INTERACTION OF DIETARY ROUGHAGE AND SULFUR CONCENTRATION ON PERFORMANCE OF BEEF CATTLE

and

EFFECTS OF TWO DIETARY CONCENTRATIONS OF LEVUCELL SC IN GROWING OR FINISHING FEEDLOT DIETS

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ABSTRACT

Two experiments were conducted to determine the interaction of dietary roughage and sulfur concentration on performance of beef cattle, and effects of two dietary concentrations of Levucell SC in growing or finishing feedlot diets. In the first experiment, effect of various dietary concentrations of roughage (R) and sulfur (S) on performance of beef cattle fed finishing diets were examined. Results suggest that increasing dietary R concentration increases DMI and decreases feed efficiency while high dietary S concentrations decrease DMI. However, no interactions occurred to suggest that performance may be enhanced by feeding increased R in high-S feedlot diets. In the second experiment, effect of *Saccharomyces cerevisiae* (SC; Levucell SC 20) on growing and finishing steers were examined. Results suggest that using dietary SC concentration may increase DMI in high-forage growing diets. The linear trend for reduced DMI in finishing cattle fed live yeast merits further research to determine effects on feed efficiency.

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INTRODUCTION

Distillers grains are a byproduct of ethanol fuel production. Since the first experiment on the use of distillers grains in cattle in 1907, production and use of this commodity in livestock have grown considerably (Weiss et al., 2007). The production of distillers grains was close to a million tonnes in 1998 and was expected to increase to near 27 million tonnes by 2020 (RFA, 2018).

Sulfur is one of the major factors limiting inclusion of distillers grains in feedlot diets. Sulfuric acid is used to control pH during grain fermentation and for cleaning production lines. This procedure adds sulfur to the co-product, which concentrates sulfur in diets formulated with distillers grains (Narendranath and Power, 2005). Results from an experiment on distillers grains, where sulfur concentration from six ethanol plants was analyzed by the University of Nebraska, indicated that sulfur concentrations ranged from 0.71% to 1.06%, with an overall mean sulfur concentration of 0.79% (Buckner et al., 2011).

The beef cattle National Research Council (NRC, 2005) set the maximum tolerable concentration of dietary sulfur at 0.3% dry matter basis (DMB) in feedlot diets with less than 15% forage, and at 0.5% DMB for diets containing more than 40% forage. Conversion of sulfur to hydrogen sulfide by bacteria is dependent upon ruminal pH (Schoonmaker and Beitz., 2012). Gould et al. (1997) suggested that sulfur-induced polioencephalomalacia (S-PEM) was associated with ruminal Hydrogen Sulfide (H_2S) concentrations above 2,000 mg/L. Nichols et al. (2013) suggested a strong correlation between roughage Neutral Detergent Fiber (NDF) concentration and dietary sulfur in incidents of S-PEM. For a given

level of dietary sulfur, the relative risk of PEM decreased 19% for each 1% roughage NDF increased (Nichols et al., 2013).

Roughages are included in feedlot diets to prevent digestive problems, such as acidosis, which permits optimization of dry matter intake (DMI; Defoor et al., 2002). In diets of newly received cattle, dietary roughage contributes to both ruminal and overall health. Adequate DMI in newly received cattle is key for mounting successful immune responses to pathogenic challenges (Lofgreen et al., 1981). Yet, in receiving cattle, stress affects DMI negatively (Hutcheson and Cole, 1986).

Because of increasing concern with antimicrobial resistance derived from animal antibiotic use, direct-fed microbials (DFM) are currently being considered for their beneficial effects on intake, cellulose digestion and modulation of immune response. Among DFM available, live yeast has been researched extensively in dairy cattle. Use of live yeast, such as *Saccharomyces cerevisiae* (SC), is thought to be beneficial for cattle weight gains (Carro et al., 1992), increases in milk production and protein digestibility in early-lactation dairy cows (Wohlt et al., 1998), and increased DMI and organic matter digestibility (OMD) (Carro et al., 1992; Plata et al., 1994).

LITERATURE REVIEW

ETHANOL PRODUCTION

Unlike fossil fuels, ethanol is a renewable energy source produced from starch or sugar fermentation. Starch from corn is the main source for ethanol production in the United States (EPA, 2010). The ethanol industry produced 43.5 million tonnes of distillers grains and nearly 1.54 billion kg of corn oil in 2017 (RFA, 2018). Six states accounted for nearly 70% of the ethanol produced in 2016 in the United States (USEIA, 2018). Corn accounts for almost 98% of the total ethanol production in the U.S., although some ethanol plants utilize other types of cereal grains such as sorghum or a combination of corn, wheat and barley. The ingredients utilized by the plants for ethanol production depend on cost, availability, and location.

The corn kernel is composed of four main parts: 1) the pericarp, protects the kernel from insects and microorganisms, the outer layer of the kernel, which contains most of the grain fiber, 2) the endosperm, which accounts for most of the dry weight (82%) of the kernel, contains carbohydrates, 3) the germ, where the oil is found, is located inside of the endosperm. 4) the cap, the area of attachment between the kernel and the cob. The conversion of starch into ethanol and oil extraction are the main functions of ethanol plants. The spent mash containing fiber, some corn oil and any non-rendered protein is known as distillers grains. Fiber, protein and oil in distillers grains make it a source of energy and fiber; its fiber and oil content enhance overall palatability of diets. The mash can be mixed with distillers solubles. Another co-product of this process is thin stillage which can be concentrated in evaporators to become condensed distillers solubles (CDS), which are

added back to wet distillers grains (WDG) and it sold under the name wet distillers grains with solubles (WDGS; Berger and Singh, 2010). Alternatively, this product can be dried down to 50% moisture (modified-wet distillers grains with solubles, MDGS) or to 10% moisture (dried distillers grains with solubles, DDGS; Crawford, 2010). There are two possible ways to extract ethanol: dry milling, in which the whole corn kernel is ground to expose the starch for fermentation; and wet milling, which consists of steeping to soften the kernels allowing the division into germ, fiber, protein, and starch prior to fermentation (RFA, 2019).

Distillers Grains in the United States

There are more than 200 ethanol plants in the United States. Most of these plants are concentrated in the Corn Belt (Iowa, Minnesota, South Dakota, Nebraska, and Wisconsin) with fewer distilleries in the South and East of the country. Setting a record, the United States exported 12.56 million tonnes of distillers grains in 2015 (RFA, 2016). These plants, depending on annual corn production, have the capacity to produce more than 40 million tonnes of distillers grains and more than 53 billion liters of ethanol per year. One bushel (25.4 kg) of corn produces 10.6 liters of ethanol and approximately 7.7 to 8.1 kg of distillers grains. In the 2016-2017 marketing year, U.S. ethanol plants produced a new record of 37.2 million tonnes of distillers grains, up 4 percent from the 2015-2016 marketing year (35.7 million tonnes). In 2018, 69% of the dry distillers grains with solubles (DDGS) were consumed in the United States and the remaining (31%) were exported (RFA, 2018). Historically, China was the leading DDGS importer of distillers grains produced by the United States, followed by Mexico, Vietnam, Japan, and Canada (Cooper,

2012). Currently, DDGS exports to China have experienced a significant drop since 2016, when the country imposed anti-dumping and countervailing duties against U.S products. However, an estimated of 31% of U.S DDGS was exported in 2018, with Mexico (17%), Vietnam (11%), South Korea (10%), Thailand (9%), and Turkey (7%) as the leading export destinations. (United States Grains Council, 2019). A 2007 USDS survey identified 9,400 livestock operations feeding distillers grains (42% of distillers grains produced) in Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. Interestingly, beef and dairy cattle account for about 79% of domestic distillers grains consumption, while swine and poultry consumes approximately 12 and 8%, respectively. Other species, such as fish and sheep, account for the remaining 1% (IRFA, 2019).

Nutrient Benefits

The nutrient composition of distillers grains depends on the type of grain (corn, wheat, sorghum, or barley) and the method (wet or dry) used by the distilleries to produce the ethanol. Distillers grains are low in starch which is converted to ethanol during fermentation (RFA, 2016). Wheat DDGS have higher protein (44%) and lower fat (3.5%) than distillers grains from corn and sorghum. The dry matter (DM) composition of DDGS compared with corn is as follows; crude protein (30% vs 7.1%), crude fiber (9.2% vs 2.1%), crude fat (6.8% vs 2.9%), phosphorus (0.8% vs 0.3%), and starch (4% vs 70%) (Feedstuffs, 2008). Due to the different milling methods, vitamin and mineral concentrations vary widely among corn-based distillers.

SULFUR CONCENTRATIONS IN FEED

Sulfur as an essential trace mineral in cattle diets

Sulfur is an important component of many functions in the body and is an essential nutrient for beef cattle. Cattle require several mineral elements for maintenance, growth, and reproduction (NRC, 2005). The source of minerals is not important if the animal's mineral requirements are met according to the stage of life (ZoBell, 2000). The recommended sulfur concentration in beef cattle diets is 0.18%-0.24% of DM, while a maximum sulfur concentration of 0.3% for diets that are more than 85% concentrate and 0.5% DM with at least 40% forage in the diet is suggested (NRC, 2005). Sulfur is an essential macro nutrient required for the normal growth and reproduction of bacteria in the rumen of cattle, and for ruminal microbial synthesis of certain amino acids (cysteine, cystine, and methionine), vitamins (thiamin and biotin), and enzymes (NRC, 2005). Sulfur deficiencies, toxicities, and imbalances require animal to metabolically compensate for the nutrient deviation (Underwood and Shuttle, 1999). Supplementation of excess sulfur may interfere with the metabolism of selenium, copper, molybdenum, and thiamin. Sulfur deficiency may lead to a decrease in DMI, a colorless hair coat, and hair loss (Hale and Olson, 2001). The amount of sulfur required for fiber and hair-production species such as sheep and goats may be higher compared with the level of sulfur recommended for cattle (Qi et al., 1994).

Sulfur toxicity

Elemental sulfur is considered among the least toxic minerals, however, Hydrogen Sulfide (H_2S), a product of sulfate metabolism in the rumen, is as toxic as cyanide (NRC,

2005). Cattle fed diets typical of beef animals in the finishing phase have a lower tolerance for sulfur. Polioencephalomalacia was first reported in 1956 and was described as a neurological disorder in cattle that affects the grey matter in the brain (Terlecki and Markson, 1961). In 1981, sulfur was first linked to PEM as investigators determined that calcium sulfate (gypsum) used to control feed intake caused blindness, recumbency, ataxia, muscular twitching, diarrhea, breathlessness, and death in some cases. When gypsum was removed from diets, symptoms previously mentioned and cases of PEM decreased (Raisbeck, 1982). It is hypothesized that H_2S released from the rumen via eructation is inhaled through the nasal passage and ends up around the brain producing necrosis of the grey matter (Gould, 1998). Gould (1998) concluded that H_2S toxicity is the main factor in S-PEM when steers consumed diets high in carbohydrates and low in fiber with added sodium sulfate. The metabolism of sulfur-reducing bacteria (SRB) is the precursor of H_2S accumulation in the rumen. Sulfur-reducing bacteria account for less than 1% of the total bacteria in the rumen (Wu et al., 2012). The number and functionality of SRB will depend on ruminal pH. A representative model was created to determine the pH level at which it no longer affects H_2S concentrations. The results suggest 5.6 pH as a cutoff point to which sulfide in the rumen should be in the H_2S form, while above this pH range H_2S concentrations are not well correlated with ruminal pH (Morine et al., 2014). The same experiment also confirms that an increase in roughage NDF (rNDF) will balance extreme swings of ruminal pH.

A seven-year meta-analysis conducted at the University of Nebraska demonstrated a strong correlation between ruminal sulfur, sulfur toxicity, and concentration of NDF (Nichols et al., 2013). While feeding ethanol co-products increased in the last decade,

incidences of S-PEM are still very low; only 1% of cattle exhibited symptoms of PEM when consuming diets with 0.5% sulfur and 4% NDF (Nichols et al., 2013). Cattle consuming high dietary sulfur concentrations do not necessarily need to show symptoms of PEM to experience reduced performance (Loneragan et al., 2001).

Ruminal sulfate reduction

In ruminants, sulfur is essential for B-vitamins, amino acids, and other cellular components (NRC, 2005). The amount of sulfur for ruminal fermentation can vary depending on degradability in the rumen. Sulfate-reducing microorganisms (SRM) are part of a group composed of SRB and sulfate-reducing archaea (SRA), both of which can perform anaerobic respiration utilizing sulfate (SO_4^{2-}) as terminal electron acceptor, reducing it to H_2S (Bradley et al., 2011). Therefore, these sulfidogenic microorganisms "breathe" sulfate rather than molecular oxygen, which is the terminal electron acceptor reduced to water in aerobic respiration (Schulze and Mooney, 1993). Bacterial sulfate reduction can be grouped into sulfate respiration “assimilatory”, where bacteria reduce sulfate to H_2S-producing sulfur-containing amino acids. Bacteria that reduce sulfate and produce H_2S as a product of metabolism are known as “dissimilatory” (Bradley et al., 2011). The SRB, which are primarily involved in a dissimilatory pathway, make up less than 1% of the total ruminal bacterial population (Callaway et al., 2010). Cummings et al. (1995) concluded when sulfur was available by feed or ruminal degradation, the main SRB found were *Desulfovibrio, Desulfohalobium,* and *Sulfolobus.* Culture techniques of SRB from steers diagnosed with S-PEM, mainly found gram negative bacteria like *Desulfovirbio* species.

Effects of high sulfur intake

In recent years, greater inclusion of ethanol co-products in feedlot diets and high sulfate water affecting some part of the United States has led to an increase in dietary sulfur. When formulating rations for cattle fed high-concentrate diets, it is important to take all sulfur sources into consideration. Sulfur is one of the major factors limiting inclusion of ethanol co-products in feedlot cattle diets, and while increasing inclusion rates of ethanol co-products may decrease cost on cattle diets, the risk of S-PEM and animal performance may be affected by variation of sulfur concentrations in ethanol co-products. The NRC (2005) recommends that water sulfate concentrations not to exceed 600 mg/L and a maximum of total sulfur concentration of 0.3% for diets that are more than 85% concentrate and 0.5% DM with at least 40% forage in the diet is suggested.

Excess of dietary sulfur may lead to S-PEM, reduced DMI and growth, negative effects on carcass quality, and limit availability of trace minerals in the diet. Sulfur-induced polioencephalomalacia is one of the main diseases associated with excess of sulfur intake in feedlot operations in the United States. Polioencephalomalacia characterized by swelling of the brain and damage of the grey matter. The process of S-PEM has not yet been fully discovered but is hypothesized that belched ruminal H_2S gas is inhaled by the animal and cause a necrosis of the grey matter. Dougherty and Cook (1962) reported that 70 to 80% of the gas belched with high concentrations of H_2S was inhaled without being detoxified by the liver. Gould et al. (2002) identified two methods by which sulfur excess consumed by ruminants affects health and performance. First, ruminal reduction of sulfur produces complex with copper, and other minerals, leading to a decreased mineral bioavailability. Second, sulfate is reduced by ruminal microbes to H_2S and its ionic forms, which interfere

with cellular respiration. If excessive sulfur is consumed, imbalances in ruminal microbial metabolism can occur and excessive ruminal sulfide accumulates. Sulfide exists in the rumen in two forms; soluble hydrosulfide anion which is in the rumen fluid phase and H_2S gas, which accumulates in the rumen gas cap. Gould et al. (2002) indicated that reduced H_2S has a higher negative effect on cattle than sulfates or elemental sulfur. These sulfides are inhaled during eructation, absorbed into the blood stream in the lung, and transported to the brain, thus bypassing the liver.

Water sulfate is a major contributor to the total sulfur intake by cattle, especially in summer months. According to Wright (2005), water sulfate concentrations under 1,000 ppm are generally safe, although dietary sulfur must relatively low to stay within (NRC, 2005) recommendations. Water concentrations between 1,000 and 2,000 ppm sulfate may result in diarrhea and reduction of copper bioavailability on a feedlot operation. An experiment with low sulfate water (393 ppm) and high sulfate (3786 ppm) with and without thiamin was conducted on sixty-three steers. Cattle on the low sulfate water group had higher DMI and greater feed efficiency than steers on high sulfate, and the incidents of S-PEM was no cases, 4.8 and 14.3% for steers on low, high sulfate water and high sulfate water with thiamine, respectively (Ward and Patterson, 2004). Delfiol et al. (2013) feed sheep for 111 d with diets containing 0.2, 0.9, or 1.2% sulfur, and reported approximately 50-fold greater H_2S concentrations in sheep fed 0.9 or 1.2% sulfur compared with the group fed 0.2% sulfur. No evidence of PEM was observed, but sheep consuming 0.9 or 1.2% sulfur had evidence of pneumonia during postmortem lungs examination. The concentration at which H_2S induced S-PEM is still unknown.

Cattle consuming forage-base diets appear to have more tolerance for swings on dietary sulfur than cattle fed high-concentrates. Various reports noted the negative effect of high sulfur diets on feedlot cattle performance. Loneragan et al. (1998) during a 2-week period, on a 0.9% sulfur intake on DMB, revealed 16 of 150 recently weaned calves developed signs of S-PEM. In the investigation reported, outbreak of S-PEM was associated with high ruminal H_2S concentrations and excess of sulfur intake. Zinn et al. (1997) reported a decrease on ADG, DMI, and feed efficiency as dietary sulfur increased from 0.15 to 0.25% in a finishing trial. They concluded that excess of sulfur over 0.20% of dietary DM may have a detrimental effect on growth performance and may affects carcass merit by decreasing longissimus muscle area. Uwituze et al. (2011) evaluated the effects of 0.42 and 0.65% sulfur dietary concentrations on yearling steers for 140 d. Steers fed diets with 0.65% sulfur had 8.9% less DMI, 12.9% less ADG than steers fed diets with 0.42% sulfur, but sulfur concentrations had no effect on feed efficiency. In addition, steers fed 0.65% dietary sulfur had significant higher ruminal H_2S concentrations than cattle fed 0.42%.

High dietary sulfur intake will greatly reduce the absorption of copper (Suttle, 1991), selenium, and molybdenum which combine to form copper tetrathiomolybdate (Wright and Patterson, 2005). The bioavailability of copper is greatly decreased by high dietary sulfur concentrations, which is most likely due to the formation of copper sulfide and/or the thiomolybdate-copper complex. Suttle (1991) reported a 50% decrease in copper absorption as concentrations of dietary sulfur increased from 0.2 to 0.4%. Excess sulfur intake may also result in conditions that lead to destruction of thiamin.

DIETARY ROUGHAGE

There are several reasons why feedlot diets contain roughage. First, roughage decreases dietary energy concentration which may prevent acidosis. Second, roughage aids ruminal functions by enhancing salivation, rumination, and digesta passage rate. Lastly, roughage may also support ruminal mixing and avoid abnormal fermentation. However, high level of animal productivity cannot be sustained by roughage alone, and concentrates must be fed. The risk of metabolic disorder increases as roughage decreases, but the magnitude can be influenced by other factors such as breed, days consuming the diet, and management. When cattle are abruptly moved from a high-roughage to a high-grain diets metabolic disorders may develop. Some level of roughage is critical to prevent metabolic disorders.

Reduction in DMI and average daily gain (ADG), and increased death loss in some cases may be the result of low roughage and excessive heat load (Hahn et al., 1994). On an energy basis, roughage in feedlot diets is one of the most expensive ingredients. Regimens that minimize roughage usage are of interest (Bartle and Preston, 1991). To better manage feed intake, producers have moved away from ad libitum access and have explored alternative feeding practices. Programming intake (Sip and Pritchard, 1991), variable roughage (Bartle and Preston, 1991), and limited intake (Xiong et al., 1991) are some of the different practices in the cattle feeding industry today. Hicks et al. (1990) determined that limiting feed intakes improved feed efficiency 8% when yearling steers were fed a high-wheat diet for 149 d at 85% of ad libitum compared with ad-libitum feeding. Reduction of metabolizable energy (ME) intake through feed restriction (ad-libitum vs

limit fed) in yearling steers fed high-corn diets resulted in a 7% decrease in ADG, and a 3.3% improvement in feed efficiency (Hicks et al., 1990). Economic gains may be accomplished by adding roughage to high concentrate diets and restricting ME intake (Mader et al., 1997).

Jensen et al. (1954) concluded that a group of fattening cattle had significantly more rumen inflammation and lower DMI intakes as concentrate: alfalfa ratio moved from 1:2 to 3:1. Galyean et al. (2003) suggested higher dietary roughage concentration may result in energy dilution, and cattle will attempt to increase feed intake to maintain energy intake. Cattle fed higher roughage diets tended to have more chewing during eating and throughout the day and yielded greater saliva output (Jiang et., 2017). Saliva produced as result of roughage in the diet acts as buffer and increase the pH in the rumen in cattle eating high-concentrate diets (Owens et al., 1998).

Bartle et al. (1994) examined energy dilution in feedlot diets by feeding cotton seed hulls (CSH) or alfalfa as the dietary roughage source at 10, 20, and 30% of dietary DM. They reported similar ADG for cattle consuming 10% CSH and 10% and 20% alfalfa. For each 1% increase in roughage concentration in the diet, DMI increased two times faster in steers consuming diets with CSH compared with alfalfa. The increased DMI was due to higher NDF in CSH compared with alfalfa. Larger amounts of alfalfa must be consumed to meet the same dietary NDF concentration as provided by CSH. Dry matter intake increased proportionally to dietary alfalfa concentration until cattle could no longer consume enough DM to compensate for the energy dilution caused by increased dietary roughage concentration. These data indicate that DMI is related to dietary NDF

concentration. Dietary roughage concentration in feedlot cattle finishing diets typically ranges from 3% to 11% of DM. At these concentrations, cattle are able maintain rumen health and increase NEg intake (Galyean, 1996).

Literature data continually shown reduced cattle performance when dietary roughage approach to zero (White and Reynolds, 1969; Kreikemeier et al., 1990). Overall, it is widely accepted that increasing roughage inclusion in finishing diets to the point of physical restriction increase DMI (Kreikemeier et al., 1990; Galyean and Hubbert, 2014). High roughage concentrations will decrease gains and feed efficiency by reducing 1) feed and energy intake 2) fiber or starch digestion in the rumen (Gill et al., 1981). To maximize ADG, Martens (2002) recommends a 12 to 15% dietary physically effective NDF (peNDF), while Fox and Tedeschi (2002) observed ideal ADG when peNDF was between 7 to 10% for feedlot diets. The appropriate roughage concentration for feedlot diets is complicated and it may be determinate by roughage type used, associative effects between roughage and grain components of the diets, and cattle genetics potential (Gill et al., 1981).

Fiber digestibility of roughage

The cell wall is composed of an intertwined mesh of mainly cellulose, hemicellulose, and pectin (Cosgrove, 2005)**.** The microbial populations of bacteria, protozoa, and fungi within the rumen attack, breakdown, and ferment carbohydrates in forage cell walls. The production of proteins and volatile fatty acids (VFA) for the host animal, is the result of carbohydrate breakdown and fermentation (Cheng et al., 1991). The rate of fiber degradation depends on access of ruminal microbes to substrate, physical structure of the forage, and the kinetics of ruminal digestion (Harbers et al., 1981). The

hydrolysis of plant cell walls is mainly possible by the Beta 1-4 cellulase, which allows ruminants to convert low-quality feeds into high-quality proteins (McAllister and Cheng, 1996)

Fiber digestion depends on; a) the plant composition and structure; b) the microbial population and the percentage of fiber-digesting microorganisms; c) adhesion and hydrolysis by complexes of hydrolytic enzymes; d) the host animal, from which mastication, digesta kinetics, and salivations depends (Cheng et al., 1991). Fibrolytic microorganisms are the main contributors in the conversion of fiber into usable product for the animal. The major types of fibrolytic bacteria include *Fibrobacter succinogenes, Ruminococcus flavefaciens, and Ruminococcus albus* (Cheng et al., 1991). Fibrolytic bacteria are often the dominant population and contribute to the degradation of easily digestible structures. Koike et al. (2003) reported *F. succinogenes, R. albus, and R. flavefaciens* in-vivo begin binding to hay stems within five minutes and increase to a maximum at 24 h. The results observed at 24 h were as follows; 10^9 cells per gram of DM for *F. succinogenes*, 10^7 per gram of DM for *R. flavefaciens*, and *R. albus* maximum binding of 10^6 per gram of DM. Fungi account for approximately 7% of the microbial population in the rumen. The role of fungi in fiber digestion is the penetration of lignified tissues of the cell wall. Fungi can degrade unruly cell wall materials such as sclerenchyma and vascular tissue (Akin, 1989). Cellulase and hemicellulase activities of fungi are enhanced by hydrogen- utilizing methanogens which decrease the suppression effect of hydrogen (Orphin et al., 1984). Protozoa are the precursor of 20% to 30% of the total cellulase activity. Although protozoa seem to be limited to very susceptible tissues, studies

show that the total reduction of protozoa reduces fiber digestion greatly (Bonhomme, 1990).

Roughage concentration and source

Due to the high energy density of concentrate diets, physical ruminal fill will rarely occur in finishing steers. As roughage is added to a concentrate diet, dietary energy is diluted, and the animal must eat more to fulfill energy requirements. The literature supports a strong relationship between NDF and DMI, and the concept that NDF in roughage could be used as a means of roughage exchanging sources in feedlot diets. Forage concentrations and source affect DMI, help to prevent digestive disorders, and maximize energy intake (Defoor et al., 2002). Theurer et al. (1999) fed CSH, wheat straw, and alfalfa in finishing diets at 2.8%, 3.7%, and 6% of dietary DM, respectively. Results showed that lower quality forage such as CSH and wheat straw were able to maintain DMI and ADG equal to higher quality forage. This effect can be attributed to the higher concentration of NDF in CSH and wheat straw compared with alfalfa. Defoor et al. (2002) reviewed the role of dietary NDF and the effects on DMI in feedlot cattle. Benton et al. (2007) concluded that higher roughage concentrations results in increased DMI, ADG, and live profit. The increase in DMI may be due to an energy dilution effect from increased roughage concentrations where cattle attempts to eat at constant energy level. It is not known the exact NDF concentration at which NDF negatively influence DMI in cattle. However, in dairy cattle NDF as percentage of body weight shows a negative effect on DMI as NDF reaches 1.2% (Mertens, 1985) to 1.5% (Murphy, 2004). Due to differences in rumen size, DMI, and

passage rate, the value in NDF intake as a % of BW impacts DMI in beef cattle is likely lower than dairy cattle (Jayakrishnan et al., 2017).

Loerch (1991) reported no differences in performance between steers fed all-concentrate and steers fed a diet containing 85% concentrate - 15% corn silage on the first 112 d. Worth to mention, from d 113 to 167, steers fed 85% concentrate diet had greater gains than steers fed all-concentrate (Loerch, 1991). Bartle et al. (1991) reported a reduction in feeding cost and no effect on steer growth by lowering dietary roughage equivalent by 2%, and an increase in DMI when roughage was increased from 2% to 10%. Thus, the optimal roughage source and concentrations in finishing diets is related to many factors such as source, availability, price, and interactions with other ingredients in the diet.

Roughage and ruminal acidosis

When cattle are abruptly switched from high-forage to a concentrate diet, or when fed a great proportion of readily available starch-containing feedstuff, a chain reaction of metabolic disorders occurs that results in the development of a metabolic disease known as acidosis. Ruminal acidosis is frequently defined as a decrease in the ruminal pH below normal concentrations that impact microbial activity, rumen function, and animal performance (Nagaraja and Lechtenberg, 2007). Acidosis is commonly noticed during the adaptation period to high-concentrate diets and occurs with extensive use of highly processed grain and low concentrations of roughage in beef cattle finishing diets (Owens et al., 1998). The severity of acidosis depends on pH concentrations, duration of low pH, ruminal bacterial population, and the type of VFA being produced. These factors classify acidosis into acute or chronic acidosis. Low ruminal pH, overpopulation of gram positive

and lactic acid- producing bacteria are typical signs of acute acidosis. During chronic acidosis, the animal may continue to show symptoms throughout the entire feeding program (Owens et al., 1998). Ruminal acidosis continues to be a common ruminal digestive disorder which can lead to considerable profit loss for feed yards. Averaged over all types of feedlots, 1.9% of cattle develop digestive disorders (Galyean and Rivera, 2003).

In general, beef cattle intake on high energy diets is likely controlled by metabolic factors, such as imbalance between microbial production, microbial utilization, and ruminal absorption of VFA (Castillo et al., 2012). Cattle can show clinical signs of acute acidosis such as a reduction of feed conversion and intake (Lean et al., 2001), laminitis (Owens et al., 1998), corium (Nocek, 1997), or very little to no signs during subacute acidosis. In general, subacute acidosis generates greater economic losses because it can affect a large percentage of the herd without being visually detected (Bramley et al., 2008). Researchers at the University of Nebraska calculated economic losses between $10 and $13/head due to sub-acute acidosis (Stock and Britton, 1996). The calculation takes into consideration reduced animal performance due to reduced DMI and extra carcass trimming as a result of severe liver abscesses.

With high-concentrate diets, the fermentation rate multiplies exponentially resulting in higher VFA production and greater concentration of lactic acid. Severity of ruminal acidosis varies depending on the concentration of organic acids in the rumen. It increases or decreases depending on the microbial production/utilization of organic acids (Nagaraja et al., 2007). Hungate et al. (1961) on four different experiments on lactating cows observed average rate of 10.5 mol butyric acid, 12.8 mol propionic acid, and 40 mol

acetic acid of production per day. Acetic acid is the more abundant VFA in the rumen because of forage fermentation. The rumen fermentation rates Propionic acid provides energy to the animal and is produced by carbohydrate fermentation. Lactic Acid is the produced in lesser amounts than acetic or propionic in the rumen under normal/lower-energy diets. At or near neutral pH conditions, there is an equilibrium between producers and utilizers of lactic acid (Nocek, 1997). A pH of 5.5 is considered the threshold below which lactic acid-producing bacteria such as *Streptococcus bovis* and *Lactobacillus spp*. proliferate (Nagaraja, 2007). As pH reaches 5, VFA producers such as cellulolytic and saccharolytic bacteria survive. *Streptococcus bovis* multiply between pH 5.5 and 5, and as pH drops to less than 5 it would favor *Lactobacillus spp.* growth. *Lactobacillus* and *S. bovis* produce D and L-lactic acid. Lactic acid is a stronger acid (pKa = 3.1) than other acids produced in the rumen (Dawson et al., 1997). Lactic acid stereoisomers, L(+) and D(-), are absorbed across the rumen wall and disturb the blood pH. In addition, lower pH damages the surface of the ruminal mucosa and creates opportunities for bacterial and mycotic organisms to invade the rumen wall which can lead to ruminitis (Lee et al., 1982).

Several management tools are available to prevent or control acidosis, such as buffer to neutralize acids (Russell and Rychlik, 2001), ionophores that modify rumen microflora (Stock et al., 1996), and certain direct fed microbials that stimulate the host's immune response (Fuller, 1989). However, their beneficial effects on acidosis and feedlot bloat, and direct effects on the ruminal microbial population are not consistent and remain unclear as these products are yet being developed. More research should be conducted in the development of specific technologies which will provide producers with tools that

allows them to remain competitive despite common ruminal digestive disorder often seen on the livestock industry.

USE OF SACCHAROMYCES CEREVISIAE IN CATTLE PRODUCTION

Direct-fed microbials (DFMs) or probiotics are naturally-occurring live bacterial supplements used to improve digestive functions (Fuller, 1989). *Saccharomyces Cerevisiae* (SC) was identified around the early 20th century (Eckles and Williams, 1925). Since its discovery, SC strains have gained in popularity in medical applications for humans, treatment of acute infectious enteritis, and antibiotic-induced gastro-intestinal disorders (Czerucka et al., 2007). *Saccharomyces Cerevisiae* CNCM I-1077 is the only naturally occurring, rumen-specific active dry yeast widely used as an additive in ruminant nutrition (Chaucheyras et al., 1996).

The symbiosis with specific micro-organisms allows ruminants the unique ability to utilize plant cell walls as nutrients and energy to produce milk, meat, hides, or wool. A large quantity of a ruminant's energy comes from cellulose, hemicelluloses, and pectins mainly present in plant cell walls. The reticulo-rumen host has many specialized anaerobic microbial communities responsible for fiber breakdown. *Saccharomyces Cerevisiae* stimulates lactic acid-utilizing bacteria, promotes a favorable environment for the development of cellulose consumers which maximize fiber degradation (McAllister et al., 2011). In vitro studies have shown SC yeast able to stimulate cellulolytic bacteria (Newbold, 1995; 1996) or fungi in the rumen (Chaucheyras, 1995).

Saccharomyces Cerevisiae yeast have the capability to alter immune function in animals, enhance performance, and alter metabolism. Thrune et al. (2009) reported that dairy cows in late lactation consuming a diet consisting of 60% forage and 40% concentrate supplemented with 0.5 g/hd/d SC increased pH to 6.53 compared with 6.32 in control diets. These authors also reported decreased duration of ruminal pH under 5.6 and total VFA concentration in the rumen was less (107.3 ± 6.35 mM) with SC supplementation compared with control (122.4 ± 6.35 mM).

Ruminal pH fluctuates throughout the day based on feed intake and dietary composition. Numerous studies demonstrated that Levucell SC (Lallemand Animal Nutrition, Blagnac, France) raised rumen pH compared with control in high-starch diets (Chaucheyras, 1995; Guedes et al., 2008). In addition, Levucell SC significantly reduces the time of ruminal pH under 6.5. Low ruminal pH for prolonged periods will negatively affect DMI, microbial metabolism, and nutrient degradation (Chaucheyras, 1995). Ruminal disorders are the result of an increase in lactate concentration and a decrease in VFA, which result in poor microbial activity and absorption of VFA from the rumen to the blood in response to the pH decrease. As pH continues to decline, the accumulation of D-Lactate continues to increase in the blood stream to the point that pH drops to non-physiological concentrations. Harmful molecules, which impact animal health, are released during acidosis. The increase of death and lysis of gram-negative bacteria under low pH, release lipopolysaccharides (LPS) in the rumen fluid, and translocation of this endotoxin can occur across the rumen mucosa (Emmanuel et al., 2007). This endotoxin triggers an inflammatory response and is suggested to be involved in metabolic disorders such as laminitis, abomasal displacement, fatty liver, and sudden death syndrome (Zebeli, 2012). Levucell SC *in-sacco*

trials demonstrated stimulating fiber colonization by cellulolytic bacteria and fungi. *In-vitro*, SC was able to outcompete *Streptococcus bovis* for utilization of sugars. The reduction of fermentable substrate available for bacterial growth limited the amount of lactate produced. Consequently, ruminal pH can maintain a physiological level which supports higher fibrolytic activities (Chaucheyras et al., 1996).

It has been reported that live yeast improves fiber digestion in some studies (Plata et al., 1994; Miranda et al.,1996), while also showing little to no difference in others (Angeles et al., 1998). While some research shows no effects on DMI (De Ondarza et al., 2010), others show increases in DMI (Desnoyers et al., 2009) with live yeast inclusion in ruminant diets. Due to inconsistent results of SC supplementation, direct-fed live yeast merits further research to determine effects on animal performance.

Effects of SC on rumen microflora and fiber degradation in the rumen

In the rumen, degradation and fermentation of plant cell wall polysaccharides is accomplished by members that belong to three domains, *Eubacteria* (Bacteria), *Archaea* (Methanogens), and *Eukarya* (Protozoa and Fungi). The cell wall degradation depends on the substrate composition, and the reciprocal action between the fibrolytic and non-fibrolytic microorganisms within the ecosystem (Newbold et al., 1995; Williams et al., 1991).

It has been demonstrated that concentrates diets can adversely alter activity of the fiber degrading community, due to decline in ruminal pH. As consequence, ruminal diegestion of NDF is decrease (Witzig et al., 2010). Generally, most of the fiber-degrading

microorganisms are sensitive to oxygen because most of them lack detoxification enzymes necessary for removal of reactive oxygen (Scott et al., 1983). Oxygen enters the rumen by water and feed intake, and rumination. Newbold et al. (1996) measured cellulolytic bacteria concentrations with either normal or low oxygen. Oxygen concentrations significantly influenced cellulolytic bacteria with 15-fold increased when low oxygen concentrations were applied in the fermenters. In the presence of oxygen, it has been reported that adhesion of cellulolytic bacteria to cellulose to be inhibit (Roger et al., 1990). Most ruminal microorganisms are considered sensitive to oxygen, specially fiber degrading organisms. One of the main beneficial effects of live yeast on fiber degradation is the capacity of yeast cells to scavenge oxygen. Respiratory deficient mutants of *Saccharomyces Cerevisiae* yeast have the capability to consume oxygen and stimulate bacterial activities (Newbold et al., 1996). Chaucheyras-Durand et al. (2002) reported redox potential of ruminal fluid in lambs, and cows by Marden et al. (2008) was lowered in the presence of *Saccharomyces Cerevisiae* suggesting live yeast could create a favorable environmental condition for the cellulolytic microbiota. Kong et al. (1998) showed that *Fibrobacter succinogenes, Ruminococcus flavefaciens,* and *Ruminococcus albus* account for 50% of the cellulolytic bacteria in the rumen. These results contradicted other research that reported the three previous mentioned bacteria only account for 1% to 5% of the cellulolytic bacteria in the rumen (Mosoni et al., 2007). Gram-positive *Ruminococcus* is one of the most important bacterial genera that break down plant fiber into the monosaccharide glucose, which can be broken down through glycolysis. *Ruminococcus albus* and *Ruminococcus flavefaciens* are the principal organisms in cellulose, xylan, and pectin degradation (Flint et al., 2008). *Butyrivibrio fibrisolvens* and *P. ruminicola*, because they cannot breakdown cellulose

polymer, are considered secondary fibrolytic species (Flint et., 2008). *Butyrivibrio fibrisolvens* and *P. ruminicola* play an important role in fiber degradation by carbosymethlycellulose-, xylan-, and pectin-degrading activities (Suen et al., 2011; Dodd et al., 2011).

Chaucheyras-Durand and Fonty (2001) established that cellulolytic bacteria inoculated in lambs tended to become established earlier in the presence of SC CNCM I-1077. In addition, the cellulolytic bacteria population tended to maintain at higher concentrations during feeding alterations and this suggests that SC stimulate the development of cellulolytic microflora and enhance microbial activity in the rumen gnotobiotically-reared lambs (Chaucheyras and Fonty, 2001). The experimental group of three lambs with 100 mg daily supplementation of Levucell SC, tended to increase the number of cellulolytic bacteria compared the control group (no additive given). In the same experiment, VFA, ammonia, and fibrolytic activities were also analyzed. The VFA concentrations were higher in the rumen of lambs consuming SC compared with the control. Significant differences were observed in B-glucosidase and B-galactosidase activities when SC I-1077 was present. Chaucheyras-Durand and Fonty (2001) demonstrated that SC CNCM I-1077 influenced microbial colonization of the rumen. The mechanism by which this occurs is not yet clearly understood. As the microflora become established earlier in life when SC is present, the microbial ecosystem will gain benefit when animals switch from a milk diet to solid feed.

Effects of SC on feed intake

Some of the benefits associated with SC consist of increased pH (Thrune et al., 2009), DMI (Desnoyers et al., 2009), and NDF degradation (Newbold, 1995, 1996; McAllister et al., 2011). These benefits could be attributed to the positive impact that probiotics like yeasts displayed in growth and viability of microflora and the fermenting process in the rumen (Lynch and Martin, 2002). *Saccharomyces cerevisiae* supplementation positively affects feed intake by increasing ruminal pH (Bach et al., 2007), ruminal ammonia concentration (Erasmus et al., 2005), and total VFA concentration, in addition to increasing numbers of cellulolytic bacteria and protozoa (Plata et al., 1994).

Feed intake is suggested to be driven by stress, environmental factors, disease, and receptors in the Central Nervous System (CNS; Forbes, 2003; Johnson, 1997). Schawartzkopf-Genswein et al. (2003) reported that when high-energy diets are consumed, fiber-fermenting bacteria are affected first, and acetic acids starts to reduce as hydrogen ion concentration increases. Certain feed additives, like SC, seem to be effective in controlling acidosis and feedlot bloat, presumably through the increase of absorption of main nutrients (Cole et al., 1992), increasing rate of digestion and regulation of feed intake (Dawson et al., 1990). To optimize fiber digestion, the ruminal environment must maintain a balance that promotes fiber-digesting bacteria. These targets could be achieved with probiotics by pH stabilization effects, or modification of the environment that promotes fiber-degrading microbiota and their action on plant cell walls. Chaucheyras-Durand (2012), showed that supplementation of 10^{10} cfu/day/cow of yeast additive promoted degradation of fibrous substrates by celluloytic bacterias (*F.succinogenes, R.flavefaciens,* and *B.firbisolvens*) and fungi. It was noticed that feed with a higher level of lignin and less

accessible digestible carbohydrates were better degraded in the presence of SC. Research suggests increased DMI with supplemented SC on forage-based diets rather than high-concentrate finishing diets (Beauchemin et al., 2003; Tang et al., 2008). Perhaps, SC have also been reported to simultaneously enhance growth and performance by enhancing ADG and DMI through the establishment of a healthy gastrointestinal tract. Supplementation of *Saccharomyces cerevisiae* appear to possess the ability to improve animal health and metabolism while decreasing mobility, and thereby enhancing profitability of the of these animals (Broadway et al., 2015).

Based on previous experimental results, we want to determine; 1) if higher concentrations of dietary sulfur may be fed successfully in higher roughage diets, 2) whether greater roughage inclusion would decrease the negative performance impact of feeding high sulfur concentrations. In the present experiment, we want to minimize S-PEM while maintaining animal performance when feeding 0.56% S in diets containing from 5% to 15% R. Drewnoski et al, (2014) were able to minimize S-PEM risk in diets containing over 0.4% S with the addition of 7 to 8% NDF from roughage sources. Numerous experiments have shown negative influence of high dietary sulfur on finishing cattle performance (Loerch, 1991; Zinn et al.,1997; Loneragan et al., 1998). Our objective is to determine how animal performance is affected by dietary sulfur 0.28 to 0.56% concentrations.

Based on R concentrations, our experiment is closely related to Kreikemeier et al. (1990). Steam-rolled wheat-based diet with 0%, 5%, 10% or 15% alfalfa/corn silage for 120 d and reported an increase in DMI as R concentrations increased (Kreikemeier et al.,1990). Galyean et al. (2003) reported that cattle attempt to increase intake to maintain

energy intake. Due to higher rumination and saliva production, as dietary roughage increases from 5 to 15%, we would expect an increase in DMI. This expectation would agree with findings reported by Bartle et al. (1991) whom observed greater DMI in steers fed high-grain diets when roughage concentration increased from 2% to 10% of diet DM.

Based on inconsistency experimental results on *Saccharomyces cerevisiae* supplementation, we want to determinate the effects of two dietary concentrations of Levucell SC 20 on growing and finishing steers consuming corn, corn earlage, and distillers grains-based diets. Our goal is to determinate with conclusive results if animal performance and carcass characteristics are affected by *Saccharomyces cerevisiae* supplementation. Ovinge et al, (2018) reports no difference on DMI, ADG, and gain to feed between treatments. Similarly, finding on a meta-analysis (Sartori et al., 2017) were a total of 12 publications reporting 22 trials conducted in 1,116 cattle were analyzed and not significant different on DMI, ADG, and gain to feed between treatments were reported.

INTERACTION OF DIETARY ROUGHAGE AND SULFUR CONCENTRATION ON PERFORMANCE OF BEEF CATTLE[1,2]

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SUMMARY

The objective of this experiment was to determine the effect of various dietary concentrations of roughage (R) and sulfur (S) on performance of beef cattle fed finishing diets. Eighty-four steers (initial BW 461 ± 36 kg), were allocated to one of four treatments in a randomized complete block design. Block was constituted by breed and source: 18 Angus-crossbred (Block 1), 30 Angus-Limousin (Block 2), or 36 Charolais steers (Block 3). Steers were fed in a Calan gate individual feeding system and treatments were arranged in a 2 x 3 factorial, with two dietary concentrations of S (0.28%, **LS** or 0.56%, **HS**) and three dietary concentrations of R (5%, **LR**; 10%, **MR**; 15%, **HR**). Steers were harvested after 134 d (blocks 1 and 2) and 92 d (block 3) on feed. Final carcass-adjusted BW was not affected by R, S, or their interaction ($P \geq 0.44$), and averaged 641 kg across treatments. Dry matter intake increased linearly ($P = 0.01$) with increasing R. Greater dietary S concentration decreased ($P = 0.02$) DMI. Average daily gain was not affected ($P \geq 0.24$) by R, S, or their interaction, and averaged 1.48 kg across treatments. Feed efficiency was not affected by dietary S concentration or the interaction ($P \geq 0.96$), but decreased linearly ($P = 0.01$) with increasing R. Hot carcass weight (413 kg across treatments), LM area (100.2 sq. cm), 12th rib fat thickness (1.17 cm), marbling score (459), and frequency of individual USDA quality grades were not affected by S, R, or their interaction ($P \geq 0.14$). A tendency ($P = 0.03$) for fewer carcasses grading USDA yield grade 1 and 2 was observed with increasing R. Results suggest that increasing dietary R concentration increases DMI and decreases feed efficiency while high dietary S concentrations decrease DMI. However,

no interactions occurred to suggest that performance may be enhanced by feeding increased R in high-S feedlot diets.

Keywords: Beef, Feedlot Cattle, Sulfur, Roughage, Distillers Grains

INTRODUCTION

One of the challenges of using distillers grains (DG) at greater dietary inclusion is the potential for consumption of diets with excessive S concentration. Distillers grains contributes energy, protein, and fiber making it an attractive feed ingredient in feedlot diets (RFA, 2019). The NRC (2005) recommended a maximum tolerable S concentration of 0.5% or 0.3% for high-forage and high-grain diets, respectively. Vanness et al. (2009) calculated that incidence of sulfur-induced polioencephalomalacia (S-PEM) was 0.14% in diets containing 0.46% or less S. Therefore, the ideal amount of DG in the diet partly depends on the amount of S in DG and dietary roughage (R) concentration.

Use of high concentrations of DG in cattle diets may result in toxic concentrations of ruminal hydrogen sulfide gas (H_2S), which may lead to poor animal performance and S-PEM (Gould et al., 1997). Ruminal H_2S production is dependent on an acidic environment, and dietary R affects ruminal pH (Binversie et al., 2016). It has been postulated that manipulation of dietary R could help mitigate H_2S production. Considering that, on an energy basis, R is one of the most expensive ingredients, diets that minimize R usage are of interest (Bartle and Preston, 1991). Adding R to high-grain diets improved rumination rate, increased ruminal pH, had a positive effect on intake (Smith et al., 2010), and thereby increased energy intake (Defoor et al., 2002). In the presence of greater dietary R and indigestible lignin in the diet, volatile fatty acid (VFA) concentration decreased while ruminal pH increased (May et al., 2010). Galyean et al. (2003) suggested that an increase in intake of dietary R may result in energy dilution, and cattle would attempt to increase intake to maintain energy intake.

Conversion of dietary S and water sulfate to H_2S increased at lower ruminal pH (Kung et al., 1998). Increased dietary R concentration; however, resulted in greater ruminal pH (Crawford et al., 2008). Therefore, the objective of this experiment was to determine the interaction between dietary S and R concentrations on feedlot performance and carcass characteristics. Our hypothesis was that increased concentrations of dietary S, associated with DG feeding, may be fed with increased dietary R concentrations to prevent negative effects of S on performance in high-energy diets.

MATERIALS AND METHODS

All procedures were approved and reviewed by the University of Minnesota Institutional Animal Care and Use Committee (IACUC).

Animal and treatments

The experiment was conducted at the University of Minnesota Rosemount Research and Outreach Center (RROC, Rosemount, MN) from February to September 2011. Eighty-four Angus-crossbred, Limousin, and Charolais steers were blocked by breed type and arranged in a randomized complete block design (initial BW 461 ± 36 kg) and treatments were arranged in a 2 x 3 factorial, with two dietary S concentrations (0.28%, LS or 0.56%, HS) and three dietary R concentrations (5%, LR; 10%, MR; 15%, HR) resulting in six treatments. Basal diets (1.40 Mcal NEg/kg, 1.36 Mcal NEg/kg, and 1.31 Mcal NEg/kgfor LR, MR, and HR, respectively) consisted of dry-rolled corn, alfalfa, and modified DG (MDG; Table 1). All diets contained 17.6% CP (DM basis). Steers were fed in a Calan Broadbent individual feeding system (American Calan, Northwood, NH) and

were weighed every 28 d throughout the experiment. Steers were harvested after 134 d (block 1 and 2) and 92 d (block 3).

Diets were formulated to meet or exceed nutrient requirements for finishing steers weighing over 461 kg (Table 1). Modified DG were delivered weekly from Big River Energy (Boyceville, WI) to the RROC where it was stored on a concrete pad and covered with plastic to protect from weather. Prior to treatment initiation, steers were vaccinated with Pyramid 5 (Boehringer Ingelheim, Duluth, GA), boostered 7 d later with Pyramid plus Presponse SQ (Boehringer Ingelheim, Duluth, GA), dewormed with DECTOMAX (Zoetis, Parsippany, NJ), implanted with Revalor-XS (Merck Animal Health, Madison, NJ), and ear tagged identifying bunk, treatment, and pen number. Within block, steers were assigned to treatment based on initial BW and allocated into 1 of 9 pens with 10 to 12 head per pen. All steers were maintained on a diet containing 25% alfalfa hay, 40% DG, 30% dry-rolled corn, and 5% liquid supplement diet for a 4-week period while training to eat from the individual feeding system. Adaptation diets were provided until d 1, when all 84 steers were introduced to their finishing diets.

Dietary S concentration of MDG were less than 0.48%; therefore, gypsum (calcium sulfate dehydrate; 19% S) was included in the diets to manipulate S concentration in the HS treatment. Limestone was added to LS treatments to balance dietary Ca concentrations across dietary S treatments.

Feeding

Body weight was measured on d 1 after a 16-h shrink period. Thereafter, individual BW was measured before feeding every 28 d. Feed was mixed daily with a Patz 1200 series vertical mixer (Patz, Pound, WI) and delivered once daily.

Each morning at 0600 h, feed refusals were collected and recorded from each bunk. Feed delivery depended on the amount of feed refusal from previous day: no feed refused for two consecutive days elicited 0.454 kg greater feed delivery, feed refusals under 0.454 kg elicited no change on feed delivery, and feed refusals > 0.454 kg led to reductions in feed deliveries by 50% of feed refusal. Steers had access to fresh clean water *ad libitum*; corn stalk bedding was delivered directly onto a bedded area (65 sq m) weekly.

Steers were harvested after 134 d (block 1 and 2) and 92 d (block 3). Block 1 and 2 steers were harvested at Tyson Fresh Meats in Dakota City, NE, and block 3 steers were harvested at Tyson Fresh Meats in Joslin, IL. Final weight was calculated from carcass weight by assuming a common dressing percentage of 62.5. Quality grade, yield grade, and marbling score were evaluated by USDA personnel; all other measures were evaluated by University of Minnesota personnel (Joslin, IL) or a custom carcass data collection service (Dakota City, NE).

Laboratory Analysis

Feed ingredient samples were collected weekly for laboratory analysis and composited monthly corresponding to each weigh period. Feed refusal (orts) were weighed and sampled when feed remaining in the bunk appeared to be more than 0.454 kg DM; ort and ingredient samples were frozen after collection in a -20° C freezer. Samples were

analyzed for DM using a 60° C drying oven (Blue M Electric, Thermal product solution, New Columbia, PA 17856) for 3 d. Dried samples were ground using a Wiley mill (Thomas Scientific, Swedesboro, NJ) with a 1 mm screen. A complete nutrient analysis profile of the diets was conducted at a commercial lab (Dairyland Laboratory, Inc., Arcadia, WI). Composite samples of feed ingredients and orts were made based on weighing period. Sample DM was determined using National Forage Testing Association (NFTA) Method 2.1.4 which included oven-drying for 3 h at 105° C on duplicate samples. Crude protein, crude fat, NDF, ADF, Ca, P, K, Mg, and S concentrations were analyzed using AOAC method 990.03, 920.39, 2002.4, 973.18, and 953.1 (AOAC, 2012), respectively, on duplicate samples.

Statistical analysis

Continuous response data were analyzed using the MIXED procedure of SAS (SAS, Inst. Inc., Cary, NC) for a randomized block design with a factorial arrangement of treatments using animal as the experimental unit. The model included treatment and block as fixed effects and pen as a random effect. The GENMOD procedure of SAS was used for categorical data with the same design model and using animal as the experimental unit. Linear and quadratic response to feeding increasing dietary R concentrations was tested using orthogonal contrasts. Significance was declared when P-values ≤ 0.05; tendencies were discussed when $0.05 \leq P \leq 0.10$.

RESULTS AND DISCUSSION

Effect of dietary R and S concentrations on feedlot performance and carcass characteristics are presented in Table 3 and Table 4, respectively. There were no interactive effects of dietary R and S concentration on performance or carcass characteristics ($P > 0.14$). As dietary R concentration increased from 5% to 15%, DMI increased ($P = 0.01$). In contrast, steers fed 0.56% dietary S consumed less DM ($P = 0.02$) than those fed 0.28% (Table 3). Average daily gain was not affected by dietary R or S concentration ($P > 0.96$; Table 3). Feed efficiency was not affected by dietary S concentration ($P = 0.31$) but decreased linearly ($P = 0.01$) with increasing R (Table 3). Cattle were harvested at similar 12^{th} rib fat depth ($P = 0.96$; Table 4). A smaller proportion of carcasses reaching Yield Grade 2 was observed with increasing dietary R ($P = 0.03$; Table 4). No other effects on carcass traits were observed ($P \geq 0.12$).

Kreikemeier et al. (1990) fed a steam-rolled wheat-based diet with 0, 5, 10, or 15% alfalfa/corn silage for 120 d. Similar to our results, cattle in that experiment consumed more DM with increasing dietary R. Kreikemeier et al. (1990) reported DMI responded positively to the initial incremental increase (0 to 5%) in R concentration due to increase of rumination and saliva production. In the present experiment, the DMI response between 5% and 10% R inclusion was 6% while that between 10% and 15% R inclusion was only 1.7%. The primary increase (Linear $P = 0.01$) in DMI, was observed from d 28 to 56 when steers consumed 8.62, 8.92, and 9.11 kg for LR, MR, and HR, respectively. Uhart and Carroll (1967) induced acidosis in Hereford steers by switching from *ad-libitum* alfalfa hay to a high-concentrate diet (45% rolled barley, 45% milo, and 10% chopped alfalfa hay) without an adaptation period. After the abrupt diet switch, VFA and lactate increased

rapidly and DMI decreased. Steers did not return to normal eating levels until 2 to 6 d later. Uhart and Carroll (1967) proposed an adaptation period for the rumen microbial ecology which may explain higher DMI after 28 d (Table 2) as result of a stabilized ruminal microbial balance in the current experiment. Kreikemeier et al. (1990), in a second experiment, evaluated the effect of feeding 0%, 5% or 15% alfalfa in a steam-rolled wheat diet fed twice daily at two- or three-times net energy for maintenance (NEm). These authors reported greater ruminal liquid passage, rumen fill, and VFA concentration as R concentration increased. Greater passage of fluid out of the rumen may explain the greater increase in DMI between cattle fed 5% and 10% R in the current experiment. According to both experiments by Kreikemeier et al. (1990), greater DMI resulted in increased microbial efficiency due to faster ruminal liquid passage and amount of substrate available. Diets with sufficient forage aid ruminal functions by enhancing salivation, rumination, and digesta passage rate (Galyean et al., 2003). In addition, cattle attempt to increase intake to maintain energy intake (Galyean et al., 2003). Bartle et al. (1991) observed greater DMI in steers fed high-grain diets when R concentration increased from 2% to 10% of diet DM.

The quadratic effect observed on the first 28 d in G:F (Table 2), with positive response to increase of R up to 10% is likely due to increase of rumination and salivary buffer. This response could be explained by the second "zone" proposed by Swingle (1995). Three dietary energy density zones based on R and productivity of feed cattle were proposed. In the first zone, energy is diluted with R and bulk-fill limits DMI, as a result NEg intake is insufficient to allow maximum feed efficiency. In the second zone, energy density of the diet is ideal to express maximum genetic potential. In the third zone, dietary energy density is very high, and cattle cannot regulate DMI. Kreikemeier et al. (1990)

reported an increase in DMI correlated with increasing R in the diet and reported a decrease in G:F in cattle fed 15% R as result of the decreased energy concentration in the diet.

Cattle fed 0.56% dietary S had lower DMI than those fed 0.28% S. Spears et al. (2011) observed DMI linearly decreased as dietary S increased from 0.12% to 0.46% on a ground-corn-based diet. This DMI reduction could be the result of high dietary S concentration, which may have caused an elevation in sulfide concentration in the rumen fluid and gas cap (Gould et al. 1991). Morine et al. (2012) fed 0.46% S diets containing 3.5%, 5.7%, 7.9%, 10.1%, or 11.4% added NDF to finishing steers fed for 84 d and found that ruminal H_2S concentrations linearly decreased as R NDF increased. Although pH measurements were not part of our experiment, results agree with Morine et al. (2012) findings: adding R to high S diets had no effect on ADG but a linear numerical increase on DMI was observed (Table 3).

Nichols et al. (2013) conducted a meta-analysis of 80 finishing trials with diets containing 0%, 4%, or 8% NDF and ranging in dietary S concentration from 0.12% to 0.73%. They reported a reduction of 19% in S-PEM incidence for each 1% increase in dietary R NDF. Additionally, Vanness et al. (2009) fed cannulated steers 0%, 7.5% or 15% grass hay in high-energy diets with dietary S concentration ranging from 0.41% to 0.47%. They reported 2.3 times greater ruminal H_2S concentration on cattle fed no R compared with those fed 7.5% R. Drewnoski et al. (2014) concluded that increased concentration of R in finishing diets containing DG likely decreased H_2S concentrations. Feeding higher-R diets is known to increase chewing and saliva production, which act as a buffer increasing rumen pH, changing the pattern of acid production in the rumen, and lowering the likelihood of PEM (Owens et al., 1998).

Fewer carcasses reaching USDA Yield Grade 2 were observed with increasing R inclusion (Table 4). This is an interesting observation as it is isolated to Yield Grade 2. When considering proportions of carcasses in Yield Grade 1 or in Yield Grade 3 and 4, increasing proportion of carcasses observed in Yield Grade 2 for steers fed 5% R was offset by fewer carcasses in Yield Grade 1 observed in this treatment.

In most studies, dietary S concentration had no effect on backfat, marbling scores, or yield grade (Zinn et al., 1997; Richter et al., 2012). Evaluation of tenderness and shelf life at different dietary S concentrations was studied (Depenbusch et al., 2009; Kroger et al., 2010). Price et al. (1997) reported a reduction without significant differences on all measures of carcass fatness on steers and bulls fed R at 20, 50, and 80%. Willms et al. (1991) fed finishing cattle with 10 or 20% R and reported no treatment difference for 12th rib fat thickness, kidney, pelvic and heart fat, and yield grade. Sorensen et al. (2013) fed finishing steers R at 20, 30, or 40% of dietary DM and reported no influence of R on body weight, carcass composition, meat quality or tenderness. However, meat color attributes were improved in carcasses from steers consuming 40% R.

This experiment indicates that steers can be fed up to 0.56% dietary S in diets containing 5 to 15% R without negative effects on growth. No clinical signs of PEM were observed though a reduction in DMI was observed with increased dietary S concentration. It appears that increasing R concentrations benefits DMI; however, G:F was numerically less. Tolerance for high dietary S by cattle consuming over 5% dietary R likely relates to the increase in saliva and/or a better ruminal environment for microbial population. Based on this experiment, effects of dietary R and S concentration in diets of feedlot cattle appeared to be independent of one another. Understanding ruminal availability of dietary

S and R inclusion seems to be a valuable tool for cattle feeders to prevent S toxicity while maintaining animal performance.

Table 1. Ingredient and nutrient composition for finishing diets (DM basis)[1].

	Low Sulfur			High Sulfur		
Item	LR	MR	HR	LR	MR	HR
Dry-rolled corn, %	45.5	40.5	35.5	45.5	40.5	35.5
MDGS[2], %	40.0	40.0	40.0	40.0	40.0	40.0
Alfalfa hay, %	5.0	10.0	15.0	5.0	10.0	15.0
Liquid supplement[3], %	3.5	3.5	3.5	3.5	3.5	3.5
Calcium sulfate, %	.	.	.	6.0	6.0	6.0
Limestone, %	6.0	6.0	6.0	.	.	.
NE_g[4] Mcal/kg	1.40	1.36	1.31	1.39	1.35	1.30
CP, %	17.6	17.6	17.7	17.6	17.6	17.7
NDF, %	20.2	22.9	25.6	20.2	22.9	25.6
DIP, % of DM	8.7	8.9	9.0	8.7	8.9	9.0
Ca, %	1.14	1.17	1.19	1.14	1.16	1.19
P, %	0.50	0.49	0.49	0.50	0.49	0.49
Fat, %	7.4	7.3	7.3	7.4	7.3	7.3
S, %	0.28	0.28	0.28	0.56	0.56	0.56

[1]LR = Low roughage; MR = Moderate roughage; HR = high roughage

[2]Modified distillers grains with solubles (47% DM) sourced from Big River Energy, Boyceville, WI.

[3]Quality Liquid Feeds, Dodgeville, WI.

[4]Values for the experimental diets were calculated from NRC (2000). Values based on proximate analysis of ingredients.

Table 2. Effects of dietary roughage (R) and sulfur (S) concentrations on interim feedlot performance of beef steers.

	Dietary R Concentration			Dietary S Concentration		SEM[2]		*P*-values[1]			
Item	5%	10%	15%	0.28%	0.56%	R	S	R Linear	R Quad	S	R x S
Day 1 to 28											
Initial BW, kg	459	462	462	462	460	36	36	0.72	0.90	0.82	1.00
d 28 BW, kg	489	495	487	493	488	33	33	0.80	0.34	0.43	0.66
DMI, kg/d	7.49	7.65	7.69	7.72	7.51	0.59	0.59	0.12	0.55	0.05	0.78
ADG, kg	1.05	1.18	0.87	1.10	0.96	0.15	0.15	0.17	0.06	0.19	0.10
Gain:Feed	0.140	0.155	0.117	0.145	0.128	0.012	0.012	0.14	0.05	0.27	0.12
Day 28 to 56											
d 28 BW, kg	489	495	487	493	488	33	33	0.80	0.34	0.43	0.66
d 56 BW, kg	527	533	526	532	526	20	19	0.85	0.42	0.42	0.94
DMI, kg/d	8.62	8.92	9.11	9.02	8.76	0.37	0.36	0.01	0.77	0.08	0.83
ADG, kg	1.20	1.27	1.12	1.24	1.15	0.30	0.29	0.44	0.28	0.35	0.85
Gain:Feed	0.139	0.142	0.123	0.137	0.131	0.017	0.017	0.20	0.27	0.54	0.86

[1] R Linear = Linear effect of dietary roughage concentration; R Quad = quadratic effect of dietary roughage concentration; S = main effect of dietary S concentration; R x S = interaction between dietary roughage and S concentrations.

[2] Standard error.

Table 3. Effects of dietary roughage (R) and sulfur (S) concentrations on feedlot performance of beef steers.

	Dietary R Concentration			Dietary S Concentration		SEM[2]		*P*-values[1]			
Item	5%	10%	15%	0.28%	0.56%	R	S	R Linear	R Quad	S	R x S
Initial BW, kg	459	462	462	462	460	36	36	0.72	0.90	0.82	0.99
Final BW, kg	638	643	632	640	636	8.43	7.29	0.60	0.40	0.62	0.96
DMI, kg/d	9.89	10.52	10.7	10.61	10.11	0.39	0.37	0.01	0.29	0.02	0.93
ADG, kg	1.46	1.49	1.38	1.45	1.43	0.18	0.17	0.24	0.40	0.45	0.96
Gain:Feed	0.148	0.142	0.129	0.137	0.141	0.008	0.008	0.01	0.59	0.31	0.99

[1] R Linear = Linear effect of dietary roughage concentration; R Quad = quadratic effect of dietary roughage concentration; S = main effect of dietary S concentration; R x S = interaction between dietary roughage and S concentrations.

[2] Standard error.

Table 4. Effects of dietary roughage (R) and sulfur (S) concentrations on carcass characteristics of beef feedlot steers.

	Dietary R Concentration			Dietary S Concentration		SEM[2]		*P*-values[1]			
Item	5%	10%	15%	0.28%	0.56%	R	S	R Linear	R Quad	S	R x S
HCW, kg	415	416	409	416	411	5	4	0.45	0.52	0.44	0.99
Backfat, cm	1.02	1.27	1.19	1.22	1.12	0.28	0.28	0.59	0.78	0.12	0.91
REA[3], sq cm	99.3	101.2	99.3	100.6	99.3	6.4	6.4	0.99	0.26	0.47	0.85
Marbling[4]	450	469	457	466	451	85	84	0.79	0.49	0.45	0.14
USDA YG[5]	2.47	2.29	2.43	2.42	2.37	0.45	0.48	0.79	0.16	0.66	0.95
YG 1, %	9.15	23.44	16.31	12.72	19.87	6.12	5.04	0.40	0.15	0.31	0.25
YG 2, %	51.70	26.70	26.72	39.80	30.22	8.10	6.66	0.03	0.20	0.30	0.06
YG 3, %	27.90	35.16	38.72	29.15	38.70	7.93	6.52	0.33	0.85	0.29	0.12
YG 4, %	11.25	14.80	18.41	18.45	11.25	5.03	4.13	0.31	1.00	0.21	0.22
Prime QG[6], %	6.88	14.02	6.88	10.45	8.07	3.86	3.12	1.00	0.13	0.59	0.31
Choice QG, %	39.70	46.85	46.88	42.12	46.89	8.41	6.91	0.54	0.72	0.62	0.37
Select QG, %	53.60	35.75	42.82	42.95	45.21	7.76	6.38	0.32	0.18	0.79	0.93
No Roll QG, %	0.00	3.41	3.41	4.60	0.00	2.78	2.29	0.36	0.60	0.14	0.57

[1] R Linear = Linear effect of dietary roughage concentration; R Quad = quadratic effect of dietary roughage concentration; S = main effect of dietary S concentration; R x S = interaction between dietary roughage and S concentrations.
[2] Standard error.
[3] Ribeye (longissimus muscle) area measured at the 12th rib.
[4] Marbling score assessed by USDA grader where 400 = Small^{0}, 500 = Modest^{0}, etc.
[5] USDA yield grade assessed by USDA grader.
[6] USDA quality grade assessed by USDA grader.

EFFECTS OF TWO DIETARY CONCENTRATIONS OF LEVUCELL SC IN GROWING OR FINISHING FEEDLOT DIETS[1,2]

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SUMMARY

Two experiments were conducted to determine the effect of *Saccharomyces cerevisiae* (SC; Levucell SC 20) on growing and finishing steers. Forty-seven Angus and Simmental steers were allocated in a randomized complete block design during a growing (Exp. 1; Initial BW = 341 ± 6.8 kg) and finishing (Exp. 2; Initial BW = 430 ± 7.7 kg) experiment to one of three dietary treatments: 0, 500, or 1,000 mg of SC/hd daily (SC0, SC500, and SC1000, respectively). Basal diets for Exp. 1 (1.14 Mcal NEg/kg, 15.6% CP) and Exp. 2 (1.39 Mcal NEg/kg, 16.7% CP) consisted primarily of corn earlage and modified distillers grains (MDG; Exp. 1) or dry-rolled corn and MDG (Exp. 2). Steers were fed in a Calan-gate individual feeding system and were weighed every 28 d throughout each experiment. Experiment 1 and Exp. 2 lasted 56 d and 115 d, respectively. For Exp.1, final BW (432 kg) and ADG (1.61 kg) were not affected ($P \geq 0.36$) by treatment. In Exp. 1, DMI averaged 9.02, 9.02, and 9.84 kg/d (linear $P = 0.12$), and G:F averaged 0.178, 0.182, and 0.166 (linear $P = 0.12$, quadratic $P = 0.17$) for SC0, SC500, and SC1000, respectively. At the end of the step-up feeding period in Exp. 2 (0 to 28 d), ADG averaged 1.63, 1.97, and 1.88 kg (linear $P = 0.16$, quadratic $P = 0.15$) and G:F averaged 0.158, 0.189, and 0.183 (linear $P = 0.11$, quadratic $P = 0.19$) for SC0, SC500, and SC1000, respectively. In Exp. 2, DMI averaged 12.05, 11.34, and 11.09 kg/d (linear $P = 0.13$) for SC0, SC500, and SC1000, respectively. In Exp. 2, ADG averaged 1.77 kg and G:F averaged 0.156 and neither was affected ($P \geq 0.30$) by SC inclusion. Inclusion of SC did not affect ($P \geq 0.16$) HCW, 12th rib fat thickness, ribeye area, marbling score, or frequency of individual USDA quality or yield grades. Results suggest that using dietary SC concentration may increase

DMI in high-forage growing diets. The linear trend for reduced DMI in finishing cattle fed live yeast merits further research to determine effects on feed efficiency.

Keywords: Yeast, Cattle, *Saccharomyces cerevisiae*, Roughage, Distillers Grains

INTRODUCTION

Saccharomyces cerevisiae (SC) yeast is a single-celled eukaryote with cells containing membrane organelles and clearly defined nuclei extensively used as additive in cattle diets (Auclair, 2001). *Saccharomyces cerevisiae* was identified around the early 20th century (Eckles and Williams, 1925). Since its discovery, SC strains have gained in popularity in medical applications for humans for treatment of acute infectious enteritis and antibiotic-induced gastro-intestinal disorders (Czerucka et al., 2007).

Supplementation of SC may improve animal performance as it modulated rumen microbial growth (Lila et al., 2004; Berchielli and Bertipaglia, 2010; Ding et al., 2014), promoted development of cellulolytic bacteria and improved fiber degradation rates (McAllister et al., 2011), increased ruminal pH (Bach et. al., 2007), and increased feed intake and weight gain (Yoon and Stern, 1996; Ghorbani et. al., 2002; Beauchemin et al., 2003). With increasing public concern associated with antibiotic resistance and use of growth hormones, live yeast has been suggested as an alternative to antibiotics and growth-promoting additives (Phillips et al., 2004; Thacker, 2013). Response to SC supplementation has been inconsistent (Yoon and Stern, 1996; Erasmus et al., 2005), depended on many factors including dosage and diet composition and strain (Lynch and Martin, 2002), cattle type and age, and season of the year (Williams et al., 1991; Newbold et al., 1995).

The objective of these experiments was to determine the effects of two dietary concentrations of SC (Levucell SC 20) on growing and finishing steers consuming corn, corn earlage, and distillers grain-based diets.

MATERIALS AND METHODS

All procedures were approved and reviewed by the University of Minnesota Institutional Animal Care and Use Committee (IACUC). Experiments were conducted at the University of Minnesota Rosemount Research and Outreach Center in Rosemount, MN from March to September 2012.

Animal and treatments

Forty-seven Angus and Simmental steers were allocated in a randomized complete block design during a growing (Exp. 1; Initial BW = 341 ± 6.8 kg) or finishing (Exp. 2; Initial BW = 430 ± 7.7 kg) experiment to one of three treatments: 0, 500, and 1,000 mg of SC/hd daily (SC0, SC500, and SC1000, respectively). Basal diets for Exp. 1 (1.14 Mcal NEg/kg, 15.6% CP) and Exp. 2 (1.39 Mcal NEg/kg, 16.7% CP) consisted of corn earlage and modified distillers grains (MDG; Exp. 1) or dry-rolled corn and MDG (Exp. 2; Table 1). Steers were fed in a Calan Broadbent individual feeding system (American Calan, Northwood, NH) and were weighed every 28 d throughout each experiment. Between Exp. 1 and Exp. 2 a 14-d washout period using diets containing 95% roughage was implemented. All steers were re-randomized at the beginning of Exp. 2. Experiment 1 and Exp. 2 lasted 56 d and 115 d, respectively.

Diets were developed to meet or exceed nutrient requirements for growing and finishing steers weighing 340 kg (Exp. 1) and 430 kg (Exp. 2), respectively. Prior to treatment initiation, steers were vaccinated with Pyramid 5 (Boehringer Ingelheim, Duluth, GA) and re-vaccinated 7 days later with Pyramid plus Presponse SQ (Boehringer Ingelheim, Duluth, GA), dewormed with DECTOMAX (Zoetis, Parsippany, NJ),

implanted with Revalor-XS (Merck Animal Health, Madison, NJ), and ear tagged identifying bunk, treatment, and pen number. Steers were blocked by initial BW and allocated into one of four pens with 11 or 12 head per pen. All steers were maintained on 25% alfalfa hay, 35% MDG, and 37% corn earlage diet (DM basis) for a 4-week period while animals were trained to consume feed in the individual feeding system. Adaptation diets were provided until d 1 when all steers were introduced to their experimental diet.

Feeding

Body weight was measured on d 1 after a 16-h shrink period at the beginning of each experiment. Thereafter, individual BW was measured every 28 d before feeding throughout each experiment. Feed was mixed daily with a Patz 1200 series vertical mixer (Patz, Pound, WI) and delivered once daily.

Each morning at 0600 feed refusals were collected and recorded from each bunk. Feed delivery depended on the amount of feed refusal from previous day: no feed refused for two consecutive days elicited a 0.454 kg DM/hd greater delivery; feed refusals under 0.454 kg elicited no change on feed delivery, while feed refusals > 0.454 kg led to reductions in feed deliveries by 50% of feed refusal. Steers had access to fresh clean water throughout the day; corn stalk bedding was delivered directly onto a bedded area (65 sq m/hd) weekly.

Laboratory Analysis

Mixed diet samples were collected weekly for laboratory analysis and composited monthly corresponding to each weigh period. Feed refusal (orts) were weighed and

sampled when feed remaining in the bunk appeared to be more than 0.454 kg DM; ort and ingredient samples were frozen after collection in a -20° C freezer. Samples were analyzed for DM using a 60° C drying oven (Blue M Electric, Thermal product solution, New Columbia, PA 17856) for 3 d. Dried samples were ground using a Wiley mill (Thomas Scientific, Swedesboro, NJ) with a 1-mm screen. A complete nutrient analysis profile of the diets was conducted at a commercial lab (Dairyland Laboratory, Inc., Arcadia, WI). Composite samples of feed ingredients and orts were made based on weighing period. Sample DM was determined using National Forage Testing Association (NFTA) Method 2.1.4 which included oven-drying for 3 hours at 105° C on duplicate samples. Crude protein, crude fat, NDF, ADF, Ca, P, K, Mg, and S concentrations were analyzed using AOAC method 990.03, 920.39, 2002.4, 973.18, and 953.1 (AOAC, 2012), respectively, on duplicate samples.

Statistical analysis

Continuous response data were analyzed using the MIXED procedure of SAS (SAS, Inst. Inc., Cary, NC) for a randomized block design using animal as the experimental unit. The model included treatment and block as fixed effects and pen as a random effect. The GENMOD procedure of SAS (SAS, Inst. Inc., Cary, NC) was used for categorical data with the same design model and using animal as the experimental unit. Significance was declared when $P \leq 0.05$; tendencies were discussed when $0.05 \leq P \leq 0.10$.

RESULTS AND DISCUSSION

Responses of cattle fed growing diets (Exp. 1) to dietary supplementation of SC are presented in Tables 2 and 3. No linear, quadratic or cubic trends were observed ($P > 0.17$) for cattle performance. A 9% numerically greater DMI was observed by SC1000 steers compared with SC0 and SC500 (linear $P = 0.12$; Table 3). This result was due primarily to a numerical 11% increase in DMI for SC1000 steers compared with SC0 and SC500 from d 28 to 56 ($P = 0.12$; Table 2) No other effects on performance were observed by supplementing SC in Exp. 1.

Effects of supplementing dry-rolled corn and MDG diets with SC on interim and overall feedlot performance of finishing feedlot steers (Exp. 2) are reported in Tables 4 and 5. No effects ($P > 0.30$) of supplementing dry-rolled corn/MDG diets with SC on ADG and feed efficiency were detected. A numerical linear trend for lower DMI by cattle fed increasing amounts of SC was observed ($P = 0.13$; Table 5). Compared with SC0, a 0.5 kg or greater numerical decrease in DMI was observed between d 56 and 115 ($P < 0.10$; Table 4) by SC500 and SC1000 steers. This contributed to a numerical decrease in overall DMI ($P = 0.13$; Table 5).

Effects of feeding 0, 500, or 1,000 mg SC in finishing steers diets on carcass characteristics are reported in Table 6. Feeding SC at 0, 500 or 1,000 mg had no effect on any measured carcass characteristic. Cattle in this experiment were harvested when their carcasses reached 1.25 cm rib fat depth and achieved USDA quality and yield grade at proportions on par with industry average (https://www.ams.usda.gov/sites/default/files/media/BeefQualityChoice.pdf).

Results from literature available on SC supplementation for feedlot cattle is inconclusive, and when found the most consistent evidence is for effects an increase in DMI (Franca and Rigo, 2011). Increased feed intake may result from improvements in fiber digestion for cattle (Desnoyers et al., 2009) and sheep (Payandeh and Kafilzadeh, 2007); therefore, stimulation of celluloytic bacteria activity by inclusion of yeast in the diet may result in increased feed intake. During receiving and starting periods the most consisting finding in cattle fed yeast is the effect that yeast (Finck et al., 2014) and SC (Young et al., 2017) has on DMI. This may explain the numerical increase in DMI observed in Exp. 1.

Chemical analysis of rumen fluid was not part of our experiment, but the 0.8 kg numerically greater intake response by growing steers consuming 1,000 mg SC/day may be an indirect result of greater ruminal pH as was observed by other researchers (Nisbet and Martin, 1991; Cole et al., 1992; Dawson et al., 1992; Chaucheyras-Durand and Fonty, 2001; Desnoyers et al., 2009) It is evident the beneficial effects of live yeast are greater in high-forage than in high-grain diets (Beauchemin et al., 2003; Tang et al., 2008). Numerical trends in Exp. 2 lead us to observe that cattle fed high-grain diets supplemented with SC responded with lower DMI. Sartori et al. (2017), in a meta-analysis, reported that feedlot cattle supplemented with SC had lower DMI compared with non-supplemented cattle. Acetate and propionate appear to influence DMI because propionate reduced feed intake, but acetate did not (Sartori et al., 2017). Propionate affects DMI at higher rate than acetate and butyrate (Allen, 2000). *Saccharomyces cerevisiae* supplementation increased propionate concentration in ruminal fluid as result of incremental activities of lactate-utilizing bacteria such as *Selenomonas ruminantium* and *Megasphaera elsdenii* (Chung et al., 2011). These types of bacteria convert lactate to propionate (Silberberg et al., 2013)

and their growth increases due to SC inclusion in the diet (Pinloche et al., 2013). Cabrera et al. (2000) and Gomes et al. (2001) supplemented SC on 90 days studies on growing steers, and DMI tended to be higher in the control group. This is in sharp contrast with the observation on numerical trends in Exp. 1, but may be reflective of the fiber-degrading benefits observed in cattle supplemented with SC.

Desnoyers et al. (2009), using a meta-analysis approach, proposed that SC supplementation increased ruminal pH and VFA concentration, tended to decrease lactic acid concentration, and increased DMI. Dawson et al. (1992) reported the concentration of cellulolytic bacteria in cattle receiving live yeast supplementation was greater than that in cattle fed a mixed microbial supplement or no microbial or yeast supplement. In the same experiment, ruminal pH tended to be greater in cultures with rumen fluid from cattle receiving the mixed microbial or yeast supplements than in those from cattle receiving no microbial or yeast supplement. In dairy cows, feeding SC supported greater ruminal pH and reduced time pH was under 5.6 (Bach et al., 2007). Reductions of ruminal lactate concentration and greater ruminal pH may support growth of cellulolytic bacterial species, such as *Fibrobacter succinogenes, Ruminococcus albus, and Ruminococcus flavefaciens* (Callaway and Martin, 1997). *Saccharomyces cerevisiae* supplementation was able to increase and maintain ruminal pH and decrease ruminal lactate concentrations in growing and lactating ruminants (Robinson, 2010). Concentrations of cellulolytic bacteria in rumen and batch cultures steers receiving yeast were also reported to be greater than in non-supplemented cattle (Dawson et al., 1990).

The inclusion of SC in beef diets had no effect on ADG, but reduced DMI and improved feed conversion (Sartori et al., 2017). This report agrees with our results that finishing steers on high concentrate had a decrease on DMI, and a slightly improved feed efficiency when SC was supplemented. Average daily gain is directly related to DMI. However, due to a lack of DMI difference in many researches, ADG has not been not different except for a few experiments (Zhou et al., 2009; Panda et al., 1995). Due to the lack of difference on DMI and/or ADG, a difference on feed efficiency is also unexpected (Lesmeister et al., 2004)

As observed in many studies, the effectiveness of SC is not consistent. Meta-analyses (Desnoyers et al., 2009; De Ondarza et al., 2010; Poppy et al., 2012) and research studies in dairy (Moallem et al., 2009; Evans et al., 2012) and beef (Swyers et al., 2009; Ovinge et al., 2018) reported inconsistent results with SC supplementation.

Our experiments with growing and finishing steers supplemented with SC indicate only numerical evidence for a role of SC supplementation on DMI. A numerical tendency for greater DMI was observed in high-forage growing diets with SC inclusion. Conversely, a numerical trend for reduced DMI in finishing cattle fed SC was observed. The discrepancies in responses to SC inclusion may be associated with type of diet, physiological stage of animals, and dose and strains of yeast.

Table 1. Dietary ingredient and nutrient composition for Exp. 1 and Exp.2 (DM basis).

	Experiment	
Item	1 (Growing)	2 (Finishing)
Dry-rolled corn, %	.	50
Corn earlage, %	37	.
MDGS[1], %	35	35
Brome hay, %	24.5	.
Corn stalks, %	.	9
Limestone, %	.	3
Liquid supp[2], %	3.5	3
NEg[3], Mcal/kg	1.14	1.39
CP, %	15.6	16.7
NDF, %	39.4	26.1
Ca, %	1.60	0.75
P, %	0.50	0.57
Fat, %	3.7	5.4
S, %	0.26	0.25

[1]Modified distillers grains with solubles (approximately 47% DM) sourced from Western Wisconsin Energy, Boyceville, WI.
[2]Quality Liquid Feeds, Dodgeville, WI.
[3]Values for the experimental diets were calculated from NRC (2000). Nutrient analysis was conducted in duplicate at Dairyland Laboratories (Arcadia, WI).

Table 2. Effects of two dietary concentrations of SC on interim feedlot performance of growing beef steers.

	SC Concentration (g/d)[1]				*P*-values[2]	
Item	0	500	1,000	SEM[3]	Linear	Quad
Day 1 to 28						
Initial BW, kg	344	335	345	0.48	0.86	0.23
Final BW, kg	395	388	400	15	0.56	0.21
DMI, kg/d	8.50	8.53	8.98	0.69	0.29	0.60
ADG, kg	1.86	1.87	1.97	0.21	0.41	0.70
Gain:Feed	0.219	0.219	0.219	0.001	0.95	0.83
Day 28 to 56						
Initial BW, kg	395	388	400	15	0.56	0.21
Final BW, kg	433	426	436	16	0.81	0.36
DMI, kg/d	9.52	9.60	10.63	0.12	0.12	0.21
ADG, kg	1.36	1.38	1.25	0.22	0.33	0.48
Gain:Feed	0.142	0.144	0.117	0.006	0.02	0.17

[1]Treatments included basal diets with 0, 500, or 1,000 g/d Levucell SC 20 (Lallemand Animal Nutrition, Blagnac, France).

[2] Linear = Linear effect of SC concentration; Quad = quadratic effect of SC concentration.

[3] Standard error

Table 3. Effects of two dietary concentrations of SC on feedlot performance of growing beef steers.

	SC Concentration (g/d)[1]				*P*-values[2]	
Item	0	500	1,000	SEM[3]	Linear	Quad
Initial BW, kg	344	335	345	7	0.86	0.23
Final BW, kg	433	426	436	8	0.81	0.36
DMI, kg/d	9.02	9.02	9.84	0.36	0.12	0.38
ADG, kg	1.6	1.62	1.61	0.07	0.88	0.86
Gain:Feed	0.180	0.180	0.164	0.006	0.12	0.17

[1] Treatments included basal diets with 0, 500, or 1,000 g/d Levucell SC 20 (C; Lallemand Animal Nutrition, Blagnac, France).

[2] Linear = Linear effect of SC concentration; Quad = quadratic effect of SC concentration.

[3] Standard error

Table 4. Effects of two dietary concentrations of SC on interim feedlot performance of finishing beef steers.

	SC Concentration (g/d)[1]				*P*-values[2]	
Item	0	500	1000	SEM[3]	Linear	Quad
Day 1 to 28						
Initial BW, kg	430	429	429	8	0.88	0.99
Final BW, kg	476	484	481	7.0	0.70	0.62
DMI, kg/d	10.3	10.4	10.3	0.5	0.93	0.76
ADG, kg	1.63	1.97	1.88	0.26	0.16	0.15
Gain:Feed	0.158	0.189	0.183	0.010	0.11	0.19
Day 28 to 56						
Initial BW, kg	476	484	481	7.0	0.70	0.62
Final BW, kg	539	541	536	9.5	0.86	0.77
DMI, kg/d	13.0	12.2	12.3	0.8	0.28	0.43
ADG, kg	2.23	2.02	1.95	0.11	0.92	0.59
Gain:Feed	0.172	0.166	0.159	0.014	0.31	0.86
Day 56 to 84						
Initial BW, kg	539	541	536	9.0	0.86	0.77
Final BW, kg	586	588	581	10.0	0.73	0.68
DMI, kg/d	11.8	11.5	10.7	0.6	0.16	0.81
ADG, kg	1.67	1.71	1.57	0.11	0.53	0.49
Gain:Feed	0.139	0.149	0.147	0.014	0.31	0.80
Day 84 to 115						
Initial BW, kg	586	588	581	10	0.73	0.68
Final BW, kg	638	632	628	11	0.53	0.92
DMI, kg/d	12.7	11.3	10.9	0.7	0.10	0.54
ADG, kg	1.57	1.48	1.48	0.15	0.62	0.80
Gain:Feed	0.124	0.131	0.136	0.022	0.15	0.22

[1] Treatments included basal diets with 0, 500, or 1,000 g/d Levucell SC 20 (C; Lallemand Animal Nutrition, Blagnac, France).

[2] Linear = Linear effect of SC concentration; Quad = quadratic effect of SC concentration.

[3] Standard error

Table 5. Effects of two dietary concentrations of SC on feedlot performance of finishing beef steers.

	SC Concentration (g/d)[1]				*P*-values[2]	
Item	0	500	1000	SEM[3]	Linear	Quad
Initial BW, kg	430	429	429	8	0.88	0.99
Final BW, kg	638	631	628	11	0.53	0.92
DMI, kg/d	12.1	11.3	11.1	1.1	0.13	0.67
ADG, kg	1.82	1.74	1.74	0.15	0.32	0.5?
Gain:Feed	0.151	0.153	0.157	0.005	0.30	0.47

[1] Treatments included basal diets with 0, 500, or 1,000 g/d Levucell SC 20 (C; Lallemand Animal Nutrition, Blagnac, France).

[2] Linear = Linear effect of SC concentration; Quad = quadratic effect of SC concentration.

[3] Standard error

Table 6. Effects of two dietary concentrations of SC on carcass characteristics of beef feedlot steers.

	SC Concentration (g/d)[1]				*P*-values[2]	
Item	0	500	1000	SEM[3]	Linear	Quad
HCW, kg	379	377	377	8	0.86	0.96
Backfat, cm	1.29	1.07	1.22	0.36	0.67	0.16
REA[4], sq cm	88.1	91.9	90.4	6.4	0.39	0.28
Marbling[5]	477	469	451	82	0.42	0.86
Avg. USDA YG[6]	2.63	2.11	2.25	0.77	0.17	0.17
YG 1, %	28.5	37.5	31.3	28.8	0.93	0.18
YG 2, %	7.0	18.8	18.8	9.3	0.31	0.56
YG 3, %	45.0	37.5	43.7	26.1	0.77	0.60
YG 4, %	13.0	6.3	6.3	8.9	0.53	0.68
YG 5, %	6.5	0.0	0.0	0.0	1.00	1.00
Prime QG[7], %	12.9	6.3	0.0	5.8	1.00	1.00
Choice QG, %	45.5	62.5	62.5	11.3	0.36	0.59
Select QG, %	41.0	18.8	25.0	10.2	0.90	0.47
Standard QG, %	0.57	12.5	12.5	6.5	0.17	0.17

[1] Treatments included control diet with 0, 500, or 1,000 g Levucell SC 20 (C; Lallemand Animal Nutrition, Blagnac, France).

[2]Linear = Linear effect of SC concentration; Quad = quadratic effect of SC concentration.

[3] Standard error.

[4] Ribeye (longissimus muscle) area measured at the 12th rib.

[5] Marbling score assessed by USDA grader where 400 = Small_0, 500 = Modest_0, etc.

[6] USDA yield grade assessed by USDA grader.

[7] USDA quality grade assessed by USDA grader.

LITERATURE CITED

A.O.A.C. 2012. Official Methods of Analysis, 19th ed. Association of Official Analytical Chemists. Washington, DC.

Akin, D. E. 1989. Histological and physical factors affecting digestibility of forages. Agric. J. 8119891725.

Allen, M. S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. J. Dairy Sci. 83:1598-1624.

Angeles, C.S., G. L. Corona, P. F. Castrejon, M. G. D. Mendoza, and P. M. Cobos. 1995. Cambios en la población de protozoarios en el metabolismo ruminal utilizando dos cultivos de levadura. Vet. Mex. (Suppl. 2) 26.275. Anim. Sci. 80:1395-1404.

Auclair, E. 2001.Yeast as an example of the mode of action of probiotics in monogastric and ruminant species. In: J. Brufau (Ed.), Feed manufacturing in the Mediterranean region. Improving safety: From feed to food. pp. 45-53.

Bach, A., C. Iglesias, and M. Devant. 2007. Daily rumen pH pattern of loose-housed dairy cattle as affected by feeding pattern and live yeast supplementation. Anim. Sci. Technol., 136:146–153.

Bartle, S. J., and R. L. Preston. 1991. Dietary roughage regimen for feedlot steers: Reduced roughage level (2%) during the mid-finishing period. J. Anim. Sci. 69:3461.

Bartle, S. J., and R. L. Preston. 1991. Effects of liver abscesses on steer performance and carcass characteristics. Texas Tech. Agric. Sci. Tech. Rep. No. T-5-297:57.

Bartle, S. J., R. L. Preston, and M. F. Miller. 1994. Dietary energy source and density: Effects of roughage source, roughage equivalent, tallow level, and steer type on feedlot performance and carcass characteristics. J. Anim. Sci. 72:1943–1953.

Beauchemin, K. A., W. Z. Yang, D. P. Morgavi, G. R. Ghorbani, W. Kautz, and J. A. Leedle. 2003. Effects of bacterial direct-fed microbials and yeast on site and extent of digestion, blood chemistry, and subclinical ruminal acidosis in feedlot cattle. J. Anim. Sci. 81:1628–1640.

Benton, J.R., G. E. Erickson, T. J. Klopfenstein, K. J. Vander Pol, and M. A. Greenquist. 2007. Effects of roughage source and level with the inclusion of wet distillers grains on finishing cattle performance and economics. in: NE Beef Cattle Rep. Uni, Nebraska–Lincoln; 2007:29–32 (MP90)

Berchielli, T. T., and L. M. A. Bertipaglia. 2010. Utilização de aditivos na produção de bovinos de corte. In: Bovinocultura. Pires, A. V. (eds.). Piracicaba, Brazil .pp. 295-330.

Berger, L., and V. Singh. 2010. Changes and evolution of corn coproducts for beef cattle. J. Anim. Sci. 88:E143-E150.

Binversie, E. Y., M. Ruiz-Moreno, A. J. Carpenter, B. J. Heins, G. I. Crawford, A. DiCostanzo, and M. D. Stern. 2016. Effects of dietary roughage and sulfur in diets

containing corn dried distillers grains with solubles on hydrogen sulfide production and fermentation by rumen microbes in vitro. J. Anim. Sci. 94:3883–3893.

Bonhomme, A. 1990. Rumen ciliates: their metabolism and relationships with bacteria and their hosts. Anim. Feed Sci. Technol. 30:203-266.

Bradley, A. S., W. D. Leavitt, and D. T. Johnston. 2011. Revisiting the dissimilatory sulfate reduction pathway. Geobiology 9:446-457.

Bramley, E., I. J. Lean, W. J. Fulkerson, M. A. Stevenson, A. R. Rabiee, and N. D. Costa. 2008. The definition of acidosis in dairy herds predominantly fed on pasture and concentrates. J. Dairy Sci. 91(1):308-321.

Broadway, P. R., J. A. Carroll, and N. C. Burdick Sanchez. 2015. Live Yeast and Yeast Cell Wall Supplements Enhance Immune Function and Performance in Food-Producing Livestock. Microorganisms 417-427.

Buckner, C. D., M. F. Wilken, J. R. Benton, S. J. Vanness, V. R. Bremer, T. J. Klopfenstein, P. J. Kononoff, and G. E. Erickson. 2011. Nutrient variability for distiller's grains plus solubles and dry matter determination of ethanol by-products. Prof. Anim. Sci. 27:57-64.

Cabrera, E. J. I., M. G. D. Mendoza, I. E. Aranda, C. Garcia-Bojalil, G. R. Bárcena, and J. J. A. Ramos. 2000. Saccharomyces cerevisiae and nitrogenous supplementation in growing steers grazing tropical pastures. J. Anim. Sci. Tech. 83:49-55.

Callaway, E. S. and S. A. Martin. 1997. Effects of Saccharomyces cerevisiae culture on ruminal bacteria that utilize lactate and digest cellulose. J. Dairy Sci. 80:2035-2044.

Callaway, T. R., S. E. Dowd, T. S. Edrington, R. C. Anderson, N. Krueger, N. Bauer, P. J. Kononoff, and D. J. Nisbet. 2010. Evaluation of bacterial diversity in the rumen and feces of cattle fed different levels of dried distillers grains plus solubles using bacterial tag encoded FLX amplicon pyrosequencing. J. Anim. Sci. 88: 3977-3983.

Carro, M. D., P. Lebzien, and K. Rohr. 1992. Influence of yeast culture on the in vitro fermentation (Rusitec) of diets containing variable portions of concentrates. Anim. Feed Sci. Technol. 37: 209-220.

Castillo, C., J. Hernandez, V. Pereira, and J. L. Benedito. 2012. Update about nutritional strategies in feedlot for preventing ruminal acidosis. In: Advances in Zoology Research. Jenkins (eds). vol. 4. Nova Science Publishers. NY. pp. 1–84.

Chaucheyras F., G. Fonty G., Bertin, and P. Gouet. 1995. Effects of live Saccharomyces cerevisiae cells on Zoospore germination, growth and cellulolytic activity of the rumen anaerobic fungus Neocallimastix frontalis MCH3. Can. J. Microbiol. 201–205.

Chaucheyras F., G. Fonty, G. Bertin, J. M. Salmon, and P. Gouet. 1996. Effects of a strain of Saccharomyces cerevisiae (Levucell SC), a microbial additive for ruminants, on lactate metabolism in vitro. Can. J. Microbiol. 42: 927-933.

Chaucheyras-Durand F., and G. Fonty. 2002. Influence of a probiotic yeast (Saccharomyces cerevisiae CNCM I-1077) on microbial colonization and fermentation in the rumen of newborn lambs. Microb. Eco. in Health and Disease. 14:30-36.

Chaucheyras-Durand, F., E. Chevaux, C. Marin, and E. Forano. 2012. Use of Yeast Probiotics in Ruminants: Effects and mechanisms of Action on Rumen Ph, Fibre Degradation, and Microbiota According to the Diet. On line. Available. https://www.intechopen.com/books/probiotic-in-animals/use-of-yeast-probiotics-in-ruminants-effects-and-mechanisms-of-action-on-rumen-ph-fibre-degradation-. Accessed March 7, 2019.

Chaucheyras-Durand., and G. Fonty. 2001. Establishment of cellulolytic bacteria and development of fermentative activities in the rumen of gnotobiotically-reared lambs receiving the microbial additive Saccharomyces cerevisiae CNCM I-1077. Reprod. Nutr. Dev. 57-68.

Cheng, K. J., C. W. Forsberg, H. Minato, and J. W. Costerton. 1991. Microbial ecology and physiology of feed degradation within the rumen. In: Physiologi- cal Aspects of Digestion and Metabolism in Ruminants. Tsuda, T., Y. Sasaki, and R. Kawashima (eds.). Academic Press, Toronto, ON. pp. 595–624.

Chung, Y. H., N. D. Walker, S. M. McGinn, and K. A. Beauchemin. 2011. Differing effects of 2 active dried yeast (Saccharomyces cerevisiae) strains on ruminal acidosis and methane production in nonlactating dairy cows. J. Dairy Sci. 92:2431-2439.

Cole, N. A., C. W. Purdy, and D. P. Hutcheson. 1992. Influence of yeast culture on feeder calves and lambs. J. Anim. Sci. 70:1682-1690.

Cooper, G. 2012. Ethanol and Distillers Grains Exports. Renewable Fuels Association. Washington DC. United States. On line. Available http://www.ethanolrfa.org/exchange/entry/september-ethanol-and-distillers-grains-exports. Accessed January 31, 2013.

Cosgrove, D. J. 2005. Growth of the plant cell wall. Nat. Rev. Mol. Cell Biol. 2005;6: 850–861.

Crawford, G. I. 2010. Feeding the next generation of corn ethanol byproducts to beef cattle. Proc. Minnesota Nutrition Conference. pp. 90-101.

Crawford, G. I., C. D. Keeler, J. J. Wagner, C. R. Krehbiel, G. E. Erickson, M. B. Crombie and G. A. Nunnery. 2008. Effects of calcium magnesium carbonate and roughage level on feedlot performance, ruminal metabolism, and site and extent of digestion in steers fed high-grain diets. J. Anim. Sci. 86:2998-3013.

Cummings, B. A., D. R. Caldwell, D. H. Gould, and D. W. Hamar. 1995. Identity and interactions of rumen microbes associated with dietary sulfate-induced polioencephalomalacia in cattle. Am. J. Vet. Res. 56:1384-1389.

Czerucka, D., T. Piche, and P. Rampal. 2007. Review article: yeast as probiotics – Saccharomyces boulardii. Aliment. Pharmacol. Ther. 26: 767–778.

Czerucka, D., T. Piche, and P. Rampal. 2007. Review article: yeast as probiotics – Saccharomyces boulardii. Aliment. Pharm. Ther. 26:767–778.

Dawson, K. A. 1992. Current and future role of yeast culture in animal production: A review of research over the past six years. In: Lyons TP (eds.): Proceedings of Alltech's 8th annual symposium, Nicholasville, KY. 1-23.

Dawson, K. A., K. E. Newman, and J. A. Boling. 1990. Effects of microbial supplements containing yeast and lactobacilli on roughage-fed ruminal microbial activities. J. Anim. Sci. 68:3392-3398.

De Ondarza, M. B., C. J. Sniffen, L. Dussert, E. Chevaux, J. Sullivan, and N. D. Walker. 2010. Case study: Multiple-Study analysis of the effect of live yeast on milk yield, milk component content and yield, and feed efficiency. Prof. Anim. Sci. 26:661–666.

De Ondarza, M. B., C. J. Sniffen, L. Dussert, E. Chevaux, J. Sullivan, and N. Walker. 2010. Case study: multiple-study analysis of the effect of live yeast on milk yield, milk component content and yield and feed efficiency. Prof. Anim. Sci. 26:661–666.

Defoor, P. J., M. L. Galyean, G. B. Salyer, G. A. Nunnery, and C. H. Parsons. 2002. Effects of roughage source and concentration on intake and performance by finishing heifers. J. Anim. Sci. 80:1395-1404.

Delfiol, D. J., D. Q. Cagnini, P. H. Cunha, N. Crosignani, A. T. Wouters, F. Wouters, D. Driemeier, and A. S. Borges. 2013. Clinical and laboratory aspects of sheep

supplemented with high levels of sulfur in diet to induce polioencephalomalacia. Pesquisa Vet. Bras. 33:435-442.

Depenbusch, B. E., C. M. Coleman, J. J. Higgins, and J. S. Drouillard. 2009. Effects of increasing levels of dried corn distillers grains with solubles on growth performance, carcass characteristics, and meat quality of yearling heifers. J. Anim. Sci. 87:2653–2663.

Desnoyers, M., S. Giger-Reverdin, G. Bertin, C. Duvaux-Ponter, and D. Sauvant. 2009. Meta-analysis of the influence of Saccharomyces cerevisiae supplementation on ruminal parameters and milk production of ruminants. J. Dairy Sci. 92:1620–1632.

Ding, G., Y. Chang, L. Zhao, Z. Zhou, L. Ren, and Q. Men. 2014. Effect of Saccharomyces cerevisiae on alfalfa nutrient degradation characteristics and rumen microbial population of steers fed diets with different concentrate-to-forage ratios. J. Anim. Sci. Biotech. 5:1-9.

Dougherty, R. W., and H. M. Cook. 1962. Routes of eructated gas expulsion in cattle—A quantitative study. Am. J. Vet. Res. 23:997–1000.

Drewnoski M. E., D. J. Pogge, and S. L. Hansen. 2014. High-sulfur in beef cattle diets: a review. J. Anim. Sci. 92:3763-80.

Eckles, C. H., and V. M. Williams. 1925. Yeast as a supplementary feed for lactating cows. J. Dairy Sci. 8:89–93.

Emmanuel, D. G, A. Jarafi, K. A. Beauchemin, J. A. Leedle, and B. N. Ametaj. 2007. Feeding live cultures of Enterococcus faecium and Saccharomyces cerevisiae induces an inflammatory response in feedlot steers. J. Anim. Sci. 85:233-9.

Environmental Protection Agency. 2010. Renewable Fuel Standard Program. On line. Available https://www.epa.gov/renewable-fuel-standard-program. Accessed May 10, 2017.

Erasmus, L.J., P. H. Robinson, A. Ahmadi, R. Hinders and J. E. Garrett. 2005. Influence of prepartum and postpartum supplementation of a yeast culture and monensin, or both, on ruminal fermentation and performance of multiparous dairy cows. Anim. Feed Sci. Technol. 122: 219–239.

Evans, E., R. J. Patterson, and N. Clark. 2012. Effects of a supplemental enhanced yeast product on digestion and milk production in dairy cows. Prof. Anim. Sci. 28:682–688.

Finck, D. N., F. R. B. Ribeiro, N. C. Burdick, S. L. Parr, J. A. Carroll, T. R. Young, B. C. Bernhard, J. R. Corley, A. G. Estefan, R. J. Rathmann, and B. J. Johnson. 2014. Yeast supplementation alters the performance and health status of receiving cattle. Prof. Anim. Sci. 30:333-341.

Flint, H. J., E. A. Bayer, M. T. Rincon, R. Lamed, and B. A. White. 2008. Polysaccharide utilization by gut bacteria: potential for new insights from genomic analysis. Nat. Rev. Microbiol. 6:121–131.

Forbes, J. M. 2003. The multifactorial nature of food intake control. J. Anim. Sci. 81:139-144.

Fox, D. G., and L. O. Tedeschi. 2002. Application of physically effective fiber in diets for feedlot cattle. Pp. 67-81 in Proc. Plains Nutr. Counc. Spring Conf. San Antonio, TX.

França, R. A., and E. J. Rigo. 2011. Utilização de leveduras vivas (Saccharomyces cerevisiae) na nutrição de ruminantes – uma revisão. FAZU em Revista, 8:187-195.

Fuller R. 1989. Probiotics in man and animals. J. Applied Bacteriol. 66: 365–378.

Galyean, M. L. 1996. Protein levels in beef cattle finishing diets: Industry application, university research, and systems results. J. Anim. Sci. 74:2860-2870.

Galyean, M. L., and J. D. Rivera. 2003. Nutritionally related disorders affecting feedlot cattle. Can. J. Anim. Sci. 83:13-20.

Galyean, M. L., and M. E. Hubbert. 2014. Review: Traditional and alternative sources of fiber—Roughage values, effectiveness, and levels in starting and finishing diets. Prof. Anim. Sci. 30:571–584.

Ghorbani, G. R., D. P. Morgavi, K. A. Beauchemin, and J. A. Z. Leedle. 2002. Effects of bacterial direct-fed microbials on ruminal fermentation blood variables, and the microbial populations of feedlot cattle. J. Anim. Sci. 80:1977–1980.

Gill, D. R., F. N. Owens, J. J. Martin, D. E. Williams, R. A. Zinn, and R. J. Hillier. 1981. Roughage levels in feedlot rations. Okla. Agr. Exp. Sta. Rep. MP-108:141.

Gomes, R. C., M. T. Antunes, S. L. Silva, and P. R. Leme. 2011. Desempenho e digestibilidade de novilhos zebuínos confinados recebendo leveduras vivas e monensina. J. Anim. Husb. Sci. 60:1077-1068.

Gould, D. H. 1998. Polioencephalomalacia. J. Anim. Sci. 76:309-314.

Gould, D. H., B. A. Cummings, and D. W. Hamar. 1997. In vivo indicators of pathologic ruminal sulfide production in steers with diet-induced polioencephalomalacia. J. Vet. Diagn. Invest. 9:72–76.

Gould, D. H., D. A. Dargatz, F. B. Garry, and D. W. Hamar. 2002. Potentially hazardous sulfur conditions on beef cattle ranches in the United States. J. Amer. Vet. Med. Asoc. 221:673-677.

Gould, D. H., M. M. McAllister, and J. C. Savage. 1991. High sulfide concentrations in the rumen fluid associated with nutritionally induced polioencephalomalacia in calves. Am. J. Vet. Res. 52:116-4.

Guedes, C. M., D. Gonçalves, M. A. M. Rodrigues, and Dias-da-Silva. 2008. Effect of yeast Saccharomyces cerevisiae on ruminal fermentation and fiber degradation of maize silage in cows. Anim. Sci. and Techn.145 27-40.

Hahn, G. L. 1994. Environmental requirements of farm animals. In: Handbook of Agricultural Meteorology. J. F. Griffiths (ed.). Oxford University Press, New York, NY. Pp. 220.

Hale, C., and Olson, K.C. 2001. Mineral Supplements for Beef Cattle, MU Guide, Published by MU Extension, University of Missouri-Columbia. Online. Available. http://extension.missouri.edu/p/G2081. Accessed May 4, 2019.

Harbers, L. H., Raiten, D. J, and G. M. Paulsen. 1981. The role of plant epiderma silica as structural inhibitor of rumen microbial digestion in steers. Nutr. Rep. Int. 24: 1057–1066.

Hicks, R. B., F. N. Owens, D. R. Gill, J. J. Martin, and C. A. Strasia. 1990. Effects of controlled feed intake on performance and carcass characteristics of feedlot steers and heifers. J. Anim. Sci. 68:233.

Hungate, R. E., R. A. Mah, and M. Simesen. 1961. Rates of production of individual volatile fatty acids in the rumen of lactatin cows. Appl. Microbiol. 554-561.

Hutcheson, D. P., and N. A. Cole. 1986. Management of transit-stress syndrome in cattle: nutritional and environmental effects. J. Anim. Sci. 62:555–560.

Iowa Renewable Fuel Association. 2019. Distillers grains facts. On line. Available https://iowarfa.org/ethanol-center/ethanol-co-products/distillers-grains-facts/. Accessed May 4, 2019.

Jayakrishnan N., D. Christensen, Y. Peiqiang, T. McAllister, N. Preston, D. Damiran, and J. J. McKinnon. 2017. Effect of variety and level of inclusion of barley varieties for silage selected to vary in neutral detergent fiber digestibility on performance and

carcass characteristics of growing and finishing beef steers. Can. J. Ani. Sci. 97: 383-394.

Jensen, D. D., and H. E. Thomas. 1954. Phytopathology. J. Econ. Entomol. 45(abstract.) 494.

Jiang, F. G., X. Y. Lin, Z. G. Yan, Z. Y. Hu, G. M. Liu, Y. D. Sun, X. W. Liu, and Z. H. Wang. 2017. Effect of dietary roughage level on chewing activity, ruminal pH, and saliva secretion in lactating Holstein cows. J. Dairy Sci. 2660-2671.

Johnson, R. W. 1997. Inhibition of growth by pro-inflammatory cytokines: An integrated view. J. Anim. Sci. 75:1244-1255.

Klopfenstein, and D. R. Smith. 2013. The effect of sulfur and use of ruminal available sulfur as a model to predict incidence of polioencephalomalacia in feedlot cattle. Bovine Pr. 47:47-53.

Koger T. J., D. M. Wulf, A. D. Weaver, C. L. Wright, K. E. Tjardes, K. S. Mateo, T. E. Engle, R. J. Maddock, and A. J. Smart. 2010. Influence of feeding various quantities of wet and dry distillers grains to finishing steers on carcass characteristics, meat quality, retail-case life of ground beef, and fatty acid profile of longissimus muscle. J. Anim. Sci. 88:3399-3408.

Koike, S., J. Pan, Y. Kobayashi, and K. Tanaka. 2003. Kinetics of in sacco fiber-attachment of representative ruminal cellulolytic bacteria monitored by competitive PCR. J. Dairy Sci. 86:1429-1435.

Kong. Y., Y. Xia, R. Seviour, M. He, T. McAllister, and R. Forster. 2012. In situ identification of carboxymethyl cellulose-digesting bacteria in the rumen of cattle fed alfalfa or triticale. Microb. Eco.80:159-167.

Kreikemeier, K. K., D. L. Harmon, R. T. Brandt Jr., T. G. Nagaraja, and R. C. Cochran. 1990. Steam-rolled wheat diets for finishing cattle: Effects of dietary roughage and feed intake on finishing steer performance and ruminal metabolism. J. Anim. Sci. 68:2130-2141.

Kung, Jr. L., J. P. Bracht, A. O. Hession, and J. Y. Tavares. 1998. High sulfate induced polioencephalomalacia (PEM) in cattle-burping can be dangerous if you are a ruminant. Proc. Chr. Hansen's Technical Symposium. Pacific Northwest Nutrition Conference. Vancouver, BC, Canada. On line. Available. http://ag.udel.edu/anfs/faculty/kung/H2S.htm. Accessed April 5, 2019.

Lean, I.J., L. K. Wade, and Z. K. Rajczyk. 1998. Managing dynamic change: Disease prevention and increased production in the peri-parturient cow. Dairy Cattl. Vet. of the NZ. Vet. Ass. pp. 1-30

Lee, G. J., and W. R. McManus. 1982. Changes in Rumen Fluid Composition and in the Rumen Epithelium when Wheat is Introduced to the Diet of Sheep: The Influence of Wheat and Hay Consumption. Aust. J. Agr. Res. 33: 321-333.

Lesmeister, K. E., A. J. Heinrichs, and M. T. Gabler. 2004. Effects of supplemental yeast (Saccharomyces cerevisiae) culture on rumen development, growth characteristics, and blood parameters in neonatal dairy calves. J. Dairy Sci. 87:1832–9.

Lila, Z. A., N. Mohammed, T. Yasui, Y. Kurokawa, S. Kanda, and H. Itabashi. 2004. Effects of a twin strain of Saccharomyces cerevisiae live cells on mixed ruminal microorganism fermentation in vitro. J. Anim. Sci. 82:1847-1854.

Loerch, S. C. 1991. Effects of feeding growing cattle high-concentrate diets at a restricted intake on feedlot performance. J. Anim. sci. 88:3088.

Loerch, S. C. 1991. Efficacy of plastic pot scrubbers as a replacement for roughage in high concentrate cattle diets. J. Anim. Sci. 69:2321.

Lofgreen, G. P., A. E. El Tayeb, and H. E. Kiesling. 1981. Millet and alfalfa hays alone and in combination with high-energy diet for receiving stressed calves. J. Anim. Sci. 52:959–968.

Loneragan, G. H. D. H. Gould, R. J. Callan, C. J. Sigurdson, and D. W. Hamar. 1998. Association of excess sulfur intake and an increase in hydrogen sulfide concentrations in the ruminal gas cap of recently weaned beef calves with polioencephalomalacia. J. Am. Vet. Med. Assoc. 213:1599–604 1571.

Lynch, H.A., and S. A. Martin. 2002. Effects of Saccharomyces cerevisiae culture and Saccharomyces cerevisiae live ells on in vitro mixed ruminal microorganism fermentation. J. Dairy Sci. 85:2603-2608.

Mader, T. L., L. R. Fell, and M. J. McPhee. 1997. Behavior response of non-brahman cattle to shade in commercial feedlots. Am. Soc. Agric. Eng., St. Joseph, MI. Proc. 5th Int. Livest. Envir. Symp. p 795.

Marden, J. P., C. Julien, V. Monteils, E. Auclair, R. Moncoulon, and C. Bayourthe. 2008. How does live yeast differ from sodium bicarbonate to stabilize ruminal pH in high-yielding dairy cows?. J. Dairy Scien. 91:3528-3535.

May, M. L., J. C. DeClerck, J. Leibovich, M. J. Quinn, N. DiLorenzo, D. R. Smith, K. E. Hales, and M. L. Galyean. 2010. Corn or sorghum wet distillers grains with solubles in combination with steam-flaked corn: In vitro fermentation and hydrogen sulfide production. J. Anim. Sci. 88:2425–2432.

McAllister, T. A. and K.-J. Cheng. 1996. Microbial strategies in the ruminal digestion of cereal grains. Anim. Feed Sci. Technol. 62:29-36.

McAllister, T. A., K. A. Beauchemin, A. Y. Alazzeh, J. Baah, R. M. Teather, and K. Stanford. 2011. Review: The use of direct fed microbials to mitigate pathogens and enhance production in cattle. Can. J. Anim. Sci. 91:93-211.

Mertens, D. R. 2002. Measuring fiber and its effectiveness in ruminant diets. AREC 02-20. p. 40–66 in Proc. Plains Nutr. Counc. Spring Conf. San Antonio, TX.

Mertens, D.R. 1985. Factors influencing feed intake in lactating cows: from theory to application using neutral detergent fiber. pp. 1–18 in Proc. Georgia Nutrition Conference. Athens, GA.

Miranda, R. L. A., M. G. D. Mendoza, J. R. Barcena-Gama, M. S. Gonzalez, R. Ferrara, C. M. E. Ortega, and P. M. A. Cobos. 1996. Effect of Saccharomyces cerevisiae

and Aspergillus oryzae cultures and NDF level on parameters of ruminal fermentation. Anim. Feed Sci. and Tech.63:289-296.

Moallem, U., H. Lehrer, L. Livshitz, M. Zachut, and S. Yakoby. 2009. The effects of live yeast supplementation to dairy cows during the hot season on production, feed efficiency and digestibility. J. Dairy Sci. 92:343–351.

Morine, S. J., M. E, Drewnoski, A. K. Johnson, and S. L. Hansen. 2014. Determining the influence of dietary roughage concentration and source on ruminal parameters related to sulfur toxicity. J. Anim. Sci. 2013-6925.

Morine, S. J., M. E. Drewnoski and S. L. Hansen. 2012. Determining the influence of dietary NDF concentration from bromegrass hay on performance of steers fed high sulfur diets. J. Anim. Sci. 90:404.

Mosoni, P., F. Chaucheyras-Durand, C. Béra-Maillet, and E. Forano. 2007. Quantification by real-time PCR of cellulolytic bacteria in the rumen of sheep after supplementation of a forage diet with readily fermentable carbohydrates. Effect of a yeast additive. J. Appl. Microb.103: 2676–2685.

Murphy M. 2004. Making the most of grass-based forages in diet formulation. Adv. Dairy Technol. 16: 205-215.

Nagaraja T.G and K. F. Lechtenberg. 2007. Acidosis in feedlot cattle. Veterinary Clinics of North America—Food Animal Practice, vol. 23, no. 2, pp. 333–350.

Nagaraja, T. G., and E. C Titgemeyer. 2007 Ruminal acidosis in beef cattle: the current microbiological and nutritional outlook. J. Dairy Sci. 1:17-38.

Narendranath, N. V., and R. Power. 2005. Relationship between pH and medium dissolved solids in terms of growth and metabolism of Lactobacilli and Saccharomyces cerevisiae during ethanol production. Appl. Environ. Microbiol. 71: 2239-2243.

Newbold, C. J., P. W. Griffin, and R. J. Wallace. 1995. Interactions between rumen bacteria and ciliate protozoa in their attachment to barley straw. Lett. Appl. Microbiol. 8:63–66.

Newbold, C. J., R. J. Wallace, X. B. Chen, and F. M. McIntosh. 1995. Different strains of Saccharomyces cerevisiae differ in their effects on ruminal bacterial numbers in vitro and in sheep, J. Anim. Sci. 73:1811–1818.

Newbold, C.J., R. J. Wallace, and F. M. McIntosh. 1996. Mode of action of the yeast Saccharomyces cerevisiae as a feed additive for ruminants. Br. J. Nutr. 76: 249–261.

Nichols, C. A., V. R. Bremer, A. K. Watson, C. D. Buckner, J. L. Harding, G. E. Erickson, T. J. Klopfenstein, and D. R. Smith. 2013. The effect of sulfur and use of ruminal available sulfur as a model to predict incidence of polioencephalomalacia in feedlot cattle. Bovine Pr. 47:47-53.

Nisbet, D.J., and S. A. Martin. 1991. Effect of a Saccharomyces cerevisiae culture on lactate utilization by the ruminal bacterium Selenomonas ruminantium. J. Anim. Sci. 69:4628-4633.

Nocek, J. E. 1997. Bovine Acidosis: Implications on Laminitis. J. Dairy Sci. 80: 1005-1028.

NRC. 2005. Mineral Tolerance of Animals (2nd Ed.). National Academies Press. Washington, D.C.

Orpin, C. G. 1984. The role of ciliate protozoa and fungi in the rumen digestion of plant cell walls. Anim. Feed Sci. Technol. 10:121-143.

Ovinge, L. A., J. O. Sarturi, M. L. Galyean, M. A. Ballou, S. J. Trojan, P. R. B. Campanili, A. A. Alrumaih, and L. A. Pellarin. 2018. Effects of a live yeast in natural-program finishing feedlot diets on growth performance, digestibility, carcass characteristics, and feeding behavior. J. Anim. Sci. 96:684-693.

Owens, F. N., D. S. Secrist, W. J. Hills, and D. R. Gill. 1998 Acidosis in cattle: A review. J. Anim. Sci. 76:275-286.

Panda, A. K., R. Singh, and N. N. Pathak. 1995. Effect of dietary inclusion of Saccharomyces cerevisiae on growth performance of crossbred calves. J. Appl. Anim. Res. 7:195–200.

Payandeh, S., and F Kafilzadeh. 2007. The effect of yeast (Saccharomyces cerevisiae) on nutrient intake, digestibility and finishing performance of lambs fed a diet based on dried molasses sugar beet pulp. Pak. J. Biol. Sci. 10:4426–4431.

Phillips, I., M. Casewell, T. Cox, B. De Groot, C. Friis, R. Jones, C. Nightingale, R. Preston, and J. Waddell. 2004. Does the use of antibiotics in food animals pose a risk to human health? A critical review of published data. J. Antimicrob. Chemother. 53: 28–52.

Pinloche, E., N. McEwan, J. P. Marden, C. Bayourthe, E. Auclair, and C.J. Newbold. 2013. The effects of a probiotic yeast on the bacterial diversity and population structure in the rumen of cattle. Plos One. 8:e67824.

Plata, F. P., J. R. Bárcena-Gama, and S. G. M. 1994. Effect of a yeast culture (Saccharomyces cerevisiae) on neutral detergent fiber digestion in steers fed oat straw-based diets. Anim. Feed Sci. Technol. 49: 203-210.

Poppy, G. D, A. R. Rabiee, I. J. Lean, W. K. Sanchez, K. J. Dorton, and P. S. Morley. 2012. A meta-analysis of the effects of feeding yeast culture produced by anaerobic fermentation of Saccharomyces Cerevisiae on milk production of lactating dairy cows. J. Dairy Sci. 95:6027–6041.

Price, M. A., and R. T. Berg. 1977. The prediction of bone weight in beef carcasses by partial dissection. Can. J. Anim. Sci. 57: 816.

Qi, K., F. N. Owens, and C. D. Lu. 1994. Effects of sulfur deficiency on performance of fiberproducing sheep and goats: a review. Small Rum. Res. 14:115-126.

Raisbeck, M. F. 1982. Is polioencephalomalacia associated with high-sulfate diets?. J. Am. Vet. Med. Assoc. 180:1303-1305.

Renewable Fuels Association (RFA). 2016. U. S exports of distillers grains set new record in 2015. Washington, DC. https://ethanolrfa.org/2016/02/u-s-exports-of-distillers-grains-set-new-record-in-2015-according-to-rfa-report/. Accessed March 25, 2019.

Renewable Fuels Association (RFA). 2018. Contribution of the ethanol industry to the economy of the United States in 2017. Grand Forks, ND. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1899. Accessed March 26, 2019.

Renewable Fuels Association (RFA). 2018. Distillers grains exports are second-highest on record. Grand Forks, ND. http://ethanolproducer.com/articles/16040/rfa-2018-distillers-grains-exports-are-second-highest-on-record/. Accessed March 25, 2019.

Renewable Fuels Association (RFA). 2019. How Ethanol is made?. Washington, DC. https://ethanolrfa.org/how-ethanol-is-made/. Accessed March 25, 2019.

Renewable Fuels Association (RFA). 2019. How Ethanol is made?. Washington (DC): On line. Available https://ethanolrfa.org/how-ethanol-is-made/ . Accessed March 25, 2019.

Richter, E. L., M. E. Drewnoski and S. L. Hansen. 2012. The effect of dietary sulfur on beef steer mineral status, performance, and meat fatty acid composition. J. Anim. Sci. 90:3945–3953.

Robinson, P.H. 2010. Yeast products for growing and lactating ruminants: A literature summary of impacts on rumen fermentation and performance. On line. Available: http://animalscience.ucdavis.edu/faculty/robinson/Articles/FullText/pdf/Web200901.pdf. Accessed April 15, 2019.

Roger, V., G. Fonty, S. Komisarczuk-Bony, and P. Gouet. 1990. Effects of physicochemical factors on the adhesion to cellulose Avicel of the rumen bacteria Ruminicoccus flavefaciens and Fibrobacter succinogenes subsp. succinogenes. Appl. Environ. Microbiol. 56:3081-3087.

Rusell, J. B., and J. L. Rychlik. 2001. Factors that alter rumen microbial ecology. J. Sci. 292:1119-1122.

Sartori, E. D., M. E. A. Canozzi, D. Zago, E. R. Prates, J. P. Velho, and J. O. J. Barcellos. 2017. The effect of live yeast supplementation on beef cattle performance: A systematic review and meta-analysis. J. Agric. Sci. 9: 21–37.

Schoonmaker, J. P., and D. C. Beitz. 2012. Hydrogen sulphide: synthesis, physiological roles and pathology associated with feeding cattle maize co-products of the ethanol industry. In Biofuel Co-products as Livestock Feed: Opportunities and Challenges, Food and Agriculture Organization of the United Nations, Rome, Italy, Vol. 1, pp. 101-114.

Schulze, E., and H. A. Mooney. 1993. Biodiversity and ecosystem function. Springer-Verlag. pp. 88–90.

Schwartzkopf-Genswein, K. S., K. A. Beauchemin, D. J. Gibb, D. H. Crews, Jr., D. D. Hickman, M. Streeter, and T. A. McAllister. 2003. Impact of bunk management on feeding behaviour, ruminal acidosis and performance of feedlot cattle: A review. J. Anim. Sci. 81 (E. Suppl.): E149-E158.

Scott, R.I., N. Yarlett, K. Hillman, T. N. Williams, A. G. Williams, and D. Lloyd. 1983. The presence of oxygen in rumen liquor and its effects on methanogenesis. J. Appl. Bacteriol. 55 :143-149.

Silberberg, M., F. Chaucheyras-Durand, L. Commun, M. M. Mialon, V. Monteils, P. Mosoni, and C. Martin. 2013. Repeated acidosis challenges and live yeast supplementation shape rumen microbiota and fermentations and modulate inflammatory status in sheep. EFSA. J. Anim. 7:1910-1920.

Sip, M. L., and R. H. Pritchard. 1991. Nitrogen utilization by ruminants during restricted intake of high-concentrate diets. J. Anim. Sci. 69:2855.

Smith, D. R., N. DiLorenzo, J. Leibovich, M. L. May, M. J. Quinn, J. W. Homm, and M. L. Galyean. 2010. Effects of sulfur and monensin concentrations on in vitro dry matter disappearance, hydrogen sulfide production, and volatile fatty acid concentrations in batch culture ruminal fermentations. J. Anim. Sci. 88:1503–1512.

Sorensen, K. S., V.L. Anderson, K.R. Maddock-Carlin, C.L. Engel, C.S. Schaue, K. Olsen, and R.J. Maddock. 2013. Effects of dietary forage concentration in finishing diets on growth and carcass characteristics of steers. On line. Available. https://www.ag.ndsu.edu/HettingerREC/beef/effects-of-dietary-forage-concentration-in-finshing-diets-on-growth-and-carcass-characteristics-of-steers . Accessed May 5, 2019.

Spears J. W., K. E. Lloyd, and R. S. Fry. 2011. Tolerance of cattle to increased dietary sulfur and effect of dietary cation-anion balance. J. Anim. Sci. 89:2502-2509.

Stock, R.A., and R. A Britton. 1996. Acidosis. University of Nebraska. NebGuide. On line. Available: http://ianrpubs.unl.edu/animaldisease/g1047.htm . Accessed April 15, 2019.

Suen, G., P. J. Weimer, D. M. Stevenson, F. O. Aylward, J. Boyum, J. Deneke, C. Drinkwater, N. N. Ivanova, N. Mikhailova, O. Chertkov, L. A. Goodwin, C. R. Currie, D. Mead, and P. Brumm. 2011. The complete genome sequence of Fibrobacter succinogenes S85 reveals a cellulolytic and metabolic specialist PLoS. Wenjun. L (eds.), vol. 6, issue 4, pp. e18814

Suttle, N. F. 1991. The interactions between copper, molybdenum, and sulphur in ruminant nutrition. Annu. Rev. Nutr. 11:121-140.

Swingle, S. 1995. Effect of roughage level and type on intake and performance of feedlot cattle. Symposium: Intake by Feedlot Cattle. Oklahoma Agric. Exp. Sta. 942:257-263.

Swyers, K. L., J. J. Wagner, K. L. Dorton, and S. L. Archibeque. 2009. Evaluation of Saccharomyces cerevisiae fermentation products as a natural alternative to an ionophore on growth performance, cost of gain, and carcass characteristics of heavy-weight yearling beef steers. Proceedings from Western Section American Association of Animal Science. 60:377-381.

Tang, S.X., G.O. Tayo, Z.L. Tan, Z.H. Sun, L.X Shen, C.S. Zhou, W.J. Xiao, G.P. Ren, X.F. Han ,and S.B. Shen. 2008. Effects of yeast culture and fibrolytic enzyme supplementation on in vitro fermentation characteristics of low-quality cereal straws. J. Anim. Sci. 86:1164-1172.

Terlecki, S., and L. M. Markson. 1961. Cerebrocortical necrosis in cattle and sheep. Vet. Rec. 73: 23-27.

Thacker, P. A. 2013. Alternatives to antibiotics as growth promoters for use in swine production: a review. J. Anim. Sci. Biotech. 4:1-12.

Theurer, C. B., R. S. Swingle, R. C. Wamderley, R. M. Kattnig, A. Urias, and G. Ghenniwa. 1999. Sorghum Grain Flake Density and Source of Roughage in Feedlot Cattle Diets. J. Anim. Sci. 77:1066-1073.

Thrune, M., Bach, A., Ruiz-Moreno, M., Stern, M., and J. Linn. 2009. Effects of saccharomyces cerevisiae on ruminal PH and microbial fermentation in dairy cows: Yeast supplementation on rumen fermentation. Livest. Sci. 124: 261–265.

U.S Energy Information Administration. 2018. Six states account for more than 70% of U.S. fuel ethanol production. Washington (DC). On line. Available. https://www.eia.gov/todayinenergy/detail.php?id=36892. Accessed April 1, 2019.

Uhart, B. A., and F. D. Carroll. 1967. Acidosis in beef steers. J. Anim. Sci. 26:1195-1198.

Underwood, E. J., and N. F. Suttle. 1999. In: The Mineral Nutrition of Livestock 3rd Ed. CABI Publishing, CAB International, Wallingford, Oxon, UK.

Uwituze, S., G. L. Parson, C. J. Schneider, K. K. Karges, M. L. Gibson, L. C. Hollis, J. J. Higgins, , and J. S. Drouillard. 2011. Evaluation of sulfur content of dried distillers grains with solubles in finishing diets based on steam-flaked corn or dry-rolled corn. J. Anim. Sci. 89:2582-2591.

Vanness, S. J., N. F. Meyer, T. J. Klopfenstein, and G. E. Erickson. 2009. Ruminal sulfide levels in corn byproduct diets with varying roughage levels. Nebraska Beef Cattle Report. 92:81-83.

Ward, E. H., and H. H. Patterson. 2004. Effects of thiamin supplementation on performance and health of growing steers consuming high sulfate water. South Dakota State Univ. Beef Report. BEEF 2004-07:36-40.

Weiss, B., M. Eastridge, D. Shoemaker and N. St-Pierre. 2007. Distillers Grains Fact Sheet. On line. Available. http://ohioline.osu.edu/as-fact/distillers.html. Accessed 12 April 2019.

White. T. W., and W. L. Reynolds. 1969. Various sources and levels of roughage in steer rations. J. Anim. Sci. 28:705.

Williams, P. E. V., C. A. G. Tait, G. M. Innes, and C. J. Newbold. 1991. Effects of the inclusion of yeast culture (Saccharomyces cerevisiae plus growth medium) in the diet of dairy cows on milk yield and forage degradation and fermentation patterns in the rumen of steers. J. Anim. Sci. 69:3016-3026.

Willms, C.L., L.L. Berger, N.R. Merchen, and G. C. Fahey Jr. 1991. Utilization of alkaline hydrogen peroxide-treated wheat straw in cattle growing and finishing diets. J. Anim. Sci. 69:3917- 3924

Witzig M., J. Boguhn, S. Kleinsteuber, I. Fetzer, and M. Rodehutscord. 2010. Influence of the maize silage to grass silage ratio and feed particle size of rations for ruminants on the community structure of ruminal Firmicutes in vitro. J. Appl. Microbiol. 109:998-2010.

Wohlt, J., T. Corcione, and P. Zajac. 1998. Effect of yeast on feed intake and performance of cows fed diets based on corn silage during early lactation. J. Dairy Sci. 1998, 81, 1345–1352.

Wright, C. L., and H. H. Patterson. 2005. Effect of high-sulfate water on trace mineral status of beef steers. South Dakota State Univ. Beef Rep. BEEF 2005-17:81-86.

Wu, S., R. L, Baldwin, W. Li, C. Li, E. E. Connor and R. W. Li. 2012. The bacterial community composition of the bovine rumen detected using pyrosequencing of 16S

rRNA Genes. Metagenomics. On line. Available. http://www.ashdin.com/journals/MG/235571.pdf. Accessed March 2019.

Xiong, Y., S. J. Bartle, and R. L. Preston. 1991. Density of steam flaked sorghum grain, roughage level, and feeding regimen for feedlot cattle. J. Anim. Sci. 89:1707.

Yoon, I. K., and M. D. Stern. 1996. Effects of Saccharomyces cerevisiae and Aspergillus oryzae cultures on ruminal fermentation in dairy cows. J. Dairy Sci. 79:411–417.

Young, T. R., F. R. B. Ribeiro, N. C. Burdick Sanchez, J. A. Carroll, M. A. Jennings, J. T. Cribbs, R. J. Rathmann, J. R. Corley, and B. J. Johnson. 2017. Yeast cell wall supplementation alters the performance and health of beef heifers during the receiving period. Prof. Anim. Sci. 33:166-175.

Zebeli, Q., and B. U Metzler-Zebeli. 2012. Interplay between rumen digestive disorders and diet induced inflammation in dairy cattle. Res. Vet. Sci. 93:1099-108.

Zhou, G., Y. G. Zhen, Z. G. Yan, and Z. Q. Li. 2009. Study on the effects of yeast culture on the digestibility and growing development in calves. J. Anim. Husb. Vet. Med. 30:8–10.

Zinn, R. A., E. Alvarez, M. Mendez, M. Montaño, E. Ramirez, and Y. Shen. 1997. Influence of dietary sulfur concentration on growth performance and digestive function in feedlot cattle. J. Anim. Sci. 75:1723–1728.

ZoBell, D. 2000. When and How to Supplement Forage with Minerals. Brigham Young Univ. Provo. Utah. On line. Available.

http://extension.usu.edu/files/publications/publication/pub__356238.pdf. Accessed March 2019.