* silage with no difference in DMI between silage treatments. Keith et al. (1981) compared the performance of cattle fed either *bm3* or non-*bm3* silage at concentrations of 88%. The authors reported that cattle fed *bm3* had greater total gain, DMI, and ADG compared to the non-*bm3* fed cattle. Cattle fed *bm3* also had a tendency for an improvement in G:F compared to non-*bm3* fed cattle (Keith et al., 1981). With high concentrations of forage in growing diets, bulk fill can limit intake and energy intake. The decreased lignin content of *bm3* hybrids allows for a greater percentage of digestible NDF, which in turn allows for increased passage rate allowing for greater intake. This increase in DMI allows for greater energy intake and translates to improved ADG, which is in agreement with the current study and previous research.

***Exp. 6 – Steer Digestion Experiment***

Feeding corn silage with the *bm3* trait tended to increase ($P$ = 0.11) DMI and OM intake compared to CON (Table 6). This was also observed in Exp 2. with identical diets fed to growing steers. Digestibility of DM tended to be impacted by treatment ($P$ = 0.11) with steers fed BM3 and BM3-EXP having greater DM digestibility than steers fed CON. Digestibility of OM was impacted by treatment ($P$ = 0.05), with steers fed BM3-EXP having greater OM digestibility than steers fed CON and steers fed BM3 being intermediate. There were significant differences in NDF excretion and NDF digestibility due to treatment ($P$ < 0.01). Steers fed both BM3 (57.8%) and BM3-EXP (57.0%) had greater ($P$ < 0.01) NDF digestibility compared to the CON (45.3%). Intake of ADF was greatest ($P$ = 0.03) for BM3 and lowest for BM3-EXP with CON being intermediate. However, there were no differences ($P$ > 0.10) in ADF digestibility between BM3

(59.6%) and BM3-EXP (56.1%), but both had greater (*P* < 0.01) ADF digestibility than CON (41.9%). Cattle fed the BM3 treatment excreted the greatest (*P* = 0.03) amount of starch and CON excreted the least amount of starch. Starch digestibility was greater than 94.5% for cattle fed all three silages, but steers fed CON (96.6%) corn silage had the greatest (*P* = 0.03) starch digestibility with BM3-EXP (95.8%) being intermediate and BM3 (94.6%) having the least starch digestibility. In a meta-analysis, Ferraretto and Shaver (2015) compared different hybrid types on lactation performance and total tract digestibility in dairy cows. These authors reported that *bm3* hybrids had greater DMI than dual purpose and leafy hybrids and DMI did not differ compared to high fiber digestibility hybrids that did not have the brown midrib trait. Ferraretto and Shaver (2015) reported no differences in DM or OM total tract digestibility between all four hybrids evaluated, however, the *bm3* and the high fiber digestibility hybrids had the greatest total tract NDF digestibility and the lowest total tract starch digestibility when compared to dual purpose and leafy hybrids. Intake can impact passage rate and in turn, passage rate can affect total tract digestibility. Oba and Allen (2000) reported that cows fed *bm3* hybrids had greater DMI when fed at low and high levels compared to an isogenic control, but there were no differences in total tract NDFD. The authors did measure rumen passage and digestion rates, and while total tract NDFD was not different, NDF passage rate for *bm3* fed cattle were faster by about 8% compared to controls. In agreement with the current study, Weller and Phipps (1986) utilized sheep feed at maintenance and reported that sheep fed a *bm3* vs a conventional silage hybrid had greater DM, OM, NDF, and ADF digestibility. Muller et al. (1972) compared just the stover fraction (ears removed prior to ensiling) of *bm3* and non-*bm3* hybrids in sheep.

Lambs fed *bm3* silage had greater DMI, DM, NDF, and ADF digestibility compared to lambs than the controls. Tjardes et al. (2000) fed steers *bm3* or isogenic controls and reported greater DMI and increases of 10.5 and 9.4 percentage unit improvements in total tract digestibility of NDF and ADF, respectively, for the *bm3* hybrid compared to the control, but there were no differences in starch digestibility. Endosperm type had no effect on NDF digestibility. In HMC, vitreousness of grain did not affect animal performance when compared to dry rolled corn (Szasz et al., 2007). With the addition of moisture and fermentation, the proteins are solubilized and starch digestibility increases in HMC with greater moisture content (Owens, 2008). As corn grain in corn silage is harvested wetter than HMC, endosperm type may not impact corn silage starch digestibility. Grant et al. (2017) compared an isogenic control to a *bm3* hybrid and a *bm3* hybrid with a softer endosperm (*bm3-E*) fed to dairy cows. The authors reported that DMI was greatest for the *bm3* hybrid and lowest for the control with the *bm3-E* being intermediate. However, total tract digestibility was not different for OM, NDF, and starch among all three treatments (Grant et al., 2017). The general improvements in NDF, ADF, and OM digestibility for steers fed BM3 and BM3-EXP likely explain the greater DMI observed in Exp. 6, as well as the greater gain observed in Exp 5.

There was a significant decrease ($P < 0.01$) in average ruminal pH between the *bm3* hybrids (6.24) and the control silage (6.50; Table 7). Additionally, the BM3 and BM3-EXP treatments had lower ($P < 0.01$) maximum pH and lower ($P < 0.01$) minimum pH compared to the CON. The molar proportions of acetate were greatest ($P < 0.01$) in CON lowest for the BM3 treatment with BM3-EXP being intermediate. The CON (22.38) and BM3-EXP (22.60) treatments had lower ($P < 0.01$) molar proportions of propionate

compared to the BM3 (23.73). The BM3 and BM3-EXP cattle did have greater ($P <$ 0.01) proportions of butyrate compared to CON. The BM3 treatment had a lower ($P =$ 0.02) acetate to propionate ratio (2.70) compared to BM3-EXP (2.85). Lower pH and changes in VFA molar proportions for *bm3* silage may be related to greater fermentation and improved rumen digestibility and is further supported by greater ($P < 0.01$) total VFA concentrations compared to the control silage. The production rate of total VFA from whole rumen contents when collected at peak fermentation showed numerical increases in VFA production rate over 6 h for the BM3 and BM3-EXP compared to CON, and were numerically greatest for the BM3 treatment (Table 8). While rate of acetate production was not different ($P = 0.40$) among hybrids, propionate production was greatest ($P \leq 0.03$) for BM3 compared to CON and BM3-EXP. Butyrate production was greatest for BM3 and BM3-EXP compared to CON but not different between *bm3* hybrids. Gas production rates of whole rumen contents when collected at peak fermentation showed a significant increase over 20 h for the BM3 and BM3-EXP compared to CON ($P = 0.03$) but were not different between *bm3* varieties. In agreement with the current study, Oba and Allen (2000) and Saunders et al (2015) reported average pH was significantly lower for *bm3* hybrids compared to controls. Hassanat et al. (2017) reported that minimum pH was lower for *bm3* compared to a conventional corn silage which agrees with the current study. However, these authors reported no differences in average and maximum pH were observed between the *bm3* and non-*bm3* which differs from the current study. In contrast to these results, Tjardes et al (2000) reported that pH from *bm3* fed steers was not significantly different from steers fed isogenic controls. In agreement with the current study, Weller and Phipps (1986) reported that feeding *bm3*

silage resulted in a lower concentration of acetate and a greater concentration of propionate, which resulted in a decreased acetate to propionate ratio when compared to a non-*bm3* hybrid. Saunders et al. (2015) reported greater concentrations of total VFA, and propionate while a decrease in acetate concentration resulting in a lower acetate to propionate ratio when steers were *bm3* hybrids to a conventional corn silage control. While Tjardes et al. (2000) reported greater concentrations of total VFA, the authors also reported greater concentrations of acetate, and no differences in propionate concentrations between *bm3* and isogenic control hybrids. Lopes et al. (2009) reported that corn containing floury endosperm had lower rumen pH and acetate concentrations while propionate concentration was increased when fed as dry rolled corn. However, when harvested as corn silage and fermented, Fanning (2002) reported no differences in molar concentration of acetate, propionate, or total VFA concentration between floury and flinty hybrids. The BM3-EXP with softer endosperm improved starch digestibility compared to BM3 but there was no difference between BM3 and BM3-EXP for OM, NDF, or ADF digestibility. However, feeding corn silage hybrids with the *bm3* trait at 80% of the diet DM resulted in greater fiber and OM digestion compared to corn silage without the trait. Based on rumen pH, VFA concentration, and VFA and gas production data, greater fermentation occurred for cattle fed corn silage with the *bm3* trait compared to a control corn silage without the *bm3* trait.

Feeding corn silage with the *bm3* trait improved performance compared to non-*bm3* corn silage when fed at 45% by offsetting the negative effects of feeding greater concentrations of corn silage by reducing gut fill and increasing DMI but was variable between the *bm3* traits when fed at 15% concentration. Feeding silage with the *bm3* trait

improved the rumen environment allowing for enhanced fiber digestion, which increased DMI and subsequent ADG in growing diets.

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**Table 3.1. Nutrient and fermentation analysis of silage hybrids[1] (DM basis)**

| | CON | | BM3 | | BM3-EXP | |
|---|---|---|---|---|---|---|
| Nutrient[2] | Mean | CV[3] | Mean | CV[3] | Mean | CV[3] |
| DM, % | 33.3 | 6.2 | 33.2 | 5.4 | 34.1 | 5.7 |
| CP, % of DM | 8.6 | 3.4 | 9.6 | 7.8 | 9.1 | 3.9 |
| NDF, % of DM | 40.9 | 4.3 | 41.0 | 4.4 | 39.0 | 3.6 |
| ADF, % of DM | 27.1 | 2.5 | 26.7 | 2.2 | 23.6 | 3.0 |
| Lignin, % of DM | 4.3 | 27.5 | 3.7 | 24.2 | 2.81 | 34.6 |
| Lignin, % of NDF | 10.4 | 29.3 | 9.2 | 31.8 | 7.3 | 31.3 |
| Starch, % of DM | 31.0 | 8.8 | 32.0 | 8.9 | 30.8 | 6.7 |
| Sugar, % of DM | 2.3 | 28.1 | 2.4 | 37.8 | 2.8 | 22.4 |
| pH | 3.89 | 2.5 | 3.86 | 1.9 | 3.81 | 6.3 |
| Lactic Acid, % of DM | 5.6 | 17.1 | 6.2 | 16.6 | 6.0 | 15.6 |
| Acetic acid, % of DM | 1.4 | 31.2 | 1.6 | 30.9 | 1.5 | 34.4 |
| Propionic acid, % of DM | 0.34 | 40.5 | 0.43 | 48.7 | 0.46 | 54.0 |
| Butyric acid, % of DM | < 0.01 | 0.0 | < 0.01 | 0.0 | < 0.01 | 0.0 |
| Total acids, % of DM | 7.3 | 10.4 | 8.2 | 11.0 | 7.9 | 10.8 |

[1] Treatments were control (CON; hybrid-TMF2R720), a *bm3* hybrid (BM3; hybrid-F15579S2), and an experimental *bm3* hybrid (BM3-EXP; hybrid-F15578XT) with a softer endosperm

[2] DM was calculated using weekly samples (n = 27) and oven dried for 48 h at $60^0$ C. All other samples are based on monthly composites (n = 7) of weekly samples taken during the finishing trial, and analyzed at Dairy One Labs (Ithaca, NY).

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

**Table 3.2. Diet composition (% DM basis) in Exp. 4**

| Ingredient | Treatments[1] 15% corn silage CON | BM3 | BM3-EXP | 45% corn silage CON | BM3 | BM3-EXP |
|---|---|---|---|---|---|---|
| Control corn silage | 15.0 | - | - | 45.0 | - | - |
| BM3 corn silage | - | 15.0 | - | - | 45.0 | - |
| BM3-EXP corn silage | - | - | 15.0 | - | - | 45.0 |
| MDGS | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| Dry rolled corn | 30.5 | 30.5 | 30.5 | 15.5 | 15.5 | 15.5 |
| High moisture corn | 30.5 | 30.5 | 30.5 | 15.5 | 15.5 | 15.5 |
| Supplement[2] | | | | | | |
| Fine ground corn | 1.3333 | 1.3333 | 1.3333 | 1.0833 | 1.0833 | 1.0833 |
| Limestone | 1.6750 | 1.6750 | 1.6750 | 1.6750 | 1.6750 | 1.6750 |
| Salt | 0.3000 | 0.3000 | 0.3000 | 0.0300 | 0.0300 | 0.0300 |
| Urea | 0.5000 | 0.5000 | 0.5000 | 0.7500 | 0.7500 | 0.7500 |
| Tallow | 0.1000 | 0.1000 | 0.1000 | 0.1000 | 0.1000 | 0.1000 |
| Trace Mineral premix[3] | 0.0500 | 0.0500 | 0.0500 | 0.0500 | 0.0500 | 0.0500 |
| Vitamin A-D-E premix[4] | 0.0150 | 0.0150 | 0.0150 | 0.0150 | 0.0150 | 0.0150 |
| Monensin[5] | 0.0165 | 0.0165 | 0.0165 | 0.0165 | 0.0165 | 0.0165 |
| Tylosin[6] | 0.0102 | 0.0102 | 0.0102 | 0.0102 | 0.0102 | 0.0102 |

[1] Treatments were control (CON; hybrid-TMF2R720), a *bm3* hybrid (BM3; hybrid-F15579S2), and an experimental *bm3* hybrid (BM3-EXP; hybrid-F15578XT) with a softer endosperm

[2] Supplement was formulated to be fed at 4.0% of diet DM

[3] Trace mineral premix contained 6% Zn, 5.0% Fe, 4.0% Mn, 2.00% Cu, 0.29% Mg, 0.2% I, and 0.05% Co

[4] Vitamin A-D-E premix contained 30,000 IU of vit A, 6,000 IU of vit D, 7.5 IU of vit E per gram.

[5] Monensin (Rumensin-90; Elanco Animal Health, Indianapolis, IN) premix contained 198 g/kg monensin.

[6] Tylosin (Tylan-40; Elanco Animal Health, Indianapolis, IN) premix contained 88 g/kg tylosin.

**Table 3.3. Diet composition ( % DM basis) in Exp. 5 and Exp. 6**

| | Treatment[1] | | |
|---|---|---|---|
| Ingredient | CON | BM3 | BM3-EXP |
| Control corn silage | 80.0 | - | - |
| BM3 corn silage | - | 80.0 | - |
| BM3-EXP corn silage | - | - | 80.0 |
| MDGS | 15.0 | 15.0 | 15.0 |
| Supplement[2] | | | |
| Fine ground corn | 3.0100 | 3.0100 | 3.0100 |
| Limestone | 0.9160 | 0.9160 | 0.9160 |
| Salt | 0.3000 | 0.3000 | 0.3000 |
| Urea | 0.5740 | 0.5740 | 0.5740 |
| Tallow | 0.1250 | 0.1250 | 0.1250 |
| Trace Mineral premix[3] | 0.0500 | 0.0500 | 0.0500 |
| Vitamin A-D-E premix[4] | 0.0150 | 0.0150 | 0.0150 |
| Monensin[5] | 0.0101 | 0.0101 | 0.0101 |

[1] Treatments were control (CON;  hybrid-TMF2R720), a *bm3* hybrid (BM3; hybrid-F15579S2), and an experimental *bm3* hybrid (BM3-EXP; hybrid-F15578XT) with a softer endosperm
[2] Supplement was formulated to be fed at 4.0% of diet DM
[3] Trace mineral premix contained 6% Zn, 5.0% Fe, 4.0% Mn, 2.00% Cu, 0.29% Mg, 0.2% I, and 0.05% Co
[4] Vitamin A-D-E premix contained 30,000 IU of vit A, 6,000 IU of vit D, 7.5 IU of vit E per gram.
[5] Monensin (Rumensin-90; Elanco Animal Health, Indianapolis, IN) premix contained 198 g/kg monensin.

**Table 3.4. The effects of silage concentration and silage hybrid on feedlot performance and carcass characteristics in calf fed steers (Exp. 4)**

| Item | Treatments[1] | | | | | | SEM | Int.[2] | Concentration[3] | Hybrid[4] |
|---|---|---|---|---|---|---|---|---|---|---|
| | 15% corn silage | | | 45% corn silage | | | | | | |
| | CON | BM3 | BM3-EXP | CON | BM3 | BM3-EXP | | | | |
| Feedlot performance | | | | | | | | | | |
| Initial BW, kg | 334 | 333 | 334 | 333 | 334 | 334 | 0.3 | 0.49 | 0.57 | 0.36 |
| Final BW[5], kg | 627[b] | 626[b] | 638[a] | 608[c] | 623[b] | 623[b] | 3.0 | 0.04 | < 0.01 | < 0.01 |
| Live Final BW, kg | 625 | 623 | 630 | 618 | 622 | 623 | 2.9 | 0.49 | 0.03 | 0.15 |
| DMI, kg/d | 9.8 | 10.0 | 9.9 | 10.1 | 10.2 | 10.4 | 0.1 | 0.19 | < 0.01 | 0.11 |
| ADG[5], kg | 1.66[b] | 1.66[b] | 1.73[a] | 1.56[c] | 1.64[b] | 1.64[b] | 0.02 | 0.05 | < 0.01 | < 0.01 |
| G:F[5] | 0.170[a] | 0.166[b] | 0.174[a] | 0.154[d] | 0.162[c] | 0.157[d] | 0.002 | 0.01 | < 0.01 | 0.07 |
| NEm, Mcal/kg DM [6] | 2.03[a,b] | 2.00[b] | 2.07[a] | 1.86[d] | 1.93[c] | 1.88[c,d] | 0.02 | 0.01 | <0.01 | 0.16 |
| NEg, Mcal/kg DM [6] | 1.37[a,b] | 1.35[b] | 1.41[a] | 1.22[d] | 1.29[c] | 1.24[c,d] | 0.02 | 0.01 | <0.01 | 0.13 |
| Carcass Characteristics | | | | | | | | | | |
| HCW, kg | 400[b] | 399[b] | 407[a] | 388[c] | 397[b] | 398[b] | 2.0 | 0.04 | <0.01 | < 0.01 |
| Dress, % | 64.05[b] | 64.15[a,b] | 64.64[a] | 62.75[c] | 63.89[b] | 63.87[b] | 0.19 | 0.03 | < 0.01 | < 0.01 |
| LM area, $cm^2$ | 87.1 | 87.7 | 87.7 | 89.3 | 90.3 | 87.1 | 0.7 | 0.08 | 0.11 | 0.29 |
| 12th rib fat, cm | 1.42 | 1.40 | 1.50 | 1.19 | 1.24 | 1.32 | 0.05 | 0.76 | < 0.01 | 0.23 |
| Marbling score[7] | 451 | 455 | 475 | 413 | 425 | 443 | 10.0 | 0.90 | < 0.01 | 0.03 |

[a,b,c,d,e] Means with different superscripts differ ($P < 0.05$).
[1] Treatments were control (CON; hybrid-TMF2R720), a *bm3* hybrid (BM3; hybrid-F15579S2), and an experimental *bm3* hybrid (BM3-EXP; hybrid-F15578XT) with a softer endosperm
[2] Silage Concentration × Silage hybrid interaction
[3] Fixed effect of silage concentration
[4] Fixed effect of silage hybrid
[5] Calculated from HCW, adjusted to a common dressing percent of 63.8%
[6] NEm and NEg were calculated using methodology of NRC (1996) using a tool developed by Galyean (2009), assuming a 624 kg target endpoint
[7] Marbling score 400 = small$^{00}$, 500 = modest$^{00}$

**Table 3.5. Effects of feeding two different *bm3* corn silage hybrids on growing steer performance (Exp. 5)**

| | Treatments | | | | |
|---|---|---|---|---|---|
| Variable | CON | BM3 | BM3-EXP | SEM | *P*-value |
| Initial BW, kg | 324 | 324 | 324 | 0.3 | 0.80 |
| Ending BW, kg | 449[b] | 469[a] | 468[a] | 2.2 | < 0.01 |
| DMI, kg/d | 9.6[b] | 10.9[a] | 10.9[a] | 0.1 | < 0.01 |
| ADG, kg | 1.64[b] | 1.92[a] | 1.90[a] | 0.03 | < 0.01 |
| G:F | 0.171 | 0.176 | 0.174 | 0.002 | 0.26 |
| NEm, Mcal/kg DM [2] | 1.78 | 1.79 | 1.77 | 0.02 | 0.82 |
| NEg, Mcal/kg DM [2] | 1.15 | 1.16 | 1.15 | 0.02 | 0.90 |

[a,b,c] Means with different superscripts differ ($P < 0.05$).
[1]Treatments were control (CON;  hybrid-TMF2R720), a *bm3* hybrid (BM3; hybrid-F15579S2), and an experimental *bm3* hybrid (BM3-EXP; hybrid-F15578XT) with a softer endosperm.
[2]NEm and NEg were calculated using methodology of NRC (1996) using a tool developed by Galyean (2009) assuming a 635 kg target endpoint.

**Table 3.6. Effects of feeding two different *bm3* corn silage hybrids on intake and digestibility of nutrients (Exp. 6)**

| | Treatments[1] | | | | |
|---|---|---|---|---|---|
| Item | Control | BM3 | BM3-EXP | SEM | *P*-Value |
| DM | | | | | |
| Intake, kg/d | 6.8 | 7.5 | 7.4 | 0.5 | 0.11 |
| Excreted, kg/d | 2.40 | 2.45 | 2.22 | 0.18 | 0.39 |
| Digestibility, % | 64.5 | 67.7 | 69.0 | 1.6 | 0.11 |
| OM | | | | | |
| Intake, kg/d | 6.3 | 6.9 | 6.9 | 0.45 | 0.11 |
| Excreted, kg/d | 2.09 | 2.09 | 1.91 | 0.14 | 0.36 |
| Digestibility, % | 66.8[b] | 70.0[a,b] | 71.6[a] | 1.4 | 0.05 |
| NDF | | | | | |
| Intake, kg/d | 2.67 | 2.94 | 2.75 | 0.18 | 0.08 |
| Excreted, kg/d | 1.45[b] | 1.23[a] | 1.17[a] | 0.09 | 0.01 |
| Digestibility, % | 45.3[b] | 57.8[a] | 57.0[a] | 2.2 | <0.01 |
| ADF | | | | | |
| Intake, kg/d | 1.68[ab] | 1.81[a] | 1.59[b] | 0.09 | 0.03 |
| Excreted, kg/d | 0.95[b] | 0.73[a] | 0.68[a] | 0.05 | <0.01 |
| Digestibility, % | 41.9[b] | 59.6[a] | 56.1[a] | 2.5 | <0.01 |
| Starch | | | | | |
| Intake, kg/d | 2.03 | 2.09 | 2.29 | 0.18 | 0.11 |
| Excreted, kg/d | 0.07[b] | 0.11[a] | 0.09[ab] | 0.01 | 0.03 |
| Digestibility, % | 96.6[a] | 94.6[b] | 95.8[ab] | 0.7 | 0.03 |

[1] Treatments were control (CON; hybrid-TMF2R720), a *bm3* hybrid (BM3; hybrid-F15579S2), and an experimental *bm3* hybrid (BM3-EXP; hybrid-F15578XT) with a softer endosperm.

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

**Table 3.7. Effects of feeding two different bm3 corn silage hybrids on rumen pH measurements and ruminal volatile fatty acid concentration (Exp. 6)**

| | Treatments[1] | | | | |
|---|---|---|---|---|---|
| Item | CON | BM3 | BM3-EXP | SEM | *P*-value |
| Ruminal pH | | | | | |
| Maximum pH | 6.64[b] | 6.37[a] | 6.41[a] | 0.07 | <0.01 |
| Average pH | 6.50[b] | 6.22[a] | 6.26[a] | 0.07 | <0.01 |
| Minimum pH | 6.38[b] | 6.08[a] | 6.12[a] | 0.07 | <0.01 |
| Magnitude | 0.26[b] | 0.29[a] | 0.29[a] | 0.17 | <0.01 |
| Variance | 0.60[b] | 0.85[a] | 0.90[a] | 0.11 | <0.01 |
| Ruminal VFA[2] | | | | | |
| Total VFA (mM) | 181.95[b] | 200.17[a] | 193.55[a] | 5.75 | <0.01 |
| Acetate[3] | 62.07[a] | 59.61[c] | 61.05[b] | 0.67 | <0.01 |
| Propionate[3] | 22.38[b] | 23.73[a] | 22.60[b] | 0.67 | 0.01 |
| Butyrate[3] | 10.73[b] | 12.25[a] | 12.34[a] | 0.27 | <0.01 |
| A:P ratio[4] | 2.83[a,b] | 2.70[b] | 2.85[a] | 0.10 | 0.06 |

[a,b,c] Means with different superscripts differ ($P < 0.05$).
[1] Treatments were control (CON; hybrid-TMF2R720), a *bm3* hybrid (BM3; hybrid-F15579S2), and an experimental *bm3* hybrid (BM3-EXP; hybrid-F15578XT) with a softer endosperm.
[2]Ruminal volatile fatty acids (VFA)
[3]VFA concentration in mol/100 mol
[4]Acetate:Propionate

**Table 3.8. Effects of feeding two different bm3 corn silage hybrids on ruminal VFA and gas production rates (Exp 6.)**

| | Treatments[1] | | | | |
|---|---|---|---|---|---|
| Production rate, mM/g DM[2] | CON | BM3 | BM3-EXP | SEM | *P*-value |
| Total VFA | 41.79 | 55.10 | 49.14 | 5.04 | 0.17 |
| Acetate | 26.32 | 31.81 | 27.23 | 3.15 | 0.40 |
| Propionate | 7.25[b] | 12.15[a] | 9.00[b] | 1.71 | 0.02 |
| Butyrate | 6.18[b] | 10.13[a] | 9.24[a] | 1.21 | 0.03 |
| Gas production rate, %/h[3] | 25.43[b] | 30.87[a] | 28.73[ab] | 2.44 | 0.03 |

[a,b,c] Means with different superscripts differ ($P < 0.05$).
[1] Treatments were control (CON; hybrid-TMF2R720), a *bm3* hybrid (BM3; hybrid-F15579S2), and an experimental *bm3* hybrid (BM3-EXP; hybrid-F15578XT) with a softer endosperm.
[2] Production rate is calculated by change in VFA mM/g DM over 6 hours
[3] Gas production rate