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GROWTH PERFORMANCE, RUMINAL FERMENTATION CHARACTERISTICS,
AND ECONOMIC RETURNS OF GROWING BEEF STEERS FED BROWN MIDRIB
CORN SILAGE-BASED DIET

by

Christopher Scott Saunders

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Animal, Dairy, and Veterinary Sciences

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2015

ABSTRACT

Growth Performance, Ruminal Fermentation Characteristics, and Economical Returns of Growing Beef Steers Fed Brown Midrib Corn Silage-Based Diet

by

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Utah State University, 2015

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In the beef cattle industry, sustainable beef production is a primary focus, as it has direct effects on environmental stewardship, farm profitability, and public concerns. Research has been and is continually being conducted to evaluate alternative forages such as Brown Midrib Corn Silage (**BMRC**S) as a major component in growing beef cattle diets, to improve animal performance, ruminal fermentation, and economic returns. The objective of this study was to determine growth performance, ruminal fermentation characteristics, and economic returns of growing beef steers when fed a brown midrib corn silage-based TMR (**BMRT**) compared with a conventional corn silage-based TMR (**CCST**). This growing beef study was performed in a completely randomized design with 24 Angus crossbred steers (initial body weight (**BW**) = 258 ± 23.2 kg) to test 2 treatments: CCST vs. BMRT. All animals were placed in individual pens, and 12 animals allocated to each treatment (n = 12). All steers were adapted to the CCST for a 2-wk period prior to start of the trial. The CCST contained 48.1% CCS whereas the BMRT

consisted of 49.0% BMRCS on a dry matter (**DM**) basis. All steers were fed once per day, and feed bunks assessed each afternoon and prior to morning feeding, which was used to determine the amount of feed to deliver to each pen the following day. The experiment lasted 84 d. For all steers, BW and ruminal fermentation characteristics were measured on wk 4, 8, and 12. Intake of DM averaged 9.54 kg/d across the treatments and was similar between the treatments. Steers fed the BMRT tended to increase average daily gain (**ADG**) compared to those fed the CCST (1.54 vs. 1.42 kg/d; $P = 0.09$). In addition, feeding the BMRT tended to increase G:F compared with the CCST (0.165 vs. 0.146; $P = 0.07$). Feeding the BMRT decreased ruminal pH (6.42 vs. 6.67; $P < 0.01$), whereas it increased total VFA concentration ($P = 0.01$) compared with the CCST. Feeding the BMRT decreased molar proportion of acetate ($P < 0.01$), but increased propionate proportion ($P = 0.01$), resulting in decreased acetate-to-propionate ratio compared with the CCST ($P < 0.02$). Steers fed BMRT increased feed margin ($P = 0.05$) and net return ($P = 0.02$) compared to those fed CCST throughout the trial. Overall data in this study indicate that feeding the BMRT to growing beef steers enhanced ruminal fermentation and beneficially shifted VFA profiles, which contributed to improved growth performance and economic performance of steers fed the BMRT.

(79 pages)

PUBLIC ABSTRACT**Growth Performance, Ruminant Fermentation Characteristics, and Economical Returns of Growing Beef Steers Fed Brown Midrib Corn Silage-Based Diet**

by

Christopher S. Saunders
Utah State University, 2015

Sustainable beef production is extremely important to the beef cattle industry. Sustainability influences the environment, overall profits, and public concerns. One factor that influences sustainability is the composition of cattle feed. This study compared conventional corn silage (CCS), which is most commonly used in beef steer feed, to brown midrib corn silage (BMR). Steers fed the two different diets were compared to determine differences in the areas of growth/animal performance, ruminal fermentation (digestion), and economic returns. The study included 24 beef steers randomly assigned to one of two treatment groups. Treatment groups were a total mixed feed ration that included all of the same basic components except for the BMR or CCS difference. Steers were fed the treatment diet during a transition phase before the start of the study. Animals were placed in individual pens and fed the treatment diet once per day. The study lasted for 84 days. Body weight and ruminal fermentation measures were taken on weeks 4, 8, and 12. Steers fed BMR tended to increase average daily gain (ADG) and the gain to feed ratio compared to the CCS treatment. Feeding BMR decreased ruminal pH and increased total volatile fatty acid (VFA) concentration compared to CCS. Feeding BMR decreased production of acetate, and increased production of propionate. Steers fed BMR had increased feed margin and net returns. Overall data showed that feeding BMR to growing beef steers improved fermentation and shifted VFA production from acetate to propionate. These differences led to improved growth and economic performance in steers fed BMR.

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LIST OF ABBREVIATIONS

ADF = acid detergent fiber

ADG = average daily gain

ATP = adenosine triphosphate

BMR = brown midrib

BMRCs = brown midrib corn silage

BMRT = brown midrib corn silage total mixed ration

BW = body weight

BWG = body weight gain

CP = crude protein

CCS = conventional corn silage

CCST = conventional corn silage total mixed ration

cwt = hundredweight

DM = Dry matter

DMI = dry matter intake

eNDF = effective NDF

G:F = gain to feed ratio

NDF = neutral detergent fiber

NDFD = neutral detergent fiber digestion

NEFA = non-esterified fatty acids

NFFS = non-forage fiber sources

OM = organic matter

pdNDF = potentially digestible NDF

pK_a = acid dissociation constant

TMR = total mixed ration

VFA = volatile fatty acid

WS = wheat straw

INTRODUCTION

The need for improving feed efficiency in ruminant production to address increasing costs of production and environmental challenges necessitates optimization of nutrient utilization in their diets. The application of this concept in a forage-based feeding program in ruminants can be achieved through conventional forage breeding as well as effective forage feeding programs. Chemical and genetic approaches have been employed to improve forage fiber digestibility by decreasing the extent of lignin concentration or lignin cross-linking with cell wall carbohydrates. Brown midrib (**BMR**) forage genotypes usually contain less lignin and may have altered lignin chemical composition (Bucholtz et al., 1980; Cherney et al., 1991; Vogel and Jung, 2001). The BMR corn is generally viewed as being lower yielding than non-BMR corn, but feeding BMR silage has resulted in increased milk production of dairy cows due to its lower lignin concentration and associated increase in ruminal digestibility and fermentability (Gencoglu et al., 2008; Sattler et al., 2010). Digestibility of forage fiber affects growth performance of rapid growing beef steers. In addition, providing adequate dietary concentrations of digestible fiber in cattle rations is essential for animal health, as it is required to support an appropriate rumen function.

Typically, growing beef steers are fed forage-based diets, but the lack of energy from forages and distention from rumen fill may limit DMI and reduce performance of high-producing dairy cows and rapidly growing beef steers (Holt et al., 2010; 2013a,b). Therefore, great emphasis has been placed on dietary factors affecting DMI of cattle. The rumen-filling effect of diets is influenced most by concentration, digestibility, and

fragility of forage NDF (Allen et al., 2009). Feeding forages with enhanced digestibility of NDF has been reported to improve DMI and milk yield in dairy cows (Oba and Allen, 1999b). Corn silage with the BMR mutation has been well documented to have higher fiber digestibility and will likely increase DMI and milk yield compared with cows fed conventional corn silage (CCS; Eastridge, 1999; Gencoglu et al., 2008). Therefore, energy sources high in digestible fiber, such as BMR, may allow for increased energy intake without disruption of fiber digestion and improved ruminal fermentation, which can enhance growth performance of growing beef steers. The objectives of this study were to investigate the influence of feeding BMR-based diet to growing beef steers on the followings: 1) growth and feed intake, 2) ruminal fermentation profiles, and 3) economic returns by comparison with those fed CCS-based diet.

REVIEW OF LITERATURE

Sustainable beef production is one of the most critical components in beef cattle industry and research community, as it directly affects environmental stewardship, farm profitability, and public concerns. Due to this challenge, there has been a renewed interest in optimizing use of forages such as BMRCs for beef cattle. It is the purpose of this review to address the role of forage to maximize ruminal fermentation and improve growth performance and economic returns of beef cattle with focus on feeding BMRCs-based diets.

Fiber Digestibility

Fiber digestion is an important component of the cattle operations in the efforts of maintaining or increasing growth performance and ruminal fermentation, while keeping the operation profitable. Forage constitutes a major portion of the diets of growing beef steers. Feeding high-forage diets can maintain ruminal pH and improve overall ruminal functionality (Holt et al., 2010). Therefore, steers fed a high-forage diet in the growing phase would be expected to have greater functionality of the rumen (Tjardes et al., 2000). While feeding high-forage diets, quality, type, and length have an important impact on animal health and productivity (Van Soest, 1994). During the growth period, forage quality may limit animal performance due to the extent of rumen fill and digestibility of fiber (Tjardes et al., 2000). Decreased production has been shown in steers consuming forages of mature grasses, which can be attributed to decrease digestibility and intake potential of poor quality forages (Castle, 1982; Steen, 1992; Rinne et al., 1997).

Without adequate forage in beef steer diets, the rumen wall could be damaged. An important aspect in feeding growing beef steers is for steers to consume sufficient amounts of neutral detergent fiber (**NDF**). However, without sufficient amounts of long particles, steers can exhibit the same metabolic disorders as steers consuming a diet deficient in chemical fiber (Fahey and Berger, 1988). Functionality of forage fiber is usually expressed as effective NDF (**eNDF**), which refers to the concentration of the NDF that effectively stimulates chewing and salivation, rumination, and rumen motility. Neutral detergent fiber represents all plant cell wall material, cellulose, hemicellulose, and lignin that are insoluble in neutral detergent (Van Soest, 1994). Research has shown that NDF concentration is negatively correlated to intake, and as NDF concentration increases, intake decreases (Allen, 1996; Tjardes et al., 2002; Parish and Rhinehart, 2008). Much research has been done on forage quality (i.e., eNDF and NDF), type, and length (Tjardes et al., 2002; Soto-Navarro et al., 2014), which collectively indicate that proper forage quality is able to increase animal performance and rumen functionality without decreasing the amount of effective forage fed.

Effective Fiber

Effective fiber is estimated by eNDF. Effective NDF refers to the percentage of the NDF effective in stimulating chewing and salivation, rumination, and rumen motility (NRC, 2000). The importance of stimulating salivary flow to buffer rumen pH is well documented. Dietary levels of eNDF impact ruminal pH and are often used to predict ruminal pH in feeding formulations. Sufficient eNDF levels are important in beef cattle diets to keep ruminal pH from dropping below acceptable levels to maintain feed intake

levels. Diets high in grains (high starch diets) will often reduce ruminal pH (Figure 1; Parish, 2007).

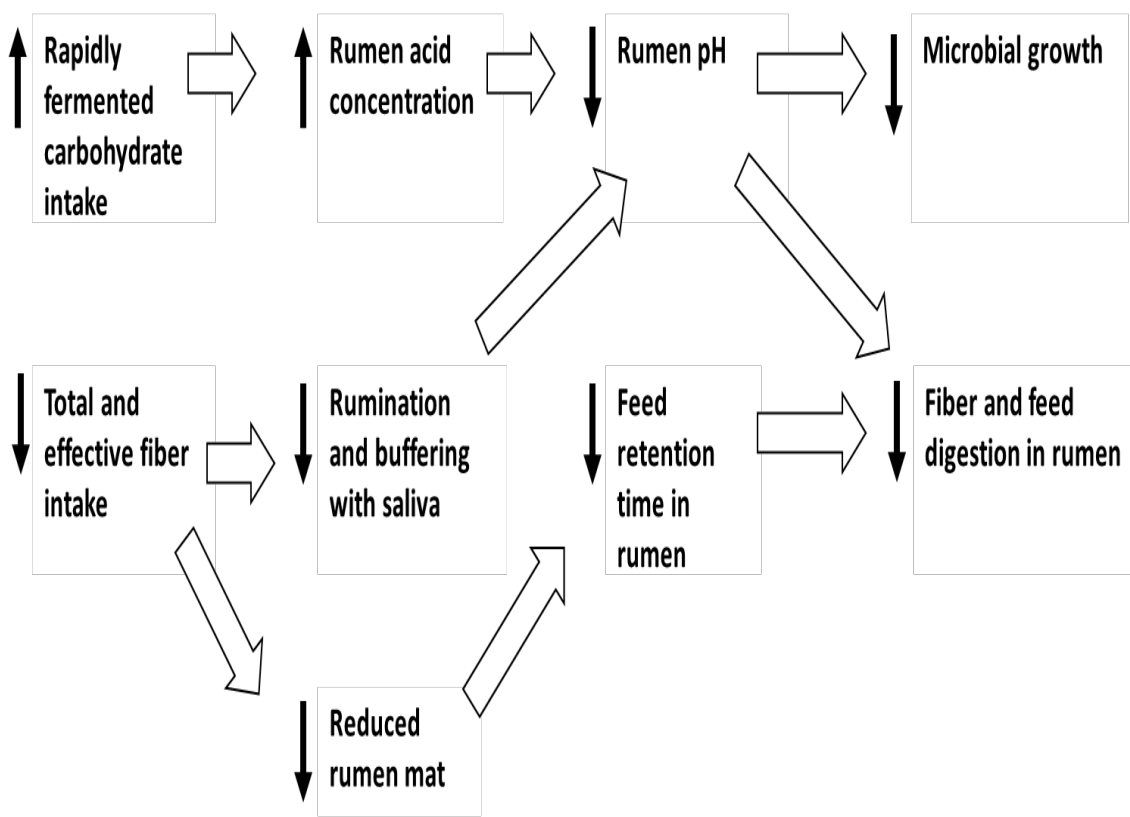


Figure 1. Rumen changes in response to decreased fiber intake (adapted from Parish, 2007).

The eNDF required in high-energy diets (e.g., finishing diets) is 8%, which is considered to be the concentration necessary to keep ruminal pH above 5.7 (Table 1). A ruminal pH below 5.7 dramatically reduces dry matter intake (**DMI**) in cattle. If cattle gorge on high-starch feeds or there is a lack of effective fiber in the diet leading to inadequate saliva secretion to buffer the rumen, ruminal pH can remain low, and intake

may drop off at the next feeding. Low pH levels for extended periods of time can shift the microbial population to favor bacteria that produce high levels of lactic acid, and then acute acidosis can occur. Cattle changing from high-roughage to high-concentrate diets need several weeks of gradual adjustment from one diet to the other to allow the development of rumen microbes to digest high starch levels without dropping rumen pH below 5.6 (Parish, 2007).

Table 1. Estimated eNDF requirements for beef cattle adjusted to high grain diets¹

Diet type	Minimum eNDF required, % of DM
High concentrate to maximize gain/feed fed mixed diet, good bunk management, and ionophores	5 to 8 ²
Fed mixed diet, variable bunk management, or no ionophore fed	20
High concentrate to maximize non-fiber carbohydrate use and microbial protein yield	20 ³

¹Nutrient Requirements of Beef Cattle, NRC, 2000

²To keep rumen pH more than 5.6 to 5.7, the threshold below which cattle stop eating.

³To keep rumen pH above 6.2 to maximize cell wall digestion and/or microbial protein yield.

National Research Council (2001) recommends NDF concentration to be maintained at 25% of dietary DM with at least 75% from forage for the NDF requirement. Therefore, there is room for up to 25% of the NDF from non-forage fiber sources (NFFS) to meet the NDF requirement. Although NFFS are less effective in stimulating chewing than formal forage fiber sources, they can be used as fiber sources in growing and lactating diets when included at a certain proportion. However, the effectiveness of fiber within byproduct feeds and forages is variable because of differences in size distribution of fiber

particles and the retention time of fiber in the rumen. Hence, chemical and physical characteristics alone should not be used as exclusive measures of fiber requirements, because ruminal fermentation of fiber is variable (Nocek and Tamminga, 1991), and adjustment of dietary fiber content affects fermentation acid production by dilution or concentration of the nonfibrous fraction of the diet.

Ruminal pH is a more meaningful response variable for determining effectiveness of forage utilization by cattle. Diets should be balanced to maintain adequate ruminal pH; as ruminal pH decreases, appetite, ruminal motility (Ash, 1959), microbial yield (Hoover, 1986), and fiber digestion (Terry et al., 1969) are reduced. Thus, low ruminal pH has direct, negative impacts on microbial fermentation and nutrient digestion, which are primary factors limiting production of cattle. When ruminal pH is substantially reduced, severe health problems such as laminitis, ruminal ulceration, liver abscess, and even death could result (Slyter, 1976). Mackie and Gilchrist (1979) suggested an index that emphasized the time spent under the optimal ruminal pH by the magnitude of the deviation from this pH. Although this index might be better related to animal performance than is mean ruminal pH, variation in ruminal pH is more closely related to feeding management practices, and more influenced by meal frequency (Bragg et al., 1986) and diet adaptation (Counotte and Prins, 1981) than diet formulation. The effects of feeding management on variation in ruminal pH should be considered when choosing the optimal mean ruminal pH, which is lower when variation over time is minimized.

Allen (1997) reported the relationship between ruminal pH and forage NDF using 106 treatment means from 28 experiments in the literature. The author used only data from ruminally cannulated lactating dairy cows with pH determined as within-day means. The

dataset included intake of DM or OM and dietary concentration of NDF and ADF in all or most of the experiments. However, the concentration of forage NDF was reported on only 6 experiments of the dataset. Ruminal pH was positively related to forage NDF on DM basis ($P < 0.01$; $r^2 = 0.63$). Ruminal pH was not related to ADF or NDF as a percentage of DM or to OM intake. A positive relationship between forage NDF and ruminal pH was expected because of the greater chewing and salivary buffer flow with increasing forage NDF. Because only 6 experiments included forage NDF, the dataset was limited ($n = 26$), and caution should be taken when these results are interpreted.

Digestibility of NDF is determined by the fraction of NDF that is potentially digestible, the rate of NDF degradation in the rumen, and the rate of passage from the rumen (Allen and Mertens, 1988). In vitro NDF digestibility can range from less than 20% to greater than 60% over a variety of forages (Allen and Oba, 1996). Potentially digestible NDF (**pdNDF**) is a laboratory measure of the absolute extent of NDF digestion by ruminal microorganisms. Increasing proportion of pdNDF and decreasing the indigestible NDF fraction could result in greater fiber digestibility.

Digestibility of NDF

Digestibility of NDF is a function of the potentially digestible fraction and its rate of digestion and passage. Digestibility of NDF is another important parameter of forage quality, because forage NDF varies widely in its degradability in the rumen, and NDF digestibility influences animal performance. Allen and Oba (1996) reported in vitro degradability of NDF after 30 h of incubation ranged from less than 30 to 60% for corn silage and alfalfa hay. Although dairy cows require forage NDF in diets for maximum

productivity, excess dietary NDF often limits voluntary feed intake because of physical fill in the rumen. Mertens (1997) suggested that DMI of dairy cows can be predicted by dietary NDF, in part because of a positive relationship between NDF and the bulk density of feeds. Hence, enhanced NDF hydrolysis in the rumen may stimulate rapid disappearance of NDF from the rumen, reduce physical fill, and allow greater voluntary feed intake (Allen and Oba, 1996). Once the rumen's capacity for fill has been reached, movement of digesta out of the rumen must occur before feed intake can resume. Early work on this subject by Crampton (1957) showed that forages with the least digestibility of cellulose and hemicelluloses were retained the longest in the rumen of sheep. He postulated that this increase in retention time of the feed in the rumen was a major factor in decreasing voluntary intake. Grant et al. (1995) and Dado and Allen (1996) showed that increased NDF digestibility can alleviate the filling effect of NDF in the rumen at similar dietary NDF concentrations. Oba and Allen (2000c) fed lactating dairy cows silages with similar NDF and CP contents but different NDF digestibility. Intake of DM and milk yield increased when cows were fed forages with higher NDF digestibility. The authors stated that increased NDF degradability can also increase the energy density of diets and stimulate microbial N production. Oba and Allen (1999a) reported that a one percentage unit increase in in vitro NDF degradability of forage elicited a 0.17 kg increase in DMI and a 0.25 kg increase in 4% fat-corrected milk yield. Jung et al. (2004) reported that in diets containing corn silage (> 40% of the dietary DM), a one percentage unit increase in in vitro NDF degradability of corn silage resulted in a 0.12 kg/d increase in DMI and a 0.14 kg/d increase in 3.5% fat-corrected milk yield. Thus, the increases in NDF digestibility of forage in vitro and in vivo have the potential to substantially

improve the productivity of cattle fed diets containing relatively high concentrations of forages, and brown midrib corn silage (**BMRC**S) can effectively improve performance of growing beef steers due to increased NDF digestibility

Brown Midrib Corn Silage (BMRCS)

Conventional Corn Silage (CCS)

High dietary concentrations of corn silage (**CS**) are typically fed during the stocker phase of beef cattle feeding systems in North America (Vance et al., 1972; Ritchie et al., 1992). Some researchers reported that feeding CS ad libitum increased DMI and performance of cattle (O'Kiely and Moloney, 1995 and 2000; Keady et al., 2007). Corn grain is incorporated within the whole plant, so there is energy from a grain along with fiber from the rest of the plant (Allen et al., 2003).

Mazzenga et al. (2009) found that increasing dietary concentration of CS with decreasing wheat straw (**WS**) increased digestibility of DM and organic matter (**OM**) due to the increased availability of CS cell walls to microbial fermentation when compared to the lignified structures of WS cell walls. Within the study, the authors formulated 4 isofibrous diets with an average NDF concentration throughout the diets of $32.6 \pm 10\%$ and an ADF concentration of $18.5 \pm 2\%$. The 4 diets were as follows: CS0 (20WS:0CS as a percentage of DM of the total diet), CS20 (10WS:20CS), CS35 (5WS:35CS), and CS50 (0WS:50CS). The diets included along with (WS and CS) dried beet pulp, soybean meal, corn meal, wheat bran, and a mineral premix; with the stepped substitution of WS with CS, the forage to concentrate ratio were as follows: 40:60, 50:50, 60:40, and 70:30 respectively. The improvement in digestibility could be a result from a decrease in

ground concentrates used as CS inclusions increased as well as a decrease in particles < 8.0 mm found with the increase in CS (81.2 vs. 62.2%) respectively. The highest digestibility data was that of 50% inclusion of CS (for DM, OM, CP, NDF and ADF). In the conclusion of the study, they stated that CS had a positive effect on DM digestibility through the increase of NDF and OM digestion while increasing CS inclusion. In addition, the authors reported increased starch digestibility with the increase of CS (Mazzenga et al., 2009).

Johnson et al. (1999) reviewed the use of CS in dairy cattle diets and reported that maturity and DM had an important role on animal performance. Through the evaluation of many studies (Huber et al., 1965; Huber et al., 1968; St. Pierre et al., 1987), the authors reported DMI and milk production increased as DM increased from 25.4% to 33.3%, while ADF and lignin concentrations decreased as maturity increased from 30 to 36% DM. In addition, it was reported that body weight gain (**BWG**), DMI, yield of 4% fat-corrected milk, and milk fat concentration were greater for cows fed CS harvested at 36% DM, but decreased as cows were fed diets containing 46% DM.

BMRCS

In 1924, a one-year self-pollinated line of northwestern dent corn at the University of Minnesota produced the first recorded traits of BMRCS. The plants exhibited a reddish brown pigment in the leaves that became visible at the 4-6 leaf stage. The coloring was predominantly located around the center midrib located on the underside of the leaf, hence the name “brown midrib.” While the coloring faded with maturity in the leaves, the stalk kept the pigmentation throughout. This pigmentation has been associated with

reduced lignin concentrations and altered lignin composition compared with CCS. Brown midrib is a natural occurring gene that is double recessive. There are four mutations of this gene: *bm1*, *bm2*, *bm3*, and *bm4* (Barrière and Argillier, 1993). The *bm3* gene has been very favorable in the commercial hybrids among cow producers because of its constantly reduced lignin concentration.

Brown midrib hybrids are usually characterized by low lignin concentrations and high fiber digestibility. Incorporation of the BMR trait into forage genotypes has been of interest for many years because of the reduction in lignin concentration of the plant. The lower lignin concentration will increase digestibility of the forage, thereby resulting in forage with higher energy concentration. The BMR gene has little, if any, effect on the concentrations of CP, NDF, ADF, and ash in corn plants (Weller et al., 1984). The low lignin concentration is associated with changes in concentration of phenolic acids and alteration in enzymes involved in lignin biosynthesis (Cherney et al., 1991).

Reduction in fiber digestion due to higher concentration of lignin was thought to be the main reason for the shielding effect on cell wall polysaccharides (Akin, 1989). The unique difference in BMR compared to conventional corn hybrids comes from the mutation of certain enzymes involved in lignin biosynthesis. One mutation in *bm3* involves low concentration or lack of *o*-methyl transferase activity to complete methylation reaction of caffeic acid to ferulic acid, which is a lignin precursor (Cherney et al., 1991). Goto et al. (1994) showed lower concentrations of *p*-coumaric (4.3 vs. 7.4 g/kg DM) and ferulic acids (2.7 vs. 3.8 g/kg DM) for *bm3* compared to normal whole plant corn silage, respectively. Similarly, Hartley and Jones (1978) reported lower total

concentration of phenolic compounds (10 vs. 16 mg/g of cell wall) for *bm3* compared to normal whole plant corn silage.

Most BMR hybrids currently used by the hybrid seed industry have the *bm3* allele, which characteristically reduces lignin concentration and increases NDF digestibility to a greater extent than the other *bm* genes. Allen et al. (1997) stated that the *bm3* mutation in corn hybrids decreased lignin concentration by 1.1 percentage units and increased in vitro NDF digestibility after 30 h of incubation by 8.4 percentage units compared with conventional control hybrids. There was no effect on the CP, NDF, ADF, or ash concentrations of corn silage.

Eastridge (1999) reported that, on average, BMRCs contained 34% less lignin and had an in situ or in vitro NDF digestibility that was 19% greater when compared with non-BMR hybrids. Ebling and Kung (2004) showed a greater difference in the concentration of lignin (55% less) between BMRCs and processed normal corn silage, which resulted in a proportionally greater increase (38%) in in vitro NDF digestibility. Also, Holt et al., (2013a) reported that in vitro NDF degradability measured after 30 h of incubation was 9.2 percentage units greater for BMRCs compared with CCS (71.4 vs. 62.2%). Increased NDF degradability increases the energy density of diets and stimulates microbial N production (Oba and Allen, 2000b). The increase in NDF degradation in BMRCs has the potential to substantially improve the productivity of cattle fed diets containing BMRCs. Greater BWG has been observed in several experiments where BMRCs replaced normal corn silage (Frenchick et al., 1976; Sommerfeldt et al., 1979; Weller and Phipps, 1986), and this effect might occur if BMRCs shifts site of starch digestion to the intestines.

Performance of Beef Cattle Fed BMRCS

Since BMRCS was introduced, it has almost exclusively been used and studied in dairy production. The results of feeding BMRCS to dairy cattle showed an increase in animal performance: increases in DMI, energy intake, and milk yield (Oba and Allen, 1999b). These favorable increases in animal performance led Keith et al. (1981) to perform a two-year study comparing the performance of feedlot cattle fed either BMRCS or its normal genetic counterpart. This study showed greater weight gains resulted with the consumption of BMRCS (160 vs. 139 kg) as well as an increase in DMI (5.90 vs. 5.43 kg/d) compared when cattle were fed CCS. With the ever-changing improvement of BMRCS genetics, Tjardes et al. (2000) conducted another beef study and found considerably different results. The authors stated that the consumption of BMRCS improved digestion, but not performance when compared with CCS. A matter of major significance that was consistent between the two studies was the increase in DMI, which agrees with the majority of other BMRCS studies (Ebling and Kung, 2004; Gehman et al., 2008; Castro et al., 2010), but not all studies reported any significant effect (Taylor and Allen, 2005c; Weiss and Wyatt, 2006; Kung et al., 2008). Dado and Allen (1995) speculated that a faster disappearance of NDF from the rumen is because of increased rate of NDF digestion of BMRCS that might reduce distention from gut fill over time and allow greater voluntary feed intake. Holt et al. (2013b) showed that during peak lactation DMI between dietary treatments was not different, but after peak lactation DMI tended to increase by feeding the BMRCS diet compared with the CCS diet (25.8 vs. 24.7 kg/d; $P = 0.07$). The authors suggested that ruminal distention from gut fill was not a limiting factor

during the first several weeks of lactation. Tine et al. (2001) reported that BMRCs provided greater amounts of energy due to the increased fiber digestibility when fed to dry cows at maintenance.

Regulation of DMI

Intake of DM in cattle has a great impact on performance. The control of feed intake requires the integration of many signals, including immediate and long-term energy needs, as well as environmental factors (Baile and McLaughlin, 1987). Feed intake is probably determined by the integration of a variety of physical, metabolic, and hormonal factors.

Metabolic and Hormonal Regulation of Feed Intake

Metabolites and nutrients can potentially serve as regulators of feed intake. Mobilization of triglycerides in adipose tissue and the subsequent release of nonesterified fatty acids (NEFA) and glycerol along with the production of ketone bodies may act as signals to decrease feed intake in periparturient dairy cattle (Ingvarsen and Andersen, 2000). Perhaps increased concentrations of circulating NEFA in the cow may result in a counterintuitive reduction in feed intake. This reduction in feed intake due to neural signaling in the liver is likely linked to mitochondrial oxidation of NEFA, which provides satiety signals mediated by vagal afferents (Scharrer and Langhans, 1990). The idea that feed intake is controlled by a signal from the liver to the brain stimulated by oxidation of fuels was coined the “Hepatic Oxidation Theory” by Allen et al. (2009). By integrating the effects of various metabolic fuels on feeding behavior, they developed a conceptual

model by which feed intake may be controlled in ruminants (Figure 2).

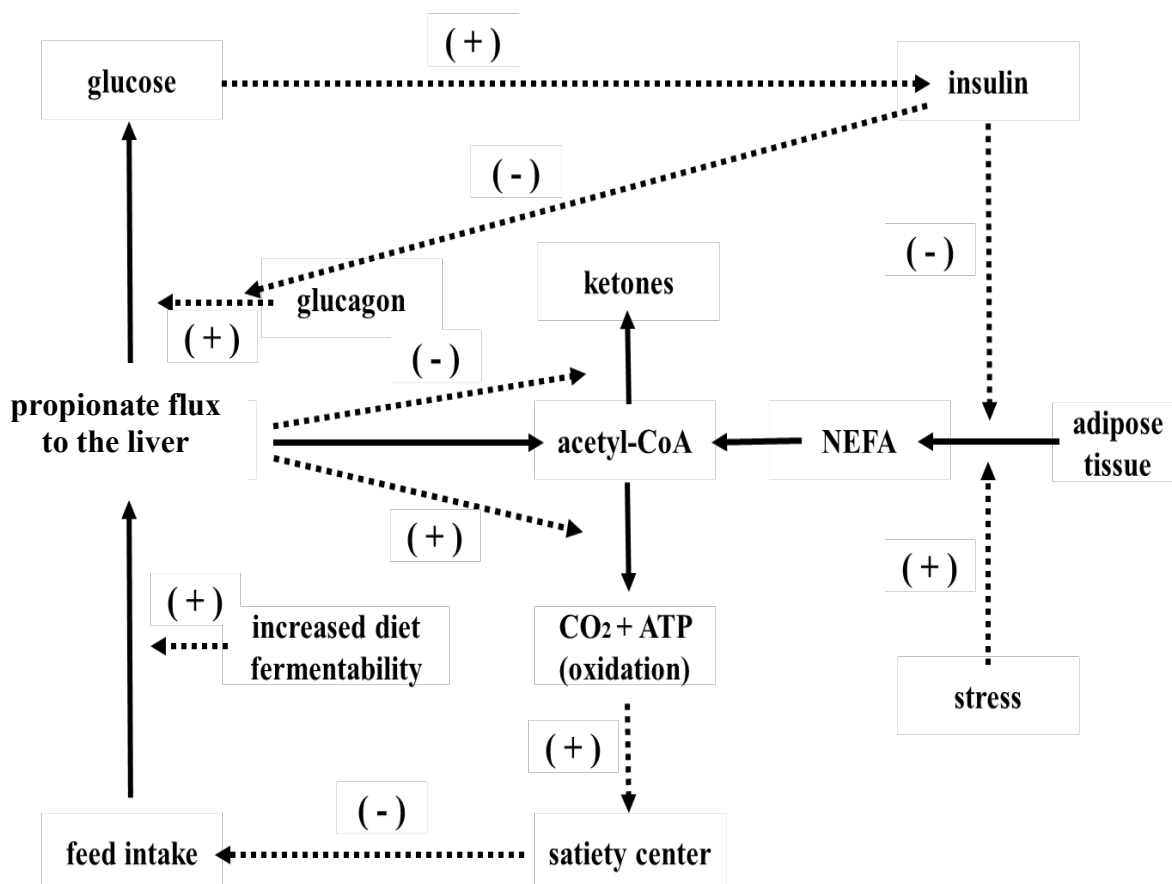


Figure 2. Model of control of feed intake by hepatic oxidation theory in ruminants (adapted from Allen et al., 2009). Although propionate is used for gluconeogenesis, there is high flux of carbon from propionate through pyruvate kinase (Steinhour and Bauman, 1988), allowing oxidation depending upon the fate of pyruvate. Oxidation of propionate within a meal increase the energy state of hepacytes, generating a satiety signal to terminate the meal. Hepatic oxidation of NEFA is limited during meals because increased insulin release inhibits lipolysis in adipose tissue and uptake of NEFA by the liver (Vasilatos and Wangsness, 1980).

Allen et al. (2009) reported that the minute to minute fluctuations of oxidized fuels play a greater role in the feeding behavior than longer periods of time (hours or days) which remain relatively constant. Hepatic oxidation increases during a meal, resulting in increased energy status of hepatocytes and decreased rate of hepatic vagal afferents, thus

resulting in satiety. However, following a meal, hepatic oxidation declines, causing decreased energy status of hepatocytes and increased discharge rate of the hepatic vagus, thus resulting in hunger (Allen et al., 2009). According to the authors, hepatic oxidation likely controls feed intake to a greater extent for cows with low nutrient requirements and for animals in a lipolytic state (e.g., periparturient and stressed animals) than those fed high forage diets or with very high nutrient requirements such as cows at peak lactation (Allen et al., 2009). Therefore, as milk yield increases, feed intake control by hepatic oxidation diminishes, and alternatively control is dominated by distension from gut fill. This change in the dominant mechanism of intake regulation might occur only 7 to 10 d after calving for some cows or more than 3 wk for others. The best signs that hepatic oxidation is less limiting are lower plasma NEFA and ketone concentrations and steadily increasing feed intake (Allen et al., 2009).

Physical Regulation of Feed Intake

Physical regulation of feed intake can occur when physical fill in the gastrointestinal tract limits feed intake. A significant amount of research has been devoted to investigate factors affecting physical regulation of intake (Allen, 1996 and 2000). The primary cause of physical limitation on intake is long retention time of the fibrous fraction of the diet. Although fiber is crucial to maintaining a healthy rumen environment, digestion of the fibrous feed fraction is slow and can increase ruminal retention time if particles cannot be broken down and passed from the rumen. Limitations to flow from the rumen have been reviewed (Allen, 1996) and include particle size and density, which are closely associated with ruminal digestibility. Ruminal digestion of fibrous feed increases particle fragility

and makes particles more susceptible to breakdown during chewing (Chai et al., 1984). Additionally, as ruminal digestion of fiber occurs, particle buoyancy decreases, and particles sink (Sutherland, 1988). With a greater rate of fiber digestion, particles are probably broken down faster, thereby sinking faster, which increases the rate of passage from the rumen and decreases the filling effect of the diet.

A body of research (Reid et al., 1988; Orskov et al., 1991; Forbes, 1996) has shown that ruminal distention from feeding a high fiber diet can decrease DMI; others (Allen et al., 2009) state that intake regulation is by satiety through metabolism of fuels. Using a replicated 4×4 Latin square design with a 2×2 factorial arrangement with 16-day periods, Tjardes et al. (2002) conducted a study using 8 ruminally cannulated steers to test the influence of NDF concentration and rumen inert bulk on DMI. The authors found that the intake of lightweight steers receiving CS-based diets within a wide range of NDF concentrations was not regulated by ruminal distension alone. It was hypothesized that there was a physiological mechanism that helped control DMI. Using a beef trial database, Arelovich et al. (2008) reported that an increase in DMI was observed with increasing dietary NDF concentration (7.5 to 35.3%). Conversely, Tjardes et al. (2002) reported that at 50% NDF concentration DMI decreased. The authors reported that feeding a high fiber compared to a low fiber diet decreased DMI (4.23 and 4.92%) with an increase in NDF intake (1.66 vs. 2.15%), respectively. Previous research has shown that increased dietary NDF by the addition of straw decreased DMI (Reid et al., 1988; Orskov et al., 1991). Intake of DM has been shown to decrease with increased production of VFA. Propionate has a greater effect on decreasing DMI than acetate and butyrate (Figure 2). As propionate increased, a direct correlation was seen in the linear reduction

in meal size from 2.5 to 1.5 kg of DM with propionate being infused from 0 to 100 % (Allen et al., 2009). Tjardes et al. (2000) reported a trend with a DMI \times hybrid interaction ($P < 0.15$) for total VFA concentration, showing that steers fed ad libitum BMRCS had the highest concentration of total VFA compared with the other three diets. These studies show that DMI is not decreased by additional energy supplied, but rather have fuel-specific mechanisms regulating feeding behavior (Allen et al., 2009). In a study conducted by Tjardes et al. (2000), comparing BMRCS to CCS, they reported that there was a trend for DMI level \times hybrid interaction ($P \leq 0.15$) for apparent total tract digestibility of NDF (63.6 vs. 53.1%) and ADF (65.5 vs. 56.1%), respectively. The authors explained that the magnitude of improvement in total tract digestibility of NDF and ADF by feeding BMRCS was dependent upon DMI level. This was shown when BMRCS was compared to the control at ad libitum intakes with 10.5 and 9.4 percentage units in total tract digestibility of NDF and ADF, respectively. The hybrid interaction was shown keeping the intake constant between the two hybrids with the limitation in DMI, when fed BMRCS steers showed a 15.8 and 15.4% increase in total tract digestibility of NDF and ADF, respectively (Tjardes et al., 2000).

Site of Digestion

Greater ruminal digestibility of fiber and starch might interact to shift site of nutrient digestion from the rumen to other sites in the gastrointestinal tract. Replacing beet pulp with high-moisture corn linearly decreased ruminal pdNDF digestibility from 67.3 to 46.1% (Voelker and Allen, 2003). While greater ruminal starch digestion is associated with lower ruminal fiber digestibility in multiple studies (Crocker et al., 1988; McCarthy

et al., 1989; Callison et al., 2001), it is not always associated with lower total tract NDF digestibility (Crocker et al., 1988; Callison et al., 2001).

In an experiment done by Crocker et al. (1988), postruminal NDF digestibility linearly increased with greater ruminal starch digestibility, but total tract NDF digestibility was not affected. Replacing dry corn with high-moisture corn lowered ruminal NDF digestibility and shifted so much NDF digestion postruminally that hindgut fermentation of NDF contributed 53% of total tract NDF digestion (Oba and Allen, 2003a). However, total tract digestion of NDF was not different between diets containing dry- or high-moisture corn. This indicates that ruminal starch digestibility can have significant effects on site of fiber digestion without affecting total tract fiber digestibility.

Controversy exists as to the benefits of ruminal vs. postruminal starch digestion. Ruminal starch digestion is needed to provide substrate for microbial growth and propionate as a main glucose precursor for animal production, but can lower ruminal pH and inhibit fiber digestibility if starch fermentation is too rapid. Ruminal starch digestibility ranges from 42 to 96% over a variety of grain sources (Nocek and Tamminga, 1991). Site of starch digestion can be manipulated by grain conservation (Oba and Allen, 2003a), method of processing (Callison et al., 2001), and endosperm type of corn grain (Philippeau et al., 1999). Apparent ruminal digestibility of starch increased from 35 to 57% when vitreous corn grain was replaced by floury endosperm grain (Taylor and Allen, 2005a). This wide range of starch digestibility can affect whether starch is digested primarily in the rumen or intestines. If ruminal starch degradation is too rapid, flux of propionate to the liver might limit DMI if it is oxidized rather than used for gluconeogenesis (Oba and Allen, 2003b). Shifting starch digestion to

the intestines can theoretically provide more glucose to the animal, but infusion experiments have suggested that increasing small intestinal glucose absorption may not increase glucose available for milk production (Knowlton et al., 1998; Areli et al., 2001). Instead, increased glucose may be used for tissue retention (Reynolds et al., 2001).

Greater BWG has been observed in several experiments where BMRCs replaced CCS (Frenchick et al., 1976; Sommerfeldt et al., 1979; Weller and Phipps, 1986), and this effect might occur if BMRCs shifts site of starch digestion to the intestines. Perhaps most striking was the experiment conducted by Block et al. (1981); in the study, feeding cows BMRCs from wk 3 to 10 postpartum increased DMI by 2.2 kg/d, and although milk yield numerically increased, the greatest effects of treatment occurred on BW change. Cows consuming BMRCs gained 10.3 kg over the 8-wk period, whereas cows consuming CCS lost 24.6 kg over the same period. Oba and Allen (1999a) found that, compared with CCS, BMRCs increased energy balance of lactating cows by 2.1 Mcal/d. Greater concentrations of metabolizable energy in BMRCs diets fed ad libitum resulted in more metabolizable energy partitioned toward tissue energy gain rather than milk energy (Tine et al., 2001). In a study by Oba and Allen (2000c), BMRCs increased ruminal propionate and shifted a substantial portion of starch digestion to the intestines; consequently, greater glucose availability in BMRCs diets might increase plasma insulin concentration and tissue energy retention.

Replacing CCS with BMRCs may decrease ruminal starch digestibility. Oba and Allen (2000a,c) reported that BMRCs decreased ruminal starch digestibility by 10%, but increased postruminal starch digestibility by 13%. Another experiment reported that ruminal starch digestibility was 36% lower for BMRCs compared with CCS, but

differences in total tract starch digestibility were small, indicating compensatory postruminal starch digestion (Greenfield et al., 2001). Greater DMI could explain the greater rate of starch passage from the rumen in the study done by Oba and Allen (2000c), but no differences in DMI were observed by Greenfield et al. (2001).

Taylor and Allen (2005a) reported that BMRCS did not affect ruminal starch digestibility when fed with floury or vitreous corn grain endosperm types. The vitreous corn grain fermented more slowly and passed from the rumen faster, resulting in decreased ruminal starch digestibility. However, compensatory postruminal starch digestion resulted in relatively small differences in total tract starch digestion compared with floury endosperm grain. Greater ruminal starch digestion in floury endosperm grain diets compared to vitreous grain (57 vs. 35%) did not affect ruminal fiber digestion kinetics of BMRCS. Furthermore, production response to BMRCS is dependent on grain source, because starch and fiber fermentability can interact to affect feeding patterns and productivity. Feeding floury endosperm grain decreased meal length and size in control silage, but increased meal length and size in BMRCS diets. In addition, total DMI decreased in BMRCS diets containing vitreous corn grain, because BMRCS tended to increase ($P = 0.10$) meal frequency/d compared with CCS (Taylor and Allen, 2005b). Greater starch passage in diets containing BMRCS could be the result of other factors; for example, the ruminal fiber mat formed by BMRCS fiber might be less effective at retaining corn grain particles

Ruminal pH

Rumen pH fluctuates throughout the day and that could have an important effect on the fermentation and digestion in the rumen. After feeding, VFA production increases, resulting in a depression in ruminal pH. As the rate of VFA production decreases and absorption continues in the hours between feeding, the ruminal pH will rise again. The ruminal pH of cattle fed a predominantly forage diet is generally higher, in the range of 6.2-7.0, than those fed diets with greater proportions of concentrates, in the range of 5.5-6.5 (Kolver and de Veth, 2002). Several factors affect changes in ruminal pH (Owens et al., 1998). The type of diet can cause a shift in the pH, with forage rations usually resulting in a pH of greater than 6. Forage (fiber) stimulates a higher rate of saliva production and secretion. Saliva contains bicarbonate, which helps with buffering the rumen environment. The physical form of feed (ground, pelleted or chopped) will affect the size of the feed particles. If the forage particle size is too short, the forage mat necessary in the dorsal rumen cannot be maintained. Fiber digestion will decrease and ruminal pH decreases. Saliva production is also reduced due to less cud chewing time. If concentrates are ground too finely, starch is exposed too rapidly to microbial digestion and increased degradation. The ruminal pH drops, and propionic acid and lactic acid production increases. Steam rolling, pelleting, or grinding will change starch structure, which makes it more available in the rumen for fermentation. The level of feed intake changes the ruminal degradation and synthesis. Rumen pH can drop as more substrate, such as starch, becomes available for microbial use, thus increasing acid production. The amount of saliva produced per unit of DM can also decline with a drop in DMI. Wet

rations can reduce ruminal pH due to less saliva production and rumination time. If the wet feed is silage, less chewing is needed to reduce particle size, lowering rumination time. If the total ration moisture exceeds 50% due to ensiled and fermented feeds, DMI can be reduced. The method of feeding may change the rumen environment. Total mixed rations, for example, may stabilize the ruminal pH more than feeding concentrate and roughage separately by minimizing the feed particle selection, synchronizing degradable protein and fermentable carbohydrate availability and increasing the DMI.

The effect of ruminal pH on digestion has been widely studied. Grant and Mertens (1992) found that the rate of fiber digestion is negatively affected by pH when it is below 6.2. Results of Yang et al. (2002) agree with this finding but stated that activity of cellulolytic bacteria in particular is depressed when ruminal pH falls below a pH of 6.2. Ørskov and Ryle (1990) stated that the reason for this depression in fiber digestion is a result of decreased multiplication of cellulolytic bacteria as well as inhibition of the process of cellulolysis itself. The inhibition of the process of cellulolysis is attributed to the sensitivity of cellulase to low pH (Stewart, 1977). Under pH of 6.0 cellulolysis and cellulolytic bacteria multiplication are slowed and below pH of 5.6 these processes are halted altogether (Ørskov and Ryle, 1990). Many amylolytic bacteria, such as *Streptococcus bovis* have optimal pH ranges that are lower than those of their fiber-digesting counterparts (Ørskov and Ryle, 1990). It has also been shown that depression of total VFA production correlates with a low ruminal pH (Yang et al., 2002).

Some studies reported a decrease in ruminal pH when cows were fed BMRCs-based diets (Greenfield et al., 2001; Oba and Allen, 2000b; Taylor and Allen, 2005c; Gehman et al., 2008). This may have been caused by the increased supply of fermentable substrate in

the rumen due to enhanced NDF digestibility of BMRCS (Weiss and Wyatt, 2006). Oba and Allen (2000b) observed depressed ruminal pH in cows fed BMRCS compared to those fed CCS (5.68 vs. 5.84), although chewing activity and OM truly fermented in the rumen were similar between the treatments. Similarly, Frenchick et al. (1976), Block et al. (1981), and Greenfield et al. (2001) observed lower ruminal pH for BMRCS compared with CCS by 0.11, 0.18, and 0.52 pH units, respectively. In an attempt to explain ruminal pH differences by salivary buffering capacity without measuring saliva flow to the rumen directly, Oba and Allen (2000b) measured chewing activity and OM truly fermented in the rumen. In their study, no explanation for the depressed ruminal pH was evident. The authors speculated that factors other than chewing time, which may affect rate of absorption and passage along with the neutralization of fermentation acids, may explain the decreased ruminal pH with the BMRCS diet (Oba and Allen, 2000b). Taylor and Allen (2005c) found that lower ruminal pH for BMRCS compared with CCS (5.99 vs. 6.22) corresponded with a 3.5 mM greater total VFA concentration, suggesting that BMRCS lowered ruminal pH by increasing total VFA concentration.

VFA Profiles

Volatile fatty acids, principally acetate, propionate, and butyrate but also lesser amounts of valerate, caproate, isobutyrate, isovalerate, 2-methylbutyrate, and traces of various higher acids, are produced in the rumen as end-products of microbial fermentation (Figure 3). During the fermentation process, energy is conserved in the form of ATP and subsequently utilized for the maintenance and growth of the microbial population. As far as the microbes are concerned, the VFA are waste products, but to the

host animal they represent the major source of absorbed energy and with most diets account for approximately 80% of the energy disappearing in the rumen (the remainder being lost as heat and methane) and for 50-70% of the digestible energy intake in sheep and cattle at approximately maintenance.

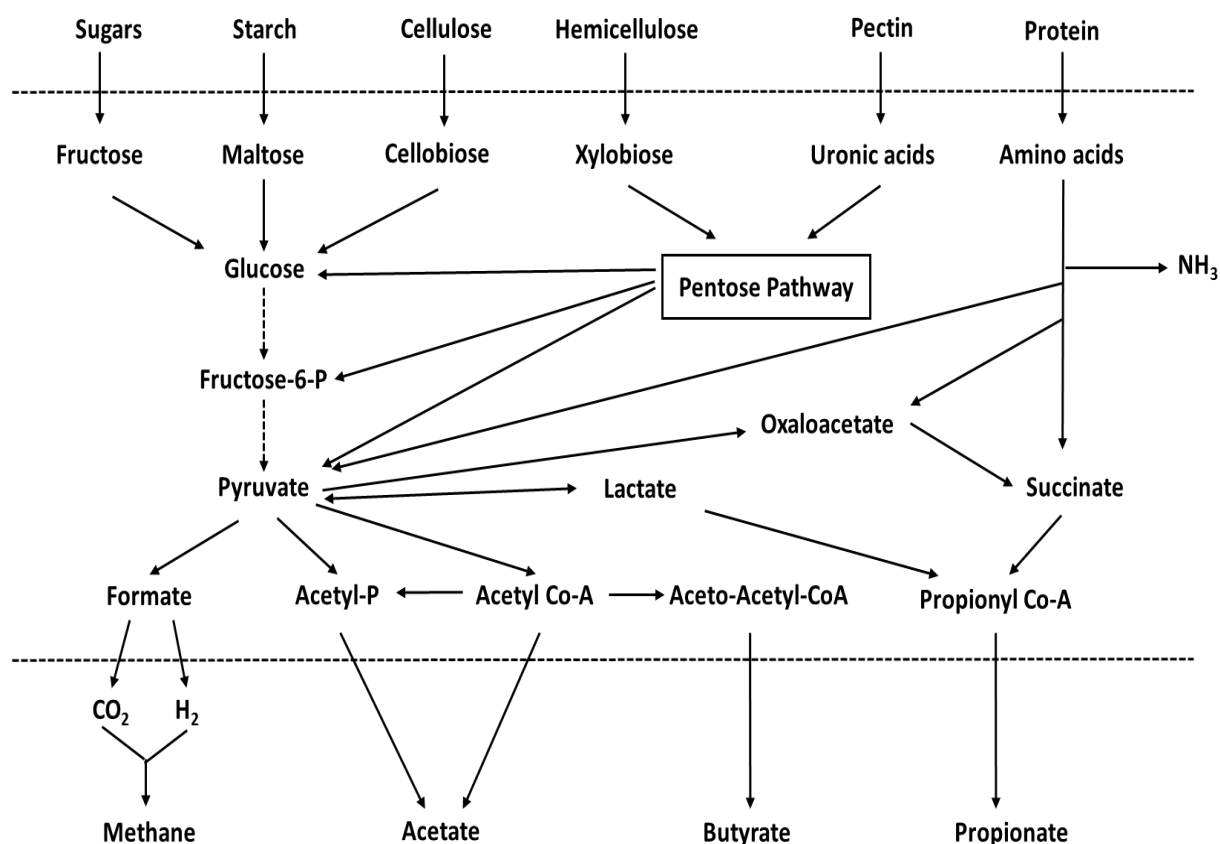


Figure 3. Fermentation of carbohydrates in the rumen (adapted from RAGFAR, 2007).

Dietary carbohydrates (i.e., cellulose, hemicellulose, pectin, starch, and soluble sugars) are the main fermentable substrates. They are degraded to their constituent hexoses and pentoses before being fermented to VFA via pyruvate (Figure 3). Pentoses are converted to hexose and triose phosphate by the transketolase and transaldolase

reactions of the pentose cycle so that the majority of dietary carbohydrate metabolism proceeds via hexose, which is metabolized to pyruvate almost exclusively by the Embden-Meyerhof glycolytic pathway. Acetyl-CoA is an intermediate in the formation of both acetate and butyrate from pyruvate, while propionate formation occurs mainly via succinate, although an alternative pathway involving acrylate is also operative. The need to maintain redox balance through reduction and reoxidation of pyridine nucleotides controls fermentation reactions. Excess reducing power generated during the conversion of hexose to acetate or butyrate is utilized in part during their formation of propionate but mainly by conversion to methane (Dijkstra et al., 2005).

In addition to dietary carbohydrates, dietary lipids and proteins also give rise to VFA in the rumen. The contribution from lipids is very small, as lipids normally represent a small proportion of the diet and only the carbohydrate moiety, i.e. glycerol and galactose arising from lipid hydrolysis, and not the long-chain fatty acids, are fermented. Dietary proteins on the other hand may be a significant source of VFA, when diets having a high rumen degradable protein concentration are fed. The proteins are hydrolyzed to amino acids, which are deaminated before conversion to VFA. Of particular importance in this respect is the formation of isobutyric, isovaleric, and 2-methylbutyric acids from valine, leucine, and isoleucine, respectively, as these branched-chain VFA are essential growth factors for certain rumen bacterial species (Cotta and Hespell, 1986).

The majority of VFA produced in the rumen are lost by absorption across the rumen wall, although a proportion (10-20% in sheep and up to 35% in dairy cattle) pass to the omasum and abomasum and are absorbed from these organs. Absorption across the rumen wall is by simple diffusion of the undissociated acids. It is a concentration-

dependent process and therefore (of the three major VFA) usually higher for acetate than for propionate and lowest for butyrate, but per unit of concentration the absorption rates of the three acids are quite similar, although at low pH VFA with a higher carbon chain have a higher fractional absorption rate due to their greater lipid solubility (Dijkstra, 1994). As the pK_a values of the acids are lower than the pH of rumen contents, they exist largely in the anionic form. A fall in ruminal pH is associated with an increase in the proportion in the undissociated form and therefore in the rate of absorption. During passage across the rumen wall, the VFA are metabolized to varying extents so that the amounts entering the bloodstream are less than the quantities absorbed from the rumen. However, some results in which VFA absorption from the temporarily isolated and washed rumen was compared with the portal VFA absorption indicate that the rumen wall does not metabolize large amounts of acetate, propionate, and isobutyrate absorbed from the rumen, although the extensive metabolism of butyric acid during absorption was confirmed (Kristensen et al., 2000).

The concentration of VFA in the rumen at any given time reflects the balance between the rate of production and rate of loss. Immediately after feeding, production exceeds loss and the concentration increases, but subsequently the situation is reversed, and the concentration falls. The total VFA concentration may fall as low as 30 mM or be in excess of 200 mM but is normally between 70 and 130 mM. The relative concentration of the individual acids, commonly referred to as the fermentation pattern, is a reliable index of the relative production rates of the acids when forage diets are given but would appear less reliable with concentrate diets.

The fermentation pattern is determined by the composition of the microbial population, which in turn is largely determined by the basal diet, particularly the type of dietary carbohydrate, and by the rate of depolymerization of available substrate (Dijkstra, 1994). High-fiber forage diets encourage the growth of acetate-producing bacterial species and the acetate:propionate:butyrate molar proportions would typically be in the region of 70:20:10, whereas starch-rich concentrate diets favor the development of propionate-producing bacterial species and are associated with an increase in the proportion of propionate at the expense of acetate, although acetate is almost always the most abundant of the acids. Under certain condition, concentrate diets may encourage the development of a large protozoal population, and this is accompanied by an increase in butyrate rather than propionate (Williams and Coleman, 1997). If levels of substrate available for fermentation are high, either from increase intake or increased rates of depolymerization, a shift in fermentation pattern from acetic acid to propionic acid occurs to dispose of excess reducing power (Dijkstra, 1994).

Within the host animal's tissues, absorbed acetate and butyrate are used primarily as energy sources through oxidation via the citric acid cycle. Acetate is also the principal substrate for lipogenesis, whereas propionate is used largely for gluconeogenesis and with most diets is the major source of glucose, since net absorption of glucose from the intestinal tract is usually small in ruminants. The balance between the supply of the glucogenic propionate relative to that of the non-gluconenic acetate and butyrate influences the efficiency with which the VFA are used for productive purposes. Thus, not only the total supply of VFA but also the molar proportions are important determinations of feed utilization by ruminants and as such a number of methods have been used to

estimate the rates of individual and total VFA production in and removal from the rumen (Dijkstra et al., 2005).

The proportions of the dominant VFA produced in the rumen vary with diets, microbial growth rates, levels of feeding, and ruminal pH (López et al., 2000). High-forage diets result in the production of greater amounts of acetate and butyrate, while high starch diets result in the production of greater proportions of propionate, although acetate is still the dominant VFA (Beever and Mould, 2000). Propionate is converted to glucose in the liver. Acetate is mostly unchanged by the liver and supplies the main source of energy by either being oxidized to ATP or stored in long-chain fatty acids.

Acetate and butyrate are the significant contributors to long-chain fatty acid production for tissue deposition or secretion into milk. Conditions that inhibit methanogenesis decrease the acetate:propionate ratio, while conditions that favor methanogenesis favor acetate production and increase energy losses to methane (Ørskov and Ryle, 1990). Increasing propionate as a proportion of VFA absorbed may cause a signal to terminate meals, because propionate flux to the liver may increase greatly during meals (Benson et al., 2002), and is rapidly metabolized in the liver (Reynolds, 1995) which can stimulate hepatic oxidation. Allen et al. (2009) reported that VFA rapidly produced and absorbed during meals are likely responsible for stimulating satiety in ruminants.

Block et al. (1981) observed an increase in molar proportion of propionate and a decrease in acetate in cows fed BMRCs. Ruminal propionate and butyrate were greater, and ruminal pH, acetate, and acetate-to-propionate ratio were lower in cows fed BMRCs. The higher ruminal propionate and lower acetate-to-propionate ratio in cows fed BMRCs

is consistent with the metabolic shift of nutrients toward body flesh and may be related to the increased BWG by cows fed the BMRCs ration.

Economic Value of BMRCs in Cattle Diets

Factors Affecting Cattle Feeding Profitability and Cost of Gain

Within the beef production system, there are three distinct operations: cow-calf, stocker, and finishing. A sufficient amount of research has emphasized the importance of the cow-calf and finishing operations and their major roles on profitability of production. However, little consideration is given to the stocker phase, which frequently is combined with the finishing phase. Stocker cattle represent an economically viable enterprise characterized by inexpensive weight gain compared with the cow-calf and finishing phases of production (Peel, 2003). Stocker cattle provide both production and marketing value (Peel, 2003). Through the stocker period, production value is added through additional weight gain and upgrading quality of cattle through the transformation of calves from the cow-calf sector into stocker cattle as demanded by the feedlots (Peel, 2011). Marketing value comes in the form of time and place utility; through the assembly of calves from widely dispersed, small to larger cow-calf operations into uniformed lots of stocker cattle (Peel, 2011). The complexity of the stocker phase has given reason for meaningful research concerning the economic components of the stocker phase (Schroeder et al., 1993).

Nelson and Purcell (1973) examined the relationships of cost and revenue between two groups of steers and concluded that marginal cost per pound of muscle declined when cattle were slaughtered at lighter weights. While examining tradeoffs among

alternative cattle feeding objectives, Melton et al. (1978) concluded that the profit per head was maximized by minimizing total feed cost. Schroeder et al. (1993) examined the relative contributions of input and output prices, cattle performance, and interest rates to cattle feeding profit variability and the contributions of corn prices and cattle performance to feed cost of gain. In conclusion, Schroeder et al. (1993) reported that cattle prices explained approximately 65 to 80% of profit variability. The authors further noted that cattle price had a tendency to be a more important profit determinant for heavy weight cattle, while corn prices had a more significant determinant with lighter weight cattle (Schroeder et al., 1993). In addition, the authors observed that feed conversion and corn price explained 90% of the variability in feed cost of gain (Schroeder et al., 1993). The study explained that placing lightweight cattle in a feedlot should emphasize concern on cattle prices due to the duration of time steers spend in the feedlot (Schroeder et al., 1993). The authors stated, when placing lightweight steers, feed prices should be taken under consideration because of the greater amount of feed needed. With a negative relationship between corn prices and lightweight steers alternative feeds are becoming more attractive, and are more readily utilized in stocker rations. Heavier steers placed on feed are more desirable because of the importance of feed efficiency on cost of gain (Schroeder et al., 1993). Lightweight steers put right into a feedlot will occur more days on feed as well as more variation in fed cattle prices; where conversely heavier steers being more constrained by purchase price than by corn prices, feed efficiency, and fed cattle price (Schroeder et al., 1993; Duncan et al., 1997; Peel, 2000). Therefore, assuming that, 1,200 calves were fed for a 50 d-period with the ability to have seven groups in a year with a total of 8,400 stocker steers, and corn prices at \$2.50 per bushel and fed cattle

prices at \$70 hundredweight (**cwt**), the returns for stocker steers would be \$87.95 per head or \$86,980 per year (Duncan et al., 1997). This example shows the importance of quickly obtaining number turns of cattle to reduce the charge per head to fixed costs (Duncan et al., 1997).

Feed margins are important in showing the breakeven price in order to make a profit. The two major contributors to feed margins are beginning and ending steer values. These two factors indicate how much a stocker ration can cost. With higher feed prices, heavier steer placement is dominant in the feedlot (Schroeder et al., 1993). Placing heavier steers in feedlots indicates that steers must be in a growing operation longer, which brings up elements that can either decrease feeding margins or increase it. Feed margins can be decreased by the fluctuation of heavier feeder steer prices. Earlier studies have shown that as feeder steers become heavier feeder prices decrease (Schroeder et al., 1993; Peel, 2000). Therefore using forages can decrease feed cost as well mitigate the high purchase price. Depending upon steer numbers entering the feedlot during times of shortages, feeder cattle prices have been shown to increase as well in times of high feed prices especially corn prices. During this period, feedlots strive to increase profits by shortening the time on feed through the purchase of heavier steers (Schroeder et al., 1993; Peel, 2000).

As an integral part of knowing what can be spent on feed the beginning value will help determine the feed margin. With cattle prices being higher for lighter weight steers feeding quality forages has been observed to increase animal performance including rate of gain while decreasing feed cost (Keith et al., 1981; McEwen et al., 1996; Peel, 2000). The proportion of the growing cattle price contributing to the variation in profitability

increases as initial BW increases entering the feedlot (Koknaroglu et al., 2005). While looking at cattle according to size of group, Koknaroglu et al. (2005) observed that as numbers of cattle increase per pen, feeder cattle price increased because initial BW decreased. Feeder cattle prices are difficult to predict due to the constantly changing demand for slaughter cattle attributed to changing feed prices and shifting demand in both domestic and international markets (Johnson et al., 2008). Therefore, an important factor affecting growing profitability is the relationship between purchase and selling price (Peel, 2000). In general as cattle prices trend up, the spread between buying and selling prices widens because prices for light-weight animals increase faster than prices of heavier animals, resulting in variation of stocker value of gain that not only change the general profitability of stockers, but also change the relative attractiveness of different classes of stocker cattle (Peel, 2000). The author showed that the long run value of gain averaged \$1.10/kg for typical stocker situations and varied from \$1.10 to \$1.43/kg for a wide range of stocker cattle enterprises.

The value of gain for stocker cattle varies dramatically over time and between different classes of cattle (Peel, 2000). Peel (2000) stated that another important factor affecting stocker profitability is the length of time for the enterprise. With the high initial costs and low variable costs, the breakeven selling price for cattle declines relatively fast with additional time.

Production and feeding efficiency is increased with larger, more uniformed lots of cattle; a premium is often paid when purchased cattle are pooled into uniformed lots (Avent et al., 2005). Schroeder et al. (1988) found feeder cattle transaction price differentials tended to significantly differ between uniformed and mixed cattle lots.

Historically feeder cattle prices are lower than those of calf prices but because of the use of quality forages and increased weight gain, the ending value of stocker cattle can be greatly increased (Duncan et al., 1997; Peel, 2000).

The stocker enterprise is in essence a margin business with highly variable input and output prices, primarily reflected in stocker calf purchasing prices and stocker cattle market fluctuations (Johnson et al., 2008). Fed and stocker cattle price differences are the most important net return determinants (Schroeder et al., 1993). Magnitudes of the coefficients of variation on fed and stocker cattle generally declined relative to those estimated over the long run. Feed conversion and ADG come to be important net return determinants in the short run explaining 11 to 21% of return variability (Schroeder et al., 1993). Therefore, animal performance has an influence on net return when looking at short-term profitability.

Economic Benefits of BMRCS

The decision to use a silage specific hybrid on growing beef steers is complex. There is a wide range of differences in yield, fiber concentration, digestibility, and NDF digestibility among hybrids (Lauer et al., 2000; Thelen et al., 2000), with BMRCS yielding 10.4% lower than CCS (Eastridge, 1999), but having much higher NDF digestibility. This lower yield in conjunction with the high price of the seed has limited the adoption of these hybrids. However, BMRCS has superior fiber digestibility, which can lead to increases in animal performance and economic benefits.

Min et al. (2007) indicated that feeding dairy cows high digestible NDF forage such as BMRCS with less grain was more economical than the diets having a higher ratio of

alfalfa silage to BMRCS. Even feeding BMRCS was more profitable in terms of feed cost per kilogram milk than feeding more alfalfa silage at the same ration fiber level (33% NDF diet). Keith et al. (1981) observed improvements in ADG of steers fed BMRCS compared with isogenic normal silage but did not observe differences in feed conversion. When steers were fed a 92% corn silage diet containing BMRCS compared with diets using a variety of commercial hybrids, ADG was increased (McEwen et al., 1996). McEwen et al. (1996) also reported that feeding a BMRCS diet resulted in increased feed efficiency compared with diets containing CS from commercial hybrids. Tjardes et al. (2000) reported that feeding BMRCS in growth-phase diets resulted in increased daily DMI and improved digestibility of DM and fiber, but did not result in improved animal performance compared with CCS. The economic benefits of the BMCS are maximized when this silage is stored separately, and the ration is carefully balanced to take advantage of the increased fiber digestibility.

MATERIALS AND METHODS

The beef steers used in this study were cared for according to the Live Animal Use in Research Guidelines of the Institutional Animal Care and Use Committee at Utah State University, Logan.

Animals, Experimental Design, and Diets

A feedlot experiment was conducted at the Animal Science Farm at Utah State University, from October, 2012 to January, 2013. Twenty-four Angus crossbred steers (258 ± 23.2 kg) were randomly assigned into one of 2 dietary treatments: CCS-based TMR (**CCST**) and BMR-based TMR (**BMRT**). The 2 treatments were assigned to 12 steers each housed in individual pens ($5.2 \text{ m} \times 2.4 \text{ m}$) in a completely randomized design, resulting in 12 replications per treatment. The steers were adapted to experimental setup in their pens for 2 wk and were fed the CCST during the adaptation period. The steers were fed the treatment diet for the duration of 84d period. The CCST contained 15.4% alfalfa hay, 48.1% CCS, 31.7% barley grain, and 5.3% feedlot supplement, whereas the BMRT consisted of 16.0% alfalfa hay, 49.0% BMR, 30.0% barley grain, and 5.0% feedlot supplement on a DM basis (Table 2). The 2 dietary treatments had similar concentrations of CP, NDF, and ADF.

Table 2. Ingredients and chemical composition of growing beef steer diets (n = 3)

Item	Diet ¹	
	CCST	BMRT
Ingredient, % DM		
Conventional corn silage	48.1	-
Brown midrib corn silage	-	49.0
Alfalfa hay, chopped	15.4	16.0
Barley grain, dry rolled	31.7	30.0
Feedlot supplement ²	5.3	5.0
Chemical composition, % DM		
DM, %	49.7 ± 0.67	50.0 ± 0.50
OM	91.5 ± 1.82	91.8 ± 1.09
CP	10.2 ± 0.25	10.6 ± 0.31
NDF	34.8 ± 2.92	32.7 ± 2.09
ADF	17.8 ± 2.09	17.1 ± 1.03
Starch	28.0 ± 2.60	27.7 ± 2.30
Ether extract	2.74 ± 0.31	2.50 ± 0.29
Ca	0.81 ± 0.05	0.79 ± 0.16
P	0.30 ± 0.03	0.27 ± 0.04

¹CCST = conventional corn silage-based TMR; BMRT = brown midrib corn silage-based TMR.

²Composition: 5.0% NaCl, 0.24% Mg, 0.76% K, 200 ppm Cu, 400 ppm Mn, 650 ppm Zn, 2 ppm Se, 22 ppm I, 9 ppm Co, 121,000 IU/kg Vitamin A, 37,400 IU/kg Vitamin D, 55 IU/kg vitamin E, and 360 ppm Rumensin[®] (Elanco Animal Health, Indianapolis, IN).

All steers were fed once per day, and each feed bunk was assessed each afternoon prior to the morning feeding. This was used to determine the amount of feed that needed to be delivered to each pen the following day. The steers were fed a TMR for ad libitum intake with at least 10% of daily feed refusal and had ad libitum access to fresh water. All steers were weighed twice every 4 wk to determine BW.

Two corn silage hybrids, conventional (Pioneer 9714; Pioneer Hi-breed International, Inc., Johnston, IA) and BMR (Mycogen Seeds, Indianapolis, IN) were planted in spring 2011. Corn silages were harvested at approximately 30% whole plant DM using a pull-type harvester (Model FP230, New Holland, PA) equipped with a mechanical processor,

and treated with a silage inoculant (Silage PT[®], Nurturite, Twin Falls, ID) at a rate of 112 g/t of fresh forage to enhance *Lactobacillus* fermentation. Silage hybrids were placed in bag silos (Ag/Bag International Ltd., Warrenton, OR) and ensiled for 120 d. Alfalfa was preserved as sun-cured hay and processed for approximately 15 min in a TMR wagon (model 455, Roto-Mix, Dodge City, KS). The alfalfa hay contained 20.6% CP and 39.9% NDF (Table 3).

Table 3. Chemical composition of forages in growing beef steer diets

Item	Forage ¹		
	CCS	BMRCS	AH
Chemical composition, % DM			
DM, %	31.0	36.5	93.6
NDF	38.1	33.9	39.9
ADF	20.1	18.2	27.8
CP	6.9	6.5	20.6
Ether extract	1.6	2.4	1.8

¹CCS = conventional corn silage; BMR = brown midrib corn silage; AH = alfalfa hay

Sampling, Data Collection, and Chemical Analyses

Samples of the TMR fed and orts for individual steers were collected weekly, dried at 60°C for 48 h, ground to pass a 1-mm screen (standard model 4; Arthur H. Thomas Co., Swedesboro, NJ), and stored for subsequent analyses. Contents of DM of the samples were used to calculate DMI. Analytical DM concentration of samples was determined by oven drying at 135°C for 3 h; OM was determined by ashing, and N concentration was determined using an elemental analyzer (Flash 2000 N/Protein Analyzer, Thermo Scientific, Cambridge, UK) (AOAC, 2000). The NDF and ADF concentrations were sequentially determined using an ANKOM^{200/220} Fiber Analyzer (ANKOM Technology,

Macedon, NY) according to the methodology supplied by the company. Sodium sulfite was used in the procedure for NDF determination and pre-treatment with heat stable amylase (Type XI-A from *Bacillus subtilis*; Sigma-Aldrich Corporation, St. Louis, MO)

Ruminal Fermentation Profiles

Ruminal fluid samples were obtained using an oral stomach tube (Geishauser, 1993) 3 h after morning feeding on wk 4, 8, and 12. The pH of the ruminal fluid was measured within 5 min of collecting the samples using a portable pH meter (Oakton pH6; Oakton Instruments, Vernon Hills, IL). VFAs were analyzed using 5 mL of ruminal fluid that was frozen and stored at -40°C . Ruminal VFA were separated and quantified using a GLC (model 6890 series II; Hewlett-Packard Co., Avondale, PA) with a capillary column (30 m \times 0.32 mm i.d., 1- μm phase thickness, Zebron ZB-FAAP; Phenomenex Inc., Torrance, CA) and flame-ionized detection. The oven temperature was held at 170°C for 4 min, increased to 185°C at a rate of $5^{\circ}\text{C}/\text{min}$, then increased by $3^{\circ}\text{C}/\text{min}$ to 220°C , and held at this temperature for 1 min. The injector and the detector temperatures were 225°C and 250°C , respectively, and the carrier gas was helium (Eun and Beauchemin, 2007).

Economic Analysis

For the economic analysis, all feedstuff prices were based on Utah Agricultural Statistics Service (2014). All feedstuff prices were calculated as a $\$/\text{kg DM}$. Beginning and ending feeder cattle prices were based on current prices in UT provided by USDA-Agricultural Marketing Service (2014) for 226.80-272.16 kg [$\$209.00$ per hundredweight

(cwt)] and 362.87-408.23 kg (\$187.97/cwt) steers, respectively. Yardage was included at \$0.28/d/steer to account for feeding and checking animals and watering daily. Health and processing (vaccination and implant administration) fee was charged over the feeding period at \$13.00/steer. Death loss of 1% was assigned based on initial steer cost. Interest rate at 5% was applied based on initial steer cost divided by 365 d. Feed cost/kg of BW gain was calculated by total feed cost divided by $ADG \times \text{days on feed}$. Total cost/kg of BW gain was calculated: $(\text{total feed cost} + \text{total non-feed cost}) \div (ADG \times \text{days on feed})$. Calculating the total non-feed cost is the sum of yardage, health and processing fee, death loss, and interest. Total feed cost was calculated by the sum of each feedstuff based on average DMI of steers for the total feeding period. Feeding margin was calculated by the difference of the beginning and the ending value of steers. The beginning value was calculated by multiplying the beginning BW and the beginning price of steers (\$/cwt). The ending value was calculated by multiplying the ending BW and the ending price of steers (\$/cwt). The net return (\$/steer) was calculated by the difference between feed margin, total feed cost, and total non-feed cost.

Statistical Analysis

All data in this study were analyzed using the MIXED procedure of SAS (SAS Institute, 2011). Animal was an experimental unit with monthly data collection periods as repeated measures of treatments. Data were analyzed using the following model: $Y_{ijk} = \mu + T_i + P_j(T)_i + M_k + TM_{ik} + \varepsilon_{ijk}$ where, μ = overall mean, T_i = fixed effect of dietary treatment i , $P_j(T)_i$ = random effect of animal j within dietary treatment i , M_k = effect of sampling month k , TM_{ik} = interaction between dietary treatment i and sampling month k ,

and ε_{ijk} = residual error. Because interactions were lacking in all cases, data were reanalyzed using a model that included treatment as a fixed effect and the random effect of animal, with months as repeated measures of the treatments. Simple, autoregressive one, and compound symmetry covariance structures were used in the analysis depending on low values for the Akaike's information criteria and Schwartz's Bayesian criterion. Economic treatments were analyzed using a model that included treatment as a fixed effect and the random effect of animal. Significant effects of the treatment were declared if $P < 0.05$, and trends were accepted if $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Growth Performance and DMI

Steers fed the CCST and the BMRT had similar initial and final BW (Table 3). Dietary treatments did not affect BW change. Intake of DM was similar between the treatments, whereas steers fed the BMRT tended to increase ADG (1.54 vs. 1.42 kg/d; $P = 0.09$) and G:F (0.165 vs. 0.146; $P = 0.07$) compared to those fed the CCST. Contrary to our results, Keith et al. (1981) observed an increase in DMI (0.47 kg/d) with steers fed BMR. Tjardes et al. (2000) also observed an increase in DMI (0.43 kg/d) when feeding BMR, but G:F decreased (0.135 vs. 0.145) with no effect on ADG (1.02 vs. 1.01 kg/d) compared when steers were fed with CCS. Similarly, Holt et al. (2013a) reported increased DMI and milk yield by dairy cows fed BMR-based diet compared with CCS-based diet with no effect on propionate. Retention of digesta in the rumen functions to supply a more consistent flow of nutrients to the small intestine, but physical fill of the gastrointestinal tract can limit feed intake when high-forage diets are fed (Holt et al., 2013a). Oba and Allen (1999b) stated that ruminal fill was more limiting to intake for higher yielding cows, and thus increasing NDF digestibility of forage by feeding the BMRT might increase DMI to a greater extent in rapidly growing beef steers. Thus, we expected increased DMI for steers offered the BMRT than those fed the CCST, and the no effect of feeding the BMRT on DMI could be attributed to increased proportion of propionate for the BMRT than for the CCST, which will be discussed more in detail later on the ruminal fermentation profiles in this paper. Propionate has been reported to induce hypophagia (Allen, 2000), so decreasing propionate production and absorption will likely

increase meal size and possibly feed intake (Allen et al., 2009). Tendencies to increase in ADG and G:F with a similar DMI due to feeding the BMRT observed in the current study imply improved nutrient utilization to support growth of growing steers. Chamberlain et al. (1971) observed an increase in ADG (0.83 vs. 0.71 kg/d) and G:F (0.160 vs. 0.134) when beef heifers were fed with late-milk stage of corn silage compared with mealy-endosperm stage of corn silage with similar DMI (5.2 vs. 5.3 kg/d). Similarly, Weller and Phipps (1986) reported that dairy calves fed with BMR increased ADG compared to those fed with CCS (0.92 vs. 0.83 kg/d) with a similar DMI. In the both studies (Chamberlain et al., 1971; Weller and Phipps, 1986), improved nutrient utilization of corn silage led to improved ADG as well as G:F.

Table 4. Growth performance of growing beef steers fed with different corn silage hybrids

Item	Treatment ¹		SEM	P
	CCST	BMRT		
BW				
Initial, kg	261	253	6.7	0.44
Final, kg	380	383	9.1	0.85
Change, kg	119	129	4.3	0.12
ADG, kg/d	1.42	1.54	0.052	0.09
DMI, kg/d	9.72	9.35	0.296	0.38
G:F	0.146	0.165	0.0041	0.07

¹CCST = conventional corn silage-based TMR; BMRT = brown midrib corn silage-based TMR.

Ruminal Fermentation Characteristics

Feeding the BMRT decreased ruminal pH compared with the CCST (6.42 vs. 6.67; Table 4). However, feeding the BMRT would not interfere with ruminal fermentation, as average ruminal pH of the BMRT was 6.42. Total VFA concentration increased due to

feeding the BMRT compared with the CCST (89.7 vs. 80.8 mM). Some studies reported a decrease in ruminal pH when BMR was fed (Oba and Allen, 2000a; Taylor and Allen, 2005b; Gehman et al., 2008). This may have been caused by the increased supply of fermentable substrate in the rumen due to enhanced NDF digestibility of BMR (Weiss and Wyatt, 2006).

Table 5. Ruminal fermentation profiles of growing beef steers fed with different corn silage hybrids

Item	Treatment ¹		SEM	P
	CCST	BMRT		
Ruminal pH	6.67	6.42	0.034	< 0.01
Total VFA, mM	80.8	89.7	2.17	0.01
Individual VFA ²				
Acetate (A)	64.9	60.5	0.69	< 0.01
Propionate (P)	18.7	21.8	0.70	0.01
Butyrate	9.52	12.3	0.37	< 0.01
Valerate	1.49	1.44	0.046	0.44
Isobutyrate	1.07	1.05	0.063	0.86
Isovalerate	2.22	1.44	0.121	< 0.01
A:P	3.39	2.75	0.136	< 0.01

¹CCST = conventional corn silage-based TMR; BMRT = brown midrib corn silage-based TMR.

²Individual VFA expressed as mol/100 mol.

Feeding the BMRT decreased molar proportion of acetate, but increased propionate proportion, resulting in decreased acetate-to-propionate ratio compared with the CCST (2.75 vs. 3.39; Table 4). In addition, feeding the BMRT increased molar proportion of butyrate compared with the CCST. In the current study, feeding the BMRT increased total VFA concentration, and favorably shifted ruminal fermentation pathway by increasing propionate proportion but decreasing acetate proportion. Besides increasing concentration of total VFA, increasing propionate as a proportion of VFA may cause a

signal to terminate meals, because propionate flux to the liver may increase greatly during meals (Benson et al., 2002) and is rapidly metabolized in the liver (Reynolds, 1995), which may down-regulate feed intake (Allen et al., 2009). Increased VFA concentration due to feeding the BMRT in this study suggests enhanced ruminal fermentability by feeding BMR and can support increased energy supply for growth. In addition, increase in propionate and decrease in acetate corresponded to improvements in fiber digestion of corn silage (Eun and Beauchemin, 2007). It is not uncommon to observe changes in VFA proportions as a direct effect of enhanced fiber digestion in the rumen, implying that feeding BMR may affect microbial growth, shift the metabolic pathways by which specific microbes utilize substrates, or both. Propionate is quantitatively the most important VFA precursor of glucose synthesis, and therefore has a major impact on hormonal release and tissue distribution of nutrients (Nagaraja et al., 1997). Consequently, increased VFA concentration and propionate proportion as a result of feeding BMR would contribute to improving nutrient supply and utilization, which may have resulted in increases in ADG and G:F observed in the current study. Therefore, responses to feeding BMR may be greatest in situations where fiber digestion and fermentation are major contributors to net energy supply, which is often the case for growing beef steers. Additionally, it would be more beneficial to induce a direct effect of feeding BMR on increased ruminal fermentability when it is fed at a relatively greater dietary concentration likely tested in the current study.

Economic Analysis

Feed cost based on BW gain was less for the BMRT than the CCST (Table 5) due to similar DMI between the 2 treatments but increased ADG by feeding the BMRT. While total feed and non-feed costs were similar, total cost for BW gain was less for the BMRT compared with the CCST (1.72 vs. 1.93 \$/kg BW gain). Beginning and ending values of steers did not differ between treatments. Steers fed the BMRT increased feed margin (\$415.7 vs. \$372.0) as well as net return (\$195.2 vs. 143.8 per steer) compared to those fed the CCST throughout the trial. These steers were fed during the same time to eliminate differences in cattle or feed prices due to market impacts. Therefore, the differences in net return per steer are a direct result of differences in ADG and feed intake. The difference of over \$50 per head is not only statistically significant, but is also economically important. Feeding BMRT compared to CCST increased returns by 36%. If it is considered at even a relatively small feedlot, for instance feeding 1,000 head of steers, total returns to the operation would increase by over \$50,000 by feeding BMRT compared with CCST.

Table 6. Economic analysis of growing beef steers fed with different corn silage hybrids

Item	Treatment ¹		SEM	<i>P</i>
	CCST	BMRT		
Feed cost, \$/kg BW gain	1.40	1.25	0.0448	0.03
Total feed cost, ² \$	165.8	160.2	5.03	0.44
Total non-feed cost, ³ \$	62.4	59.8	1.47	0.22
Total cost, ⁴ \$/kg BW gain	1.93	1.72	0.056	0.01
Beginning value of steers, ⁵ \$	1201	1167	31.1	0.44
Ending value of steers, ⁶ \$	1573	1582	37.8	0.87
Feed margin, ⁷ \$	372.0	415.7	17.48	0.09
Net return, ⁸ \$/steer	143.8	195.2	15.42	0.03

¹CCST = conventional corn silage-based TMR; BMRT = brown midrib corn silage-based TMR.

²Total feed cost = total kg of individual feedstuff × individual feedstuff price, \$/kg throughout experiment.

³Total non-feed cost = veterinary and medical costs + yardage + interest at 5%.

⁴Total cost = total feed cost + total non-feed cost.

⁵\$209.0 per cwt.

⁶\$188.0/cwt.

⁷Feed margin = beginning value of steers – ending value of steers.

⁸Net return = feed margin – (total feed cost + total non-feed cost).

CONCLUSIONS

Forage quality affects feed intake and energy density and growth performance of growing beef steers. In addition, recent increase in grain price has been unprecedented, making forage quality of paramount importance for reducing purchased feed costs and improving economic returns on beef operation. The current study was focused on a linkage between enhanced ruminal fermentability and improved growth and economic performance of growing beef steers fed with BMR. Overall results reported in this study indicate that feeding BMR silage in a growing beef steer diet with a relative greater dietary concentration can have beneficial effects to increase ruminal fermentation with a favorable shift in fermentation pathways, resulting in greater ADG, G:F, feed margin, and net return compared with CCS. However, increase in propionate may have interfered with a potential benefit of feeding BMR to increase feed intake of growing beef steers. As improving feed efficiency of beef steers is a primary means to achieve sustainable cattle production so as to enhance farm profitability, more animal experiments are needed to investigate how the increased growth performance of beef steers fed with BMR-based growing diet can take advantage to further improve growth performance of finishing beef steers.

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APPENDIX

Table A1. Growth performance of growing beef steers fed with different corn silage hybrids according to week

Item	Treatment ¹		SEM	<i>P</i>
	CCST	BMRT		
Week 1-4				
BW				
Initial, kg	261	253	6.7	0.44
Final, kg	295	293	7.2	0.87
Change, kg	34	40	2.4	0.08
ADG, kg/d	1.21	1.42	0.081	0.08
DMI, kg/d	7.96	9.36	0.435	0.03
G:F	0.153	0.154	0.0079	0.95
Week 5-8				
BW				
Initial, kg	295	293	7.2	0.87
Final, kg	331	334	8.3	0.79
Change, kg	36	41	2.0	0.10
ADG, kg/d	1.28	1.45	0.071	0.10
DMI, kg/d	9.36	8.88	0.405	0.42
G:F	0.138	0.167	0.0093	0.04
Week 9-12				
BW				
Initial, kg	331	334	8.3	0.79
Final, kg	380	383	9.1	0.85
Change, kg	49	48	3.0	0.87
ADG, kg/d	1.76	1.73	0.102	0.86
DMI, kg/d	10.14	9.44	0.282	0.09
G:F	0.174	0.185	0.0101	0.44

¹CCST = conventional corn silage-based TMR; BMRT = brown midrib corn silage-based TMR.