CORN VERSUS BARLEY IN BEEF CATTLE FINISHING DIETS: EFFECT ON STEER PERFORMANCE, FEEDING BEHAVIOR, AND RUMINAL ENVIRONMENT

by

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

of

Doctor of Philosophy

in

Animal and Range Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

December 2021

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ACKNOWLEDGEMENTS

I am so appreciative to the many people who provided guidance, support, and friendship throughout my graduate career. I would first like to thank Dr. Janice Bowman for taking me on as a student. Your career is something to emulate and I appreciate your mentorship, guidance and understanding throughout my PhD program. Thank you to Dr. Megan Van Emon for stepping in as my major professor. Your encouragement and advice have allowed me to complete this program. I would like to acknowledge and thank the rest of my committee members, Drs. Darrin Boss, Jane Ann Boles, and Rachel Endecott. I appreciate the time you have taken to contribute to my graduate program and for the continuous help and encouragement. A huge thank you goes to the entire crew at the Northern Agricultural Research Center. Julia Dafoe and Cory Parsons for aiding in data collection throughout the research project, Darrin Boss for facilitating this project, and the rest of the crew who truly did the heavy lifting and made this research possible. I would like to thank my family. To my parents for instilling in me a love for animal science and education. Your encouragement throughout my life has pushed me to be better. To my husband, Sam for your unwavering support. Not only did you help me in conducting this research through completion, but you have also supported me in every facet of life and have been a source of great stability throughout this process. Finally, to my daughter Grace. Thank you for reminding me what is truly important in life.

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ABSTRACT

While corn is the most common feed ingredient in the United States, barley, which is more suitable for the growing and climatic conditions at northern latitudes, can be a common feed alternative to corn. The different digestive utilization of unique feedstuffs coupled with extreme environmental conditions can pose challenges to efficiently feeding cattle in different climates. Thus, to further our understanding of the use of barley in feedlot diets at northern latitudes this study evaluated the effects of barley and corn finishing rations on feedlot performance, feeding behavior, and ruminal environment. For two consecutive years, Angus-based yearling steer calves were fed in a feedlot trial (427.3 ± 3.7 kg; n = 48 in year 1, and 406.8 ± 3.4 kg; n = 47 in year 2). Steers were randomly assigned to one of two primary basal grain dietary treatments: 1) Number 2 feed corn or 2) Hockett barley. Steers were fed in a GrowSafe system to measure individual animal intake and behavior throughout the duration of the study. Twelve steers per treatment group for each year of the study were also fitted with a HOBO pendent G accelerometer to measure activity and a SmaXtec ruminal bolus for continuous rumen monitoring of temperature and pH. Limited differences were observed in regard to performance and eating behavior of steers fed corn or barley-based diets. The steer's diet interacted with short term environmental changes to influence animal feeding behavior, but diet had limited impact on cattle lying activity. Continuous ruminal monitoring revealed average daily ruminal pH and temperature were not impacted by diet; however, diet did affect daily variation in ruminal pH and temperature. Intake patterns were also different between corn and barley-fed steers in which corn-fed steers consumed more feed the first 6 hours directly after feeding while barley-fed steers consumed more feed later in the day. Presumably, these intake patterns could be influenced by differences in diurnal patterns of ruminal pH between corn and barley. Depending on cost and production year, both barley and corn can be high quality feedstuffs to use in beef cattle finishing rations.

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

United States Beef Cattle Feedlots

High Concentrate Diets

In the United States, cattle production is one of the most important agricultural industries, accounting for $86.7 billion in cash receipts during 2018 (USDA NASS, 2019). The beef cattle industry is highly specialized and diverse ranging from cow-calf operations which typically graze rangeland to cattle feedlots focusing on finishing cattle for harvest (USDA, June 2016). While the diets of most calves prior to weaning are typically composed of grass, feedlot diets are generally 70 to 90% grain and grain byproducts. The reason for this dietary transition is due to the energy required for feedlot animals to efficiently reach target finish weights (630.95 kilograms (kg); LMIC, 2021). In today's beef cattle industry, the cost per megacalorie of net energy maintenance (NE_m) or net energy gain (NE_g) favors feeding high concentrate diets in the feedlot (Samuelson et al., 2016). Additionally, handling characteristics favor minimizing inclusion of dry forage to improve operational efficiency of mills at feedlots (Brown et al., 2006). Thus, emphasis has been placed on maximizing energy intake to produce the most efficient gains (Stock et al., 1990).

Use of Corn in Cattle Diets

A variety of feedstuffs can be used in cattle feedlot rations; however, the most common ingredient in the United States is corn (Samuelson et al., 2016). Corn is often the most economical and efficient grain source for finishing cattle (Anderson and Boyles, 1989) and,

according to a recent feedlot survey, is the primary grain used in both receiving (87.5% of respondents) and finishing (100% of respondents) diets (Samuelson et al., 2016). In the Midwestern region of the country, corn is readily available and widely produced, and the Midwest is home to a large number of cattle feed-yards. Corn is also known to be a relatively "safe" grain source to use in finishing cattle. Corn starch is less ruminally digestible relative to other feed grain alternatives, such as barley or wheat (Ørskov, 1986), with up to 30% of corn starch escaping ruminal fermentation. Corn also has a slower rate of *in situ* dry matter (DM) and starch disappearance (Surber et al., 1998). This slower rate of digestion reduces the risk of low reticulorumen pH, bloat, and acidosis.

Feed is one of the most significant expenses in livestock production. In general, feedlots often select feedstuffs based on the cost of grain, cost of processing, and availability (Owens et al., 1997). It has been demonstrated that alternative grain sources to corn, such as barley, milo, oats, and wheat can be utilized in beef cattle diets at various stages of production (Owens et al., 1997; Boss and Bowman, 1996; Johnson et al., 2020). These grain sources can yield both positive performance and economical returns (Table 1).

Table 1. A comparison of the performance of cattle fed different feed grains and the energy in the grains

Item	**Barley**	**Corn**	**Milo**	**Oats**	**Wheat**
Average Daily Gain, kg.	1.48	1.50	1.38	1.50	1.33
Dry Matter (DM) Intake, kg/day	9.17	9.08	9.53	9.13	8.53
Feed/Gain	2.82	2.93	3.15	2.78	2.90
Metabolizable Energy of Grain					
Observed DM, Mcal/kg	0.69	0.67	0.64	0.66	0.69
National Research Council[1] DM, Mcal/kg	0.63	0.67	0.59	0.57	0.65

Adapted from Owens et al, 1997

[1]NRC. 1984. Nutrient Requirements of Beef Cattle. 4th ed. The National Academies Press, Washington, DC.

However, careful attention should be paid to the nutritional quality of each unique feedstuff. While corn is readily available in the Midwest, other regions of the country rely on transporting corn to feed cattle. Due to shorter growing seasons in the northern U.S. and Canada, corn is not readily grown which can make it a costly grain source for these regions' feedlot operators (USITC, 2000). Therefore, alternative grains should be considered when feeding cattle in regions where corn is not readily available.

Use of Barley in Cattle Diets

A common alternative to corn in the northern U.S. and Canada is barley. Barley is considered one of the most widely adapted grain crops in the world and has a wide variety of uses for both humans and animals (Ulrich, 2010). Barley is extremely important for malting and cereal grain markets and is primarily developed and selected based on its malting quality characteristics (Bowman et al., 2001). A higher price is usually associated with malting barley destined for brewing (Fox, 2009). However, if barley does not meet malting standards, it is typically diverted for use as a livestock feed (Anderson et al., 2012). The state of Montana ranked second in the U.S. in barley production, with 293,000 hectares harvested in 2019 (Barr and Schwarz, 2020), and primary products including malt, feed grain, and hay (McVay et al., 2017). The use of barley as a livestock feed source has been used for cattle winter supplementation, backgrounding diets, and when managed appropriately an effective feed source in cattle feedlot rations.

Many have evaluated the use of corn and barley in finishing beef cattle rations. One of the advantages of barley grain compared to corn is the greater crude protein (CP) value (Table 2). Corn diets may need additional protein supplementation to reach a desired level of CP in the

finishing diet. However, traditionally corn grain has been considered the superior feed source due to its greater energy value (Table 2). Morrison (1956) reviewed 22 research trials conducted between 1904 and 1955 and found that ground barley was worth 88% of the value of shelled corn when fattening cattle. One would assume that cattle fed these higher energy feedstuffs would yield more positive performance outcomes. However, others have found barley and corn to be of comparative nutritive value and to yield equivalent performance and carcass quality (average daily gain, ADG; quality grade, QG; and yield grade, YG) when compared to corn (Nichols, 1988; Dion and Seoane, 1992). Owens et al. (1997) reviewed studies published after 1974 and reported no differences in ADG, dry matter intake (DMI), or feed efficiency between cattle fed corn or barley-based finishing diets. In a recent metanalysis, Bowman et al. (unpublished) reviewed literature on the performance and carcass differences observed from corn and barley fed steers from research published after 1994. In this analysis corn-fed steers exhibited greater ADG and 12th rib fat thickness. In work specific to Montana State University, Bowman et al. analyzed records from eighteen beef finishing trials conducted from 1997 to 2006 at either the Montana Agricultural Experiment Station, Bozeman, Montana or the Northern Agricultural Research Center, Havre, Montana. Findings of this metanalysis concluded while DMI did not differ between cattle fed corn and barley-based finishing diets, corn-fed cattle had greater ADG than cattle fed barley. This relationship resulted in greater gain:feed (G:F) by cattle fed corn compared to cattle fed barley-based finishing diets. In addition, corn-fed cattle had greater hot carcass weight (HCW), kidney, pelvic, and heart fat (KPH), 12th-rib fat thickness, and yield grade scores compared to cattle fed barley; percent retail cuts were greater from carcasses of steers fed barley compared to corn.

Table 2. National Research Council (NRC) Means and Standard Deviations for Corn or Barley Commonly Used in Beef Diets

Item	Barley Grain	Corn Grain, Dry Rolled
Dry Matter (% As Fed)	89.69 ± 2.40	87.22 ± 3.25
Total Digestible Nutrients (% DM)	84.1 ± 2.13	87.6 ± 1.83
Digestible Energy (Mcal/kg)	3.71 ± 0.09	3.86 ± 0.07
Metabolizable Energy (Mcal/kg)	3.04	3.17
Net Energy Maintenance (Mcal/kg)	2.06	2.17
Net Energy Gain (Mcal/kg)	1.40	1.49
Starch (% DM)	56.74 ± 4.54	72.07 ± 3.18
Neutral Detergent Fiber (% DM)	18.29 ± 3.96	9.72 ± 1.83
Acid Detergent Fiber (% DM)	7.09 ± 2.11	3.56 ± 0.88
Crude Protein (% DM)	12.78 ± 2.83	8.79 ± 0.97

NRC. 2016. Nutrient requirements of beef cattle. 8th Revised Edition ed. The National Academies Press, Washington DC.

While extensive research has been conducted evaluating the use of corn and barley in beef cattle diets, to date, the results of these studies have been inconsistent. There are several factors that may lead to this inconsistency including grain processing method or barley variety fed. In addition, research has indicated that barley has equal or greater energy values than corn in feedlot diets based on cattle performance (Boss and Bowman, 1996; Milner et al., 1996; Kincheloe et al., 2002). These performance findings also suggest that the National Research Council (NRC) could potentially underestimate the energy value of barley grain (Owens et al., 1997). Recent NRC means and standard deviations for corn and barley in beef cattle diets can be found in Table 2. Work by Bowman et al. (2019) suggested that corn and barley often have similar net energy values. However, there is substantial variation in the barley available for feeding (Hunt, 1996) and this could ultimately explain disparities in research results comparing barley and corn in cattle performance and nutritive value.

Barley Types and Barley Quality

Barley is often classified into one of two types: malt-type barley and feed-type barley. Malting barley is inferred to have greater nutritive value than feed-type barley as the starch is more available for fermentation to make beers, while feed varieties have more acceptable agronomic characteristics, but are unacceptable in malting and brewing qualities (Molina-Cano et al., 1997). Malt-type barley has been selected for the ability to be broken down by yeast, in which the protein matrix in the starchy endosperm is degraded to expose starch. This process, being similar to that of digestion in the animal, often allows for malting barleys to have greater nutritional value compared to feed varieties (Bowman, 2001). In this regard, Boss and Bowman (1996) found that steers fed Harrington, a two-row malting barley, had greater ADG, carcass quality grade, and intake of digestible starch compared to steers fed Gunhilde and Medallion, two feed-type barleys.

Barley varieties can also be classified as hulled or hulless cultivars. Hulless varieties have been shown to have increased metabolizable energy content likely due to removing the dilution effect of the fibrous hull (Ankrah et al., 1999). Beames et al. (1996) reported that hulless barley had greater digestibility and energy value when fed to pigs. Furthermore, Zinn et al. (1996) found that the net energy value was 5.6% greater in hulless barley compared to hulled when fed as the grain component to feedlot steers, however this did not translate into any difference observed in ADG. A potential disadvantage to hulless varieties was noted by Lehman et al. (1995) who suggested hulless cultivators might allow for increased rate of digestion in ruminant diets. This increase in ruminal digestion rate could allow animals to become more susceptible to metabolic disturbances like acidosis.

Other factors that contribute to variation amongst barley cultivars is whether the variety contains six-row or two-row kernel arrangement. The difference in these two classifications refers to the arrangement of kernels within the head of the plant and the number of kernels present on the head in a row (Briggs, 2012). Givens et al. (1993) proposed that barley varieties differ in terms of the composition of the protein matrix in the starchy endosperm, and thus, these characteristics might influence ruminal degradability. Additionally, the two-row varieties produce fewer kernels but allow for larger kernels with greater starch content. When analyzing soluble fractions and slowly degradable fractions of barley degradation curves, two-rowed barley was more degradable than six-rowed (Lehman et al., 1995). Thus, two-rowed barley often elicits improved cattle performance compared to six-rowed (Boss and Bowman, 1996; Ovenell-Roy et al., 1998). This improvement in animal performance may again be due, to some extent, to kernel plumpness. Six-row varieties tend to be less plump, thus starch accounts for a lower proportion of the total kernel weight, which can result in reduced starch content with increased protein and fiber content (Bowman et al., 2001; O'Donovan, 2015).

Finally, barley varieties differ in amylose content. Rich amylose content is found in non-waxy and relatively low amylose is found in waxy varieties. These waxy and non-waxy varieties have also been shown to be different in starch consistency, gelatinization, and viscosity (Gudmundsson and Eliasson, 1992); and in general, waxy starch types hydrate faster and have increased rate of digestion compared to non-waxy starch types (Huntington, 1997). Hristov et al. (2002) sought to investigate the effect of barley amylopectin content on ruminal fermentation and ammonia utilization by ruminant bacteria in *in vitro* systems. Ammonia-N uptake was enhanced when barley was used instead of corn, and waxy barleys further stimulated this

process. Previous research has been conducted to determine the nutritional quality of barley varieties for ruminants with varying levels of amylose. In a study conducted by Damiran and Yu (2011), the zero-amylose waxy barley variety tested had the greater effective degradability of protein. Thus, it was concluded that ruminal response to barley depends on its variety and starch composition.

In addition to barley variety, multiple other factors can impact the nutritional value of barley (Ovenell-Roy et al., 1998; Bowman, 2001). The measure of the nutritive value of barley has traditionally been test weight. Greater test weights commonly are associated with plumper kernels that presumably have greater starch and lower fiber content. While it is widely believed that test weight is a good indicator of barley feed quality, previous research suggests this relationship is weak (Hunt, 1996). Additionally, bulk weight could not be used accurately to predict digestible energy of barley (Christison and Bell, 1975), and similar net energy values have been reported between barleys having different bulk densities (McDonnell et al., 2003). It has also been shown that higher test weight barleys did not yield any differences in animal growth performance (Mathison et al., 1991). To further define cereal grain quality, it is necessary to evaluate starch and fiber content and not test weight alone (Hunt, 1996).

Growing conditions can have a significant influence on barley composition from year to year. Research at Montana State University found that growing year impacted feed quality traits with average starch content varying from 52.8 to 56.9 % (Surber et al., 1999). Additionally, growing conditions such as irrigated or dryland environments affected varying types of feed value. In a Montana State University study, the same barley varieties were grown under both irrigated and dryland environments. Dryland barley yielded lower NE_m and NE_g; however, DMI

was greater for diets containing barley from dryland environments compared to the irrigated cultivar when fed to cattle (McDonnell, 2004). Generally, when comparing barley grown in irrigated and dryland environments the dryland barley yields greater crude protein and reduced acid detergent fiber (ADF) and starch content (Bowman, 2001).

Starch Utilization in Ruminants

The structure of grain kernels is reflective of their biological function. The pericarp encases the embryo or germ, as well as, the endosperm, which contains most of the starch. The endosperm contains starch granules often embedded in a protein matrix (Kotarski et al., 1992). Starch is the major energy component of grains and occurs in two important molecular configurations of glucose polymers: amylose and amylopectin. Amylose (α1-4 linkages) is a linear polymer of glucose while amylopectin (α1-4 and α1-6 linkages) is a larger, highly branched polymer (Kellems, 2003). Proportions of the two polysaccharides, as well as the total starch content can vary widely between grain types and thus animal performance can differ significantly depending on production scenario and grain types fed (Huntington, 1997).

Ruminants do not produce salivary amylase; therefore, the first site of starch digestion is the rumen (Pond et al., 2004). Bacteria, protozoa, and fungi are all known to play a role in ruminal digestive processes; however, the bulk of fermentation is performed by ruminal bacteria. Kotarski et al. (1992) identified 15 strains of amylolytic bacteria often present when the animal is fed a high grain diet. Ruminal starch fermentation rates vary and can be influenced by interrelationships of several factors such as grain type, grain processing method, diet, and ruminal species. The rate and extent of starch digestion in the ruminant can ultimately influence

the ruminal environment as well as the starch available for post ruminal digestion (Kotarski et al., 1992).

Starch utilization in the small intestine is similar in both ruminants and non-ruminants. The process of starch assimilation begins in the small intestine with the secretion of pancreatic α-amylase (Harmon et al., 2004). Amylases break starch into glucose which can be absorbed through the intestinal wall. Energetically, small intestinal digestion can offer efficiency advantages over ruminal fermentation of non-structural carbohydrates (Owens et al., 1986; Harmon et al., 2004). Data from cattle fed processed corn and sorghum indicated starch was utilized 42% more efficiently if digested in the small intestine compared to the rumen (Tyrrell and Moe, 1974; Owens et al., 1986); however, Huntington (1997) and Taniguchi et al. (1995) concluded that the greatest amount of energy was supplied to ruminants when starch was digested in the rumen. Maximizing starch flow to the small intestine may be accompanied by decreased total tract digestion. Digestion and absorption of starch in the small intestine may be incomplete (Ørskov, 1986; Huntington et al., 2006) thereby limiting the usefulness of starch escaping ruminal fermentation. While the large intestine does participate in fermentation and can utilize starch components and produce VFAs prior to excretion, digestive efficiency is the lowest in this region of the digestive tract. Cereal grains are the primary component of rations fed to cattle to promote high levels of performance in intensive systems. Thus, understanding starch utilization and digestive efficiency in different regions of the gastrointestinal tract is important for evaluating efficiency of cattle production (Theurer, 1986).

Common sources of cereal grains in beef cattle diets include corn, sorghum, and barley. Corn and sorghum contained approximately 72% starch and barley averaged 57% (Herrera-

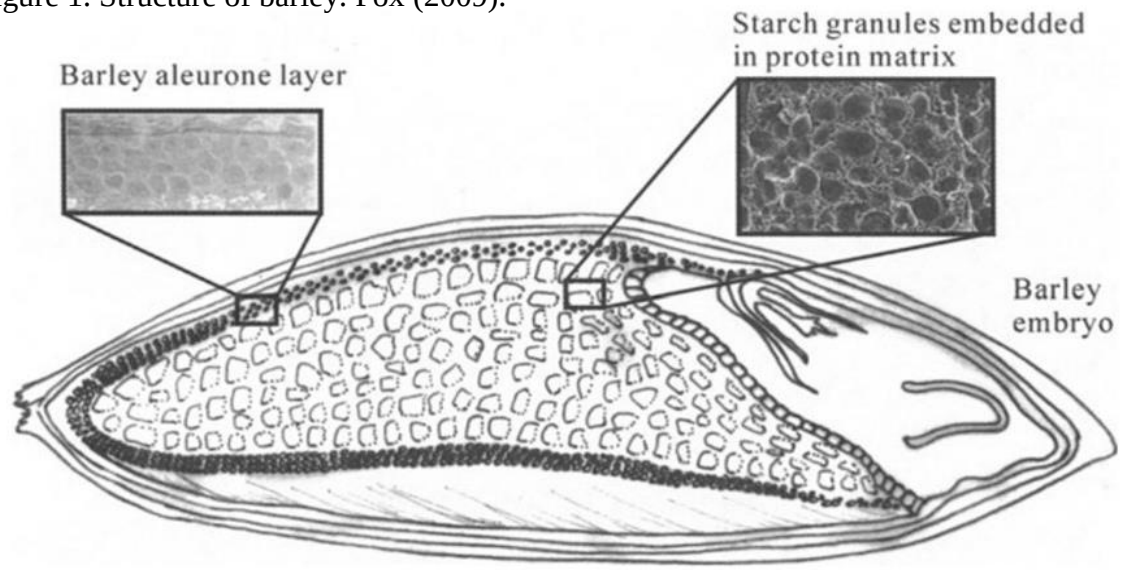
Saldana et al., 1990; Huntington, 1997). Total tract digestibility is usually very high for cereal grains regardless of type (Owens et al., 1986a; Boss, 1994). However, ruminal starch fermentation rates and site of starch digestion varies, and considerable differences have been observed with different basal grains. When oats, barley, or wheat are fed to ruminants, 90% of the starch is fermented in the rumen. Due to corn's slower rate of starch digestion, up to 40% of the starch can escape ruminal fermentation (Ørskov, 1986). It is estimated that starch digested in the rumen is used only 70% as efficiently as starch digested in the small intestine. Yet, there is often similar animal performance regardless of grain type (Owens et al., 1986).

Differences in the rate and extent of starch digestion in the rumen is likely determined by an intricate relationship among several factors, including source of dietary starch, diet composition, amount of feed consumed per unit time, mechanical alterations (grain processing, chewing), chemical alterations (degree of hydration, gelatinization), and degree of adaptation of ruminal microbiota to the diet (Huntington, 1997). For instance, whole grain with an intact pericarp is largely resistant to digestion by ruminants because whole kernels are resistant to bacterial attachment. Thus, differences in natural structure of grains and starch granules as well as subsequent processing appear to alter utilization and breakdown by the ruminant animal (Kotarski et al., 1992; McAllister et al., 1994; Huntington, 1997).

A barley kernel is composed of primarily five layers: the husk, pericarp, testa, aleurone and endosperm (Figure 1). The husk is the outermost layer of barley and is composed of two floral layers, the lemma and palea (Grant et al., 2020). The barley husk adheres to the barley seed during grain development and is highly resistant to digestion (Macgregor, 2003). As a result, using barley as a livestock feed necessitates processing for digestion of starch and subsequent

increases in livestock performance (McDonnell et al., 2003). Mathison (1996) concluded that whole barley was 15 to 30% less digestible compared to dry rolled barley. The husk, pericarp, and testa comprise the fibrous portion of the barley kernel and can account for up to 25% of the total weight. The aleurone is a very thin protein layer within the seed coat that encases the endosperm; and the endosperm is home to the starch granules (Fox, 2009).

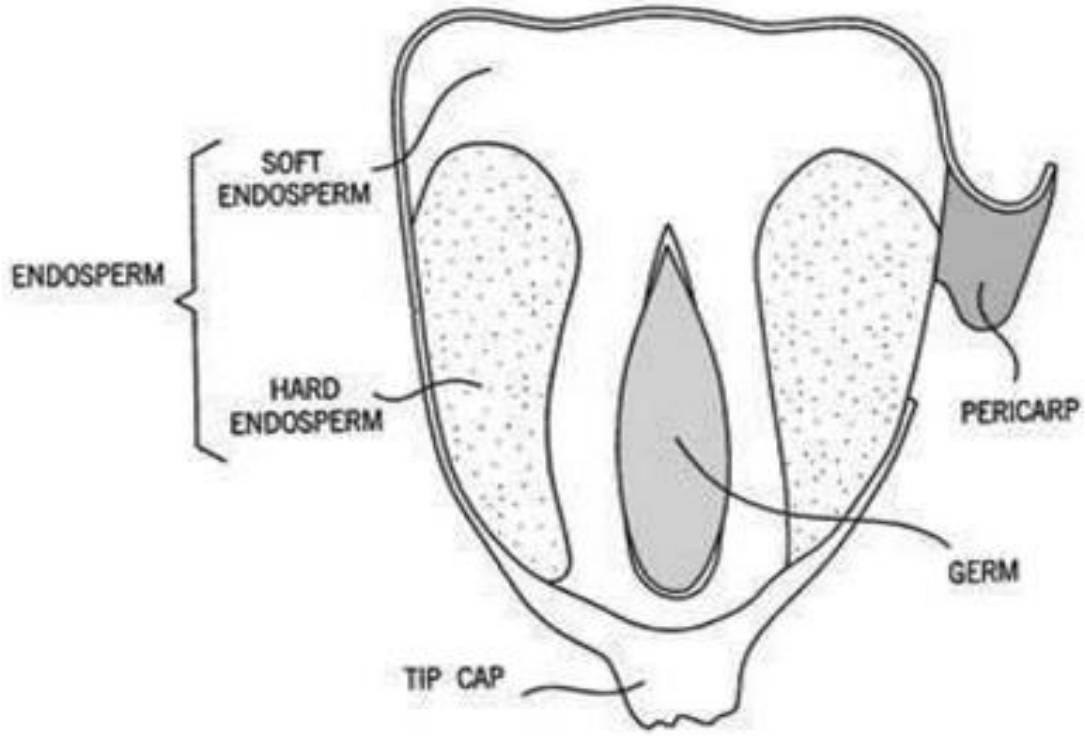
Figure 1. Structure of barley. Fox (2009).



Corn grains differ from the structure of barley grains in that while they have a pericarp they do not have testa or hull (Figure 2). There are diverse corn varieties differing primarily in the nature of the endosperm. The starch contained in the endosperm is generally classified as floury or vitreous (Lopes et al., 2009). Vitreous starch is found along the outer edge of the endosperm and is translucent in color with starch granules that are tightly compacted within a protein matrix. Floury starch is opaque in color due to more loosely condensed starch granules (Lopes et al., 2009). McAllister et al. (1993) found the protein matrix (which contains the starch

granules) seemed to be the major factor responsible for differences in ruminal digestion of ground corn and barley. Additionally, the corn protein matrix appeared to be more resistant to microbial attachment and penetration when compared to barley (McAllister et al., 1994). Simple changes in morphology, such as surface pores of the starch granule, may influence digestibility. Many of our grains have small openings (pores) randomly distributed over their surfaces and it has been proposed these pores affect pattern of attack by amylases (Fannon et al., 1992). Fannon et al. (1992) found that sorghum and corn pores were similar and found randomly over the surface. Barley and wheat pores were found along the equatorial groove. This difference in orientation may alter the ability of α-amylases to attach to the starch and thus may equate to limited bacterial attachment and digestion and be another reason why corn and sorghum starch is less fermentable in the rumen (Gudmundsson and Eliasson, 1992).

Figure 2. Structure of corn. Burger and Rheeder (2017).



Beef cattle managers have utilized different methods to ultimately control rate and extent of starch digestion. The main ways are by management of feed consumption, grain processing, and use of feed additives. Use of feed additives, such as ionophores, improve the feed efficiency of cattle and may allow the feeding of higher levels of rapidly fermentable grains with less risk of metabolic disturbances (Wagner, 1984; Stock et al., 1990). Processing of cereal grains, on the other hand, ultimately increases energy (starch) availability (Owens et al., 1997). This can be done by disrupting the fibrous seed coat and allowing more surface area and access of microbes to the endosperm (Mathison, 1996). However, there can be "too much of a good thing" by making starch too digestible. Many of the adversities we witness with feeding high grain diets are a result of excessively fermented starch such as bloat, acidosis, founder, and abscessed livers (Owens et al., 1998). Thus, it is important to continue our understanding of site, rate, and extent of digestion and how this ultimately can affect animal performance.

Metabolic Disorders and Ruminal pH

Digestive disorders account for approximately 25% to 33% of deaths in the feedlot and can have a marked impact on cattle health and efficiency of production (Galyean and Rivera, 2003). One of the biggest criticisms of the use of barley in feedlot diets is its fast rate of digestion making cattle more susceptible to metabolic disorders like bloat and/or acidosis. Acidosis refers to a ruminal condition brought about by excessive ingestion of feeds which are rich in readily available carbohydrates, such as sugar and starch (Elam, 1976). In an ideal rumen environment, ruminal fermentation is stable and mean ruminal pH is generally greater than 5.5, often ranging from 5.8 to 6.5 in grain fed cattle (Nagaraja and Titgemeyer, 2007). Ruminal pH is a critical factor in rumen function because of its impact on microbial populations and

fermentation products, as well as the physiological function of the rumen including motility and absorptive function. However, when acidosis occurs and the pH drops below 5.6, there is often a shift in microbial populations toward lactic acid production which will continue to reduce ruminal pH (Nagaraja and Titgemeyer, 2007).

Different levels and severity of acidosis can occur. A pH range of 5.0 to 5.6 is regarded as subacute or chronic acidosis; and a pH below 5.0 is considered acute acidosis. Cattle with acute acidosis often experience a drastic decrease in ruminal pH which can lead to absorption of acids into the bloodstream and systemic acidosis. In contrast, cattle with sub-acute acidosis may not show typical outward signs of illness but can have reduced intake and decreased performance (Galyean and Rivera, 2003). Laminitis, polioencephalomalacia, and liver abscesses often accompany acidosis. In serious cases, as ruminal acidity and osmolality increase, acids can accumulate which can damage the ruminal intestinal wall, decrease blood pH, and can cause dehydration and death. Even if the animal does recover from acidosis, nutrient absorption may later be retarded (Owens et al., 1998).

Most cereal grains require processing to obtain maximum cattle performance; however, processed barley grain is rapidly and extensively digested in the rumen (Beauchemin, 2000). When compared to corn, which has a slower rate of digestion and larger likelihood of starch escaping to be digested post-ruminally, starch digestion is greater in the rumen for steers fed barley-based diets. Thus, cattle fed diets containing barley tend to have a ruminal pH that is 0.2 units lower than those fed corn (Yang et al., 1997).

Ruminal pH tends to fluctuate during the day and is often high before the morning feeding due to the extensive rumination and limited feed intake that occurs at night. After a

feeding, the pH drops, declining in proportion to the size and fermentability of the meal (Beauchemin, 2000). Environmental factors can also affect feed consumption and, in turn, ruminal pH. Beef cattle intake is sensitive to changes in barometric pressure observed with weather changes. It has been hypothesized that changes in weather, such as extreme temperature changes or storms, are risk factors for ruminal acidosis (González et al., 2012). As a result, acidosis in feedlot cattle can often be associated with weather fluctuations (Elam, 1976).

Feedlot Cattle Behavior

Factors Influencing Feed Intake

In livestock production systems, profitability is the critical measure of success and is dependent on both inputs and outputs. In most livestock enterprises, the single largest input cost is animal feed. Thus, improvements in intake and feed utilization can prove extremely beneficial in cutting cost of production and increasing the producer's bottom line. Just a 1% increase in efficiency of feed conversion has been shown to reduce feed costs approximately $23 million for the cattle feedlot industry (Huntington et al., 2006). Feed intake and subsequent utilization by the animal involve complex biological processes as well as interactions with environmental factors (Arthur et al., 2004).

Many factors are known to affect feed intake including management strategies such as bunk space (McKinnon et al., 2001) and bunk management (Schwartzkopf-Genswein et al., 2003), climatic conditions (Birkelo et al., 1991; Mader et al., 2006; NRC, 2016), temperament (Burrow and Dillon, 1997; Olson et al., 2019), health status (Sowell et al., 1999; Bareille et al., 2003; González et al., 2008), production status, physiological age, and growth rate (Hicks et al., 1990; Arthur et al., 2004). Traditionally, intake has been managed on a pen or herd average,

however, recent technological advancement has shown significant differences in feeding behavior among individuals (Arthur et al., 2004). For example, in a Midwest feedlot trial the magnitude of intake variance was 5 to 10 times greater with individually fed steers than with steers fed in commercial feedlot pens (Stock et al., 1995).

Numerous factors determine an individual's likelihood of developing digestive disturbances such as acidosis. Not only do these factors include alterations in ruminal environment and digestive physiology but could also include individual animal behaviors such as dominance and temperament (Schwartzkopf-Genswein et al., 2003). Further research is needed to better understand the complexity of individual feed utilization and efficiency to improve overall enterprise profitability, thus, when possible, studies should record individual animal measurements when measuring intake.

Feeding Management Strategies

Traditionally, nutritional management in beef cattle feedlots has been administered on a pen basis, with the goal of achieving stable intake levels to maximize intake. Feedlot managers often employ three main types of feed delivery methods or feeding programs: *ad libitum* or traditional, restricted or limit feeding, or clean bunk management. *Ad libitum* or traditional feed bunk management allows the animal continuous access to feed but still aims at achieving minimal amounts of feed remaining by the next feed delivery to maintain bunk hygiene (González et al., 2012). Overall, *ad libitum* feeding attempts to maximize daily intake while, restricted feeding strives to maximize mean intake over the course of the entire feeding period. The goal of restricted feed delivery is to improve performance by reducing digestive problems due to overconsumption of feed. Usually, in a restricted feeding system feed is restricted by 0.5

or 1 kg per meal compared to *ad libitum* consumption (Schwartzkopf-Genswein et al., 2003). In doing so, this feeding method aims to reduce feed wastage and sorting behavior and improve feed conversion efficiency. Another management strategy that can be employed is a clean bunk management program, in which cattle achieve empty bunks at certain times of the day and feed is often not available for 8- to 12-hour periods (Pritchard and Bruns, 2003; Schwartzkopf-Genswein et al., 2003). In a survey conducted by Galyean (1996) all six consultants surveyed believed that the use of clean bunk management ultimately stimulates greater feed intake by cattle than other bunk management programs. While the clean bunk management method is thought to promote higher intakes, one of the main criticisms of this system is that animals become meal eaters, which may result in greater within-day variability in ruminal fluid pH (Schwartzkopf-Genswein et al., 2003).

Individual Cattle Behavior and Physiology

In addition to management factors employed to alter and enhance intake, physiological factors, social behavior, and individual cattle traits can influence intake in both confined and grazing scenarios. In grazing beef cattle, herds are composed of social subgroups that can influence distribution. Research has demonstrated that more dominant animals may consume a greater proportion of supplement than subordinate animals (Bowman and Sowell, 1997). Biological factors such as age and physiological status also may contribute to differing intake levels (Sowell et al., 2000). Numerous factors that may contribute to intake and potentially feed efficiency have also been evaluated in confinement settings. Social dominance rank is known to affect feeding behavior. High social dominance typically gives priority access to resources. Thus, in times of low resources or limited feed bunk access, low dominance rank or younger animals

are often displaced by higher ranking animals. This, however, may not have an impact on overall performance or efficiency (Gibbons et al., 2009). Temperament and excitability are also behavioral factors that have been linked to intake and subsequent performance. Historically, calm cattle have been viewed as more economical. Previous research has demonstrated that cattle with excitable temperaments have reduced performance and less favorable efficiency of gain (Burrow and Dillon, 1997). Olson et al. (2019) demonstrated that heifers with a calmer temperament at arrival had a 12% greater ADG and 8% greater DMI. Although not fully understood, many of the performance challenges observed in excitable cattle may be due to heightened levels of stress and stress-related hormones (Llonch et al., 2016).

In addition to intake being influenced by stress, temperament, and social status, intake behavior has been linked to morbidity in cattle. Early detection of morbidity in cattle entering feedlots can have significant impacts on costs of treatment and long-term profitability of the cattle. Feedlots often employ visual appraisal for detection of illness; however, clinical signs may take a while to manifest visually and rely on subjective measurements (Wolfger et al., 2015b). One of the first signs of declining health may be a reduction in appetite which is often associated with fever (Hart, 1988). Daily time spent eating was observed to be shorter in newly arrived sick cattle compared to their healthy contemporaries (Sowell et al., 1999; Buhman et al., 2000)

Impact of Environmental Factors on Behavior

Climatic conditions have a major influence on performance, health, and overall well-being of cattle. Weather events such as heat waves and/or periods of severe winter weather can cause major losses in various regions of the country. Mader (2003) estimated that for each

animal that died from climatic stress there was an associated $5000 loss due to mortality and associated loss of live animal performance. Environmental conditions affect voluntary intake of cattle. In general, voluntary feed intakes tend to decrease as ambient temperatures increase. Estimates of feed intake also become more variable within and among animals as temperatures vary further from 20°C (NRC, 1981). Animals exposed to extremely low temperatures consume more feed but grow slower and produce less milk, comparatively, because more energy is needed to obtain homeothermy (Young, 1981). Milligan and Christison (1974) analyzed records from a 7-year period in which steers were fed out at the University of Saskatchewan feedlot. The findings concluded that during the months of December, January, and February, ADG fell to 70% of the average recorded over the remainder of the year. Feed required per unit of gain and the metabolizable energy intake per unit of gain during the winter months were 149 and 140% of the mean requirements from March to November. This difference in animal performance appeared to be related to climatic factors, as ADG and feed per unit gain were significantly correlated with mean ambient temperatures, days below -23°C, windchill, and dewpoint. Elam (1971) noted the cost of gain was greater in winter months for both feedlots located in California and Midwestern states. In fact, climatic factors were most likely noted as the biggest variable in relative cost of gains for feedlots across the U.S. In addition to low temperatures, wind and moisture can have significant impacts on animal's performance and overall comfort. A wet coat reduces the insulative value and may also markedly increase the thermal demand of the animals through latent heat of melting and vaporization (Young, 1981). It has been suggested that wind velocity above a threshold level may reduce feed consumption and feeding duration and/or simply reduce feeding duration so that consumption occurs over a shorter period (Streeter et al.,

1999). In one set of cattle, average daily wind speeds above 14 mph appeared to result in a reduction in head-down feeding duration during the first 50 to 60 days on feed (Streeter et al., 1999). Seasonal changes are also characterized by alterations in natural photoperiods. These photoperiods affect melatonin levels which can play a substantial role in endocrine control of animal metabolism (Bergen et al., 2007). Research has demonstrated that extending photoperiod can increase growth rate, feed intake, and efficiency of growing cattle (Peters et al., 1978; Mossberg and Jonsson, 1996; Kennedy et al., 2004; Bergen et al., 2008). Peters et al. (1978) found that a daily photoperiod of 16 hours of light increased body growth in heifers by 10 to 15% compared to heifers exposed to the natural light periods (9-12 hours) of the fall and winter months in Michigan. Continual work will need to be done to further analyze these impacts on feeding behavior and how they relate to time on feed and season of the year.

Impact of Basal Grain on Behavior

The feedlot ration itself is likely a large contributor to animal behavior and subsequent performance. Type of basal grain, energy density, roughage level, and extent of processing can all contribute to animal utilization of the ration. Research has reported differences in feeding behavior when steers were fed differing basal diets such as wheat or barley. Steers fed wheat diets had shorter meal length and tended to have lower DMI, meal size and feeding time compared to steers fed barley-based rations (Moya et al., 2015). It was hypothesized that the greater starch, TDN, and energy content of wheat compared to barley were factors that could potentially lead to the differences observed in feeding behavior (Moya et al., 2015). Shorter and smaller meals for cattle fed a wheat-based diet has previously been suggested as a mechanism to avoid the potentially harmful effects of large meals consisting of acidogenic diets (Moya et al.,

2011; González et al., 2012). Additionally, it has also been reported that cattle consuming increased amounts of barley in the diet have altered feeding behavior in a manner that reduced risk of acidosis (Moya et al., 2011). In addition, Schwartzkopf-Genswein et al. (2011b) reported that steers fed barley-based backgrounding and finishing diets exhibiting more variable eating patterns had greater ADG and tended to have greater G:F. While limited work has been conducted specifically comparing the behavior of cattle consuming corn- or barley-based diets it is likely that the structure of the grain and the physiological mechanisms mentioned previously might be factors impacting cattle intake behavior when feeding barley or corn.

Factors Influencing Activity

Technological advancements have and will continue to aid in the study of animal activity and behavior. Pedometers, GPS, and/or accelerometers are all useful in monitoring individual behavior (Richeson et al., 2018; Rodriguez-Baena et al., 2020). Most of the electronic accelerometers used in cattle research today consist of three-axis detection, with the ability to continuously log data. They can quantify step count, standing and lying time, lying bouts, and overall activity. To date, accelerometers have been used more extensively in dairy operations to detect mastitis, fertility, or locomotion issues (Rutten et al., 2013). There is currently limited use in the beef cattle industry (Richeson et al., 2018).

In the dairy cattle industry, time spent lying down and the frequency and the duration of lying bouts are considered to be useful indicators of cow comfort, health, and welfare, as well as production status (Tullo et al., 2019). Rumination time and blood flow to the udder have been reported to be greater when cows are lying down than when they are standing (Haley et al., 2000). There is considerable interest in utilizing these behavioral measurements as indicators of

"cow comfort" to help in understanding housing systems (Haley et al., 2000) and as a potential tool in health management and earlier disease detection (González et al., 2008; Rutten et al., 2013; Wolfger et al., 2015b).

In cattle, we often observe reduced activity with cattle afflicted by diseases or lameness. Hanzlicek et al. (2010) found beef steers showed reduced activity following a *Mannheimia haemolytica* challenge. Theurer et al. (2013) found calves inoculated with *Mannheimia haemolytica* spent less time at the grain bunk, less time at the hay feeder, and more time lying down during the early pneumonia period. Finally, Pillen et al. (2016) observed a reduction in activity in newly received feedlot steers six days before a BRD diagnosis with the difference most pronounced during the day before disease identification. All these findings shed light on the potential use of activity measurements to determine health status of calves and potential early detection of disease.

For dairy cattle there is a diurnal pattern of lying behavior. Generally, cows spend a peak time lying down before the morning milking and in the middle of day between the two daily milkings (Fregonesi et al., 2007). It has also been demonstrated that there seems to be a bimodal pattern to cattle activity in a feedlot setting. Both Smith et al. (2015) and Pillen et al. (2016) noted an increase in step count observed early morning, likely in concert with anticipation of initial feeding. A second rise in activity occurred in the feedlot near the time of dusk. Likely, cattle movement and this diurnal behavior is tied to cattle feeding behavior and sunlight (Richeson et al., 2018).

Environments, however, could also influence animal activity. In cattle exposed to cold temperatures and winter weather conditions, feedlot steers increased time spent lying down but

decreased wet grooming (licking) behavior as temperature decreased (Gonyou et al., 1979). While limited work has been conducted predicting behavior as a function of environmental factors, Tullo et al. (2019) developed a highly significant model that predicted lying behavior in dairy cows based on temperature-humidity index, solar radiation, air velocity, and rainfall. In grazing cattle, shorter lying times have also been reported when cattle experience colder or inclement weather conditions (Tucker, 2007). Conversely, other authors have found cattle exposed to cold temperatures and winter weather conditions increased time spent lying down as temperature decreased; however, cattle in these studies had access to bedding (Gonyou et al., 1979; Redbo et al., 2001). Thus, it has been suggested frozen ground conditions underfoot may impact standing and lying time (Hendriks et al., 2020).

Finally, interest has been demonstrated in attempting to classify steers into performance groups based on behavior categories. While it has already been observed that temperament can play a factor in feedlot performance (Burrow and Dillon, 1997), further work has looked to classify this into activity levels. Richardson et al. (2000) demonstrated that inefficient animals, with larger RFI, took a greater number of steps per day, however this finding was not confirmed in beef cattle from other studies (Lawrence et al., 2011). Damiran et al. (2019) evaluated RFI groups based on lying behavior and found steer classes did not differ in lying duration or lying bout frequency. Thus, their study concluded there appeared to be very little or no evidence of relationships between feedlot steer feed efficiency and lying behavior.

Conclusion

There is increased interest to expand the backgrounding, feedlot, and packing sectors of the cattle industry in Montana and the Pacific Northwest. To do so, producers must look for

viable and practical resources to grow these sectors of the industry. Regionally, Montana produces approximately 1.1 million steers and heifers that are destined for feedlot finishing; however, of those, only approximately 45,000 cattle are on feed in Montana annually (USDA, 2018). Many of these calves could be retained in the state on backgrounding and/or finishing programs. Calves raised through a backgrounding program ate more feed and gained faster in the feedlot and produced heavier carcasses with greater profit, than calves put in the feedlot immediately after weaning (Lewis et al., 1990a; Lewis et al., 1990b).

While corn has traditionally been the feed grain of choice in beef cattle diets, barley, more commonly grown in Canada and the northwest region of the United States, could serve as a practical and economical alternative. The use of barley has been criticized due to its rapid digestion in the rumen, which can result in digestive disorders such as decreased ruminal pH and lactic acidosis (Kellems, 2003). However, the extent to which feeding behavior and rate of digestion influences animal performance remains to be fully defined.

Animal performance is influenced by physical and chemical characteristics of grain, as well as by the interaction between these and environmental factors. Little is known about the relationship between feeding behavior or temperature and barometric pressure and the ruminal environment of cattle, which could prove valuable in evaluating efficiency. This research investigates feeding behavior for cattle fed corn and barley-based finishing diets, and how this behavior relates to environmental factors and live-time ruminal pH and temperature. In chapter 2, we evaluate the effect of corn and barley in feedlot diets on steer performance and feeding behavior. In chapter 3, we evaluate the influence of environmental conditions on intake behavior and activity by feedlot steers fed corn or barley-based diets. In chapter 4, we evaluate diurnal

ruminal pH and temperature patterns of steers fed corn or barley-based finishing diets. By furthering our understanding of differing basal grains in beef cattle diets and environmental conditions as it relates to intake, behavior, and performance, we hope to provide cattle producers more information when making nutritional management decisions.

CHAPTER TWO

CORN VERSUS BARLEY IN FINISHING DIETS: EFFECT ON STEER PERFORMANCE AND FEEDING BEHAVIOR

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Animals

Status of Manuscript:

____ Prepared for submission to a peer-reviewed journal

____ Officially submitted to a peer-reviewed journal

____ Accepted by a peer-reviewed journal

_X__ Published in a peer-reviewed journal

MDPI

(submitted manuscript – 14 February 2021)

(accepted work – 24 March 2021)

(published work – Animals 2021, 11(4), 935)

doi:10.3390/ani11040935

CHAPTER TWO

CORN VERSUS BARLEY IN FINISHING DIETS: EFFECT ON STEER PERFORMANCE AND FEEDING BEHAVIOR

Abstract

This study evaluated the effects of barley and corn finishing rations on feedlot performance and behavior of steers. Feedlot rations in this study were comprised of a main concentrate of either corn or barley. Steers were fed in a GrowSafe system to measure individual animal intake and behavior. Weight gain, average daily gain (ADG), and gain:feed were measured for each steer. Feeding behavior including time spent eating (min/day), visits per day, time per visit (min), eating rate (g/min), intake (kg/day), and intake per visit (g) were measured for each individual. Corn-fed steers had greater ADG ($P < 0.01$) and heavier hot carcass weights (HCW; $P < 0.01$). In addition, corn-fed steers had a higher yield grade than barley fed steers ($P < 0.01$). No treatment effects ($P \geq 0.11$) were observed for time spent eating, visits per day, time per visit, eating rate, intake g/kg body weight, or intake per visit. Although corn-fed steers had a greater ADG and HCW than barley-fed steers, they tended to consume more feed ($P = 0.06$). Depending on the difference of costs associated with feeding corn or barley, barley could be a potential high-quality feed source in beef cattle finishing rations.

Keywords: barley; cattle behavior; corn; diet; feedlot performance

Introduction

Finishing rations for beef cattle often require high amounts of energy to efficiently reach target end points. To accomplish this, a variety of high energy cereal grains may be used in cattle

feedlot rations. Corn is the most common feed grain in the United States (Samuelson et al., 2016); however, barley is more widely grown in the Pacific Northwest and Northern Great Plains, as it is more adapted to the growing and/or climatic conditions of the region (Bowman, 2001). This region of the country also accounts for approximately 20% of the U.S. cattle inventory (USDA-NASS, 2018). While barley is already a popular ingredient in Canadian feedlots, the opportunity exists to expand its use in United States beef cattle production systems, particularly in regions where corn production is limited and barley is widely available.

Previous work has demonstrated that barley and corn have comparative nutritive value (Boss and Bowman, 1996; Milner et al., 1996; Bowman et al., 2019). However, research results regarding animal performance have been inconsistent (average daily gain, ADG; quality grade, QG; and yield grade, YG), where some researchers have found that barley-fed animals had equivalent performance or outperformed corn-fed cattle (Nichols, 1988; Dion and Seoane, 1992; Johnson et al., 2020), while others have found barley-fed steers to have poorer performance than corn-fed animals (Boss et al., 1994). Disparities in research results comparing barley- and corn-fed cattle in performance trials could partially be attributed to variability in the nutritive value of feed barley (Hunt, 1996). Barley starch is more ruminally digestible than starch from corn (Ørskov, 1986) with a faster rate of in situ dry matter and starch disappearance (Surber et al., 1998). Thus, when barley and corn are similarly processed, the starch and protein from barley is degraded faster and to a greater extent in the rumen than corn (Herrera-Saldana et al., 1990; Nixdorff et al., 2020) which can result in an increased likelihood of digestive disorders such as lactic acidosis and reduced performance (Owens et al., 1997; Owens et al., 1998).

Additionally, variation in beef cattle performance may also be contributed to individual feeding behavior (Golden et al., 2008; Schwartzkopf-Genswein et al., 2011; Richeson et al., 2018). The digestive differences in barley and corn grains could potentially influence cattle feeding behavior and subsequent performance. However, information relating individual feeding behavior of animals on barley- or corn-based diets is limited. Understanding the feeding behavior of individual cattle in the feedlot could provide insight into performance differences not always reported in studies based on pen averages.

Although previous research has evaluated the use of corn and barley in finishing beef cattle rations, results of these studies have been inconsistent. Further, there is limited information available relating individual feeding behavior to animal performance with differing basal diets. Therefore, the objectives of this study were to evaluate the effects of corn or barley finishing diets on feedlot performance and feed intake behavior and to evaluate the relationship of feeding behavior to performance. We hypothesized that barley-fed steers would have comparable performance characteristics, but physical and chemical characteristics of grain sources could influence feeding behavior.

Materials and Methods

Experimental procedures described herein were approved by the Agriculture Animal Care and Use Committee of Montana State University (#2016-AA26). All animals used in this study were provided by the Montana Agricultural Experiment Station, and the study was conducted at the Northern Agricultural Research Center in Havre, Montana.

For two consecutive years, Angus-based yearling steer calves were fed in a feedlot trial from 27 February 2017 to 12 June 2017 (105 days; 427.3 ± 3.7 kg; n = 48) in year 1, and 26

February 2018 to 11 June 2018 (105 days; 406.8 ± 3.4 kg; n = 47) in year 2. Prior to the study, steers were implanted with a Synovex One Feedlot Implant (Zoetis, Parsippany-Troy Hills, NJ, USA). Upon entry to the feedlot, steers were stratified by body weight and assigned to one of two primary basal grain dietary treatments including: (1) Number 2 feed corn or (2) Hockett barley. Hockett barley is a two-rowed dry-land malting barley often fed to livestock when malting parameters are not met (Barley Breeding Program, 2008). Both barley and corn were dry-rolled, and diets were formulated based on initial basal grain nutrient analysis and contained 80% grain, 12% barley straw, 3% canola oil, and 5% supplement with the exception of year 2 barley ration that contained 10% supplement due to differences in initial protein content. Supplements consisted of vitamin/mineral packages for feedlot steers and protein sources including wheat middlings and canola meal. Diets were not balanced to be isocaloric; rations were designed based on percent concentration in an effort to be relevant to a production scenario. Ingredient and nutrient composition of the diets are presented in Table 3. Steers were acclimated to their respective diet for 14 days prior to the start of the data collection period. Steers were fed their respective diets once daily at 0800. Diets were fed to achieve maximum individual intake without excessive feed refusals. When clean bunks were present by mid-day for two consecutive days, rations were increased 0.23 kg per head. Feed refusals were removed weekly. All animals had ad libitum water access for the entirety of the trial.

Table 3. Composition and nutrient content of finishing diets containing corn or Hockett barley as basal grains**.**

	Year 1		Year 2	
	Barley	**Corn**	**Barley**	**Corn**
Ingredient				
Corn, %	-	80.00	-	75.00
Barley, %	80.00	-	80.00	-
Barley straw, %	12.00	12.00	12.00	12.00
Canola oil, %	3.00	3.00	3.00	3.00
Supplement, % [1]	5.00	5.00	5.00	10.00
Chemical composition				
Dry matter, %	91.40	91.00	91.40	91.30
Crude protein, %	9.50	11.20	8.80	11.60
Acid detergent fiber, %	18.80	15.40	20.10	11.30
Neutral detergent fiber, %	31.70	26.60	36.60	24.10
Total digestible nutrients, %	69.00	75.00	68.00	76.00
Net energy maintenance, Mcal/kg	0.34	0.39	0.32	0.39
Net energy gain, Mcal/kg	0.22	0.26	0.21	0.26

[1] The supplement composition was formulated based on initial basal grain nutrient analysis and designed to make diets similar in crude protein, minerals and vitamins.

Steers were fitted with an electronic identification ear tag and were adapted to a GrowSafe system (GrowSafe Systems Ltd., Airdrie, AB, Canada) for 14-days prior to the start of the study. A total of 24 GrowSafe electronic feed bunks (12 per treatment; 1 per 2 steers) were used in this study, each equipped with an antenna to detect animal presence. Load cells measured feed disappearance and neck bars allowed for only one animal to enter the feed bunk at a time. Individual animal intake was continuously recorded via wireless transfer to a data-acquisition computer. The system was monitored daily for unaccounted feed balance. When an unaccounted feed balance or adverse weather event occurred in which we could not account for 95% of the feed disappearance, the GrowSafe system automatically deemed the 24-h period as failed. Prior validation of GrowSafe has demonstrated that accuracy of dry matter intake was not impacted when up to 30% of the data was missing (Wang et al., 2006). In our study, 8.54% of the dry

matter intake data failed in year 1 and 10.92% failed in year 2, with an average fail rate of 9.73% across both years of the study.

Initial and final unshrunk weights were obtained on two consecutive days and averaged at the beginning and end of the study period. Additionally, steers were weighed once every 28 days during the study. Performance measurements: ADG and feed efficiency (indexed as the ratio kg weight gain: kg feed intake; G:F) were calculated for each steer. In addition, ADG and G:F were adjusted by dressing percentage to calculate carcass-adjusted ADG and G:F. Feeding behavior measurements: daily dry matter intake (DMI, kg/day), intake g/kg body weight (BW)/day, visits per day, intake per visit (g), time spent eating (min/day), time per visit (min), and eating rate (g/min) were all calculated from GrowSafe data for each individual steer on a daily basis. The length of time between intake readings that constitute a new visit to the feeder was predetermined as 300 s for beef cattle (Sowell et al., 1998; Schwartzkopf-Genswein et al., 2002; Parsons et al., 2004). Daily intake variation, measured as coefficient of variation (CV, %), was based on daily intake estimates for individual animals. When 70% of all steers were visually estimated to have 1.0 cm of back-fat, steers were transported 13 h (1315 km) and slaughtered after a 12-h rest period at a commercial processing plant. After a 48-h chill at 4°C carcass measurements (hot carcass weight, HCW; marbling; back-fat; ribeye area, REA; kidney pelvic and heart fat, KPH; and yield grade) were collected by a USDA grader (see Appendix A).

Carcass and performance measurements were analyzed using generalized linear mixed models including diet as a fixed effect and year as a random intercept. Feeding behavior was also analyzed using generalized linear mixed models including diet as a fixed effect with year and individual steer as random intercepts. Individual steer was used as a random intercept to account

for autocorrelation of multiple measurements for each individual. The relationship between individual feeding behavior, performance, and carcass characteristics were evaluated using a Pearson product-moment correlation test. Individual steer was considered the experimental unit. An $\alpha \leq 0.05$ was considered a significant relationship. A tendency was classified as an $\alpha \leq 0.10$. All statistical procedures were conducted in R (R Core Team, 2017).

Results

Corn-fed steers had 0.14 kg greater ADG ($P < 0.01$) and heavier final live weight ($P = 0.02$) than barley-fed steers (Table 4). A tendency was observed for corn-fed steers to have greater G:F ($P = 0.08$) than barley-fed steers. Carcass adjusted ADG and G:F were greater for corn-fed steers than barley-fed steers ($P \leq 0.02$). Hot carcass weights were 16-kg heavier ($P < 0.01$) and tended to have greater back-fat thickness ($P = 0.06$) for steers fed corn compared to steers fed barley. In addition, corn-fed steers had a higher yield grade than barley-fed steers ($P < 0.01$). However, no differences among treatments were detected for marbling or REA ($P \geq 0.19$).

Table 4. Performance and carcass characteristics of steers consuming finishing diets containing corn or Hockett barley as basal grains at the Northern Agricultural Research Center.

	Barley	**Corn**	**SEM [1]**	***p*-Value**
Performance				
Initial weight, kg	416.36	417.67	10.56	0.79
Final weight, kg	596.45	612.59	15.74	0.02
ADG	1.67	1.81	0.01	<0.01
G:F	0.15	0.16	0.01	0.08
Adjusted ADG [2]	0.97	1.07	0.06	<0.01
Adjusted G:F [2]	0.08	0.09	0.01	0.02
Carcass				
Hot carcass weight, kg	347.29	363.19	10.08	<0.01
Marbling [3]	455.13	478.96	18.60	0.19
12^{th} rib fat, cm	0.94	1.09	0.06	0.06
Ribeye area, cm^2	87.42	86.17	3.17	0.38
Yield grade [4]	2.4	2.74	0.11	<0.01

[1] SEM = standard error of the means. [2] Adjusted by dressing percentage. [3] Based on USDA quality grade/marbling scores: 200–299 = traces; 300–399 = slight; 400–499 = small; 500–599 = modest; 600–699 = moderate. [4] Calculated yield grade = 2.5 + (2.5 × adjusted fat thickness, 12th rib, inches) + (0.0038 × hot carcass weight, pounds) + (0.2× percentage kidney, pelvic and heart fat) − (0.32 × ribeye area, square inches).

No treatment effect was observed for time spent eating, visits per day, time per visit, eating rate, intake g/kg BW, or intake per visit ($P \geq 0.11$; Table 5). There was a tendency for corn-fed steers to eat more feed per day ($P = 0.06$) than barley-fed steers. Additionally, corn-fed steers had a greater variation in intake (CV, %) compared to barley-fed steers ($P < 0.01$).

Table 5. Feeding behavior of steers consuming finishing diets containing corn or Hockett barley as basal grains at the Northern Agricultural Research Center**.**

	Barley	**Corn**	**SEM [1]**	***p*-Value**
Time spent eating, min/day	105.99	107.92	2.87	0.58
Visits per day	16.40	15.83	0.54	0.14
Time per visit, min	1.38	1.37	0.08	0.94
Eating rate, g/min	101.10	104.38	11.66	0.45
Intake per day, kg*	11.30	11.72	0.52	0.06
Intake g/kg BW*	21.91	22.46	0.24	0.11
Intake per visit, g*	400.70	412.14	15.18	0.34
Intake CV, % [2]	20.38	24.20	1.59	<0.01

[1] SEM = standard error of the means. [2] CV, coefficient of variation. * Intake reported on a dry mater (DM) basis.

When evaluating Pearson's correlations between feeding behavior and performance variables, eating rate was positively correlated to G:F for both barley and corn-fed steers (R = 0.51, R = 0.40, respectively; $P < 0.01$; Table 6). Conversely, time spent eating per day was negatively correlated to G:F for steers fed both diets ($R = -0.38$; $P < 0.01$). Additionally, intake per day for barley- and corn-fed steers was negatively correlated to G:F ($R = -0.37$, $R = -0.50$; $P < 0.05$) and positively correlated to ADG (R = 0.42, R = 0.41; $P < 0.01$) and HCW (R = 0.49, R = 0.63; $P < 0.01$). For both barley- and corn-fed steers, intake g/kg BW was negatively correlated to G:F ($R = -0.48$, $R = -0.65$; $P < 0.01$). For barley-fed steers specifically, visits per day was positively correlated to HCW (R = 0.30; $P < 0.05$) and yield grade was positively correlated to time per visit (R = 0.33; $P < 0.05$) and intake per visit (R = 0.34; $P < 0.05$). Additionally, back-fat thickness of barley-fed steers was negatively correlated to intake CV ($R = -0.43$; $P < 0.01$). Corn-fed steers displayed a negative relationship between time per visit and G:F ($R = -0.28$; $P < 0.05$) and a positive relationship between intake per visit and HCW (R = 0.44; $P < 0.01$).

Table 6. Pearson correlation coefficients for pair-wise associations between feeding behavior, performance (gain to feed, G:F; average daily gain, ADG) and carcass characteristics (hot carcass weight, HCW; yield grade, YG) of steers consuming finishing diets containing corn or Hockett barley as basal grains at the Northern Agricultural Research Center**.**

	Barley					**Corn**				
	G:F	**ADG**	**HCW**	**YG**	**FAT**	**G:F**	**ADG**	**HCW**	**YG**	**FAT**
Time per day	−0.38 **	−0.04	0.01	0.19	0.17	−0.38 **	<0.01	0.03	0.10	0.19
Visits per day	−0.11	0.05	0.3 *	−0.21	0.01	−0.16	0.03	0.07	0.11	0.10
Time per visit	−0.25	−0.09	−0.22	0.33 *	0.16	−0.28 *	−0.03	−0.02	0.02	0.14
Eating rate	0.51 **	0.14	0.31	−0.28	−0.12	0.40 **	0.20	0.17	−0.02	−0.07
Intake per day	−0.37 *	0.42 **	0.49 **	0.22	0.19	−0.50 **	0.41 **	0.63 **	0.23	0.23
Intake per visit	−0.15	0.23	0.08	0.34 *	0.15	−0.28	0.27	0.44 **	0.09	0.10
Intake g/kg BW [1]	−0.48 **	0.13	−0.16	0.12	0.11	−0.65 **	0.01	0.02	0.13	0.11
Intake CV [2]	0.23	−0.15	−0.26	−0.26	−0.43 **	−0.10	−0.15	−0.10	−0.24	−0.11

[1] BW, Body weight. [2] CV, coefficient of variation. * Significant associations $p \leq 0.05$. ** Significant associations $p \leq 0.01$.

Discussion

Although corn and barley diets were formulated to be isonitrogenous, barley diets had a lower percent CP than corn diets, likely due to initial sampling error of the bulk feed delivery. To evaluate if protein differences in our dietary treatments had an impact on energy and protein availability and subsequently daily intakes, we used the Beef Cattle Nutrient Requirements model (Model–BCNRM, 2016) to predict daily intakes based on the nutrient analysis of each diet for each year. For all steers, regardless of treatment, intake was greater than what the BCNRM model predicted (Table 7). The rumen degradable protein balance derived from the BCNRM model suggests that both dietary treatments for both years were in excess of NRC requirements. Additionally, for both years, corn and barley-fed steers had greater average daily intakes than the BCNRM predictions, suggesting the differences in dietary protein levels did not limit daily intake.

Table 7**.** Observed average daily intake (ADI) and BCNRM predicted ADI, rumen degradable protein (RDP) requirements, available RDP and RDP balance for steers consuming finishing diets containing corn or Hockett barley as basal grains at the Northern Agricultural Research Center.

	Year 1		**Year 2**	
	Barley	**Corn**	**Barley**	**Corn**
Observed ADI, kg	11.53	12.24	10.69	10.81
BCNRM [1] predicted ADI, kg	9.13	8.40	9.29	8.28
RDP required kg/day	0.80	0.93	0.73	0.83
RDP available kg/day	1.20	1.51	1.03	1.37
RDP balance kg/day	0.40	0.58	0.30	0.54

[1] Model–BCNRM, Beef Cattle Nutrient Requirements Model.

As previously noted, research comparing the use of barley and corn in beef cattle diets has yielded inconsistent results. This inconsistency could be due to the biological nature of the

grains themselves and the diversity in nutrient value of varying barley varieties (Bowman et al., 2001). In general, corn is higher in starch compared to barley and is also more likely to escape ruminal digestion and be utilized in the small intestine (Ørskov, 1986). Starch digestion in the small intestine is theoretically more energy efficient than ruminal fermentation (Owens et al., 1986) which might explain why corn-fed steers often have improved performance over barley-fed steers (Boss and Bowman, 1996). Still, some barley diets have resulted in performance similar to that of corn-fed cattle (Nichols, 1988; Dion and Seoane, 1992).

Our findings are similar to that of Boss and Bowman (1996) as well as Tiffany and Spears (2005) where corn-fed cattle had greater ADG and HCW compared to barley-fed cattle. It is commonly accepted that net energy is a better measure of energy availability than total digestible nutrients; however, animal performance from previous work seem to be more related to intake of digestible nutrients than by net energy value, as ADG has been reported to be linearly related to digestible starch intake but not digestible DMI (Boss and Bowman, 1996). Presumably, due to corn having higher starch compared to barley, the differences in ADG, HCW, and yield grade observed between grain sources in our study may be due to the increased intake of starch by corn-fed cattle. However, it should be noted other studies have reported no differences in carcass characteristics due to grain source (Ovenell-Roy et al., 1998; Beauchemin and Koenig, 2005).

Overall, the feeding behavior of corn and barley-fed steers in our study were similar. Other research has reported differences in feeding behavior when steers are fed differing basal diets such as wheat or barley (Moya et al., 2015). It has also been reported that when cattle consume increased amounts of barley in the diet, feeding behavior is altered in a manner that

reduced risk of acidosis (Moya et al., 2011). We did not see these unique differences in feeding behavior between corn and barley-fed steers within our study. When evaluating the relationship of feeding behavior and performance, both barley- and corn-fed steers displayed a positive correlation between intake and ADG as well as HCW. However, intake was negatively correlated to G:F, suggesting that steers with greater intakes gain more weight but have lower G:F. Eating rate was positively correlated to G:F for both corn- and barley-fed steers which is similar to previous research with barley-fed cattle (Schwartzkopf-Genswein et al., 2011a). Additionally, Schwartzkopf-Genswein and coworkers (2011), reported that steers fed barley-based backgrounding and finishing diets with more variable eating patterns exhibited greater ADG and tended to have greater G:F, however, these relationships were not observed for the barley-fed steers in our study. We did not observe any relationship to frequency of bunk visits to animal growth efficiency, which is similar to Streeter et al. (1999) where visits were not reflective of ADG. Additionally, in our study, visits per day was only positively associated with HCW for barley-fed steers. Others have observed positive correlations between average daily bunk attendance and duration with ADG and DMI, which suggests cattle that spend more time at the bunk consume more feed and have higher rates of gain (Gibb et al., 1998; Schwartzkopf-Genswein et al., 1999; Schwartzkopf-Genswein et al., 2002). However, in our study, time spent at the feeder was only negatively associated with G:F.

Conclusion

While economic analysis of the use of barley and corn diets for beef cattle is beyond the scope of the current study, it should be noted that feeding behavior was similar across dietary treatments and although differences were observed in performance and carcass characteristics,

the differences were relatively small. For example, the difference in fat thickness between treatments was < 0.2 cm and differences in yield grade were slight, particularly when you consider that yield grade scores are not rounded up (i.e., a yield grade 3.1 and 3.9 are both considered to be a yield grade 3 (USDA, 2020). Although corn-fed steers had a greater HCW than barley-fed steers, this tended to be accompanied by greater daily intake. Depending on the difference of costs associated with feeding corn or barley in a given year, barley could be a potential high-quality feed source in beef cattle finishing rations.

CHAPTER THREE

THE INFLUENCE OF ENVIRONMENTAL CONDITIONS ON INTAKE BEHAVIOR AND ACTIVITY BY FEEDLOT STEERS FED CORN OR BARLEY-BASED DIETS

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Animals

Status of Manuscript:

____ Prepared for submission to a peer-reviewed journal

____ Officially submitted to a peer-reviewed journal

____ Accepted by a peer-reviewed journal

_X__ Published in a peer-reviewed journal

MDPI

(submitted manuscript – 2 April 2021)

(accepted work – 26 April 2021)

(published work – Animals 2021, 11(5), 1261)

doi:10.3390/ani11051261

CHAPTER THREE

THE INFLUENCE OF ENVIRONMENTAL CONDITIONS ON INTAKE BEHAVIOR AND ACTIVITY BY FEEDLOT STEERS FED CORN- OR BARLEY-BASED DIETS

Abstract

This study evaluated the influence of diet and environmental conditions on intake behavior and activity of feedlot steers. Feedlot rations used were comprised of a main concentrate: 1) corn or 2) barley. A GrowSafe system measured individual animal intake and behavior and HOBO accelerometers measured steer standing time. An Onset weather station collected on-site weather data. Steer daily intake displayed a diet by temperature class interaction ($P \leq 0.05$). Relative temperature change had no effect on variation in intake ($P = 0.60$); however, diet influenced variation of intake ($P < 0.01$), where corn-fed steers had a greater CV than barley-fed steers (21.89 ± 1.46 vs. $18.72 \pm 1.46\%$). Time spent eating ($min \cdot d^{-1}$) and eating rate ($g \cdot min^{-1}$) both displayed a diet by temperature class interaction ($P \leq 0.05$). Diet did not affect steer lying activity ($P \geq 0.12$), however, time spent lying ($min \cdot d^{-1}$) and frequency of lying bouts ($bouts \cdot d^{-1}$) increased on relatively cold days while the duration of lying bouts ($min \cdot bout^{-1}$; $P < 0.01$) decreased. Short-term environmental temperature changes interacted with diet influencing feedlot beef cattle intake behavior, however, did not interact with basal diet in respect to steer activity.

Keywords: barley, behavior, corn, environment, intake, steer

Introduction

Environmental conditions and their impact on beef cattle production have long been recognized (Birkelo et al., 1991; Delfino and Mathison, 1991; Mader, 2003), and seasonal variations of climatic conditions have been documented to impact feedlot cattle performance (Elam, 1971; Milligan and Christison, 1974). Cattle wintered at northern latitudes are often exposed to periods of severe cold, which increases energy expenditure to maintain homeothermy (Webster, 1970; Webster, 1971). Thus, during periods of cold stress, animal behavior is altered (Gonyou et al., 1979), and feed consumption will often increase with a decrease in average daily gain (ADG), resulting in an overall decline in feed efficiency (Young, 1981). Research conducted over seven years at the University of Saskatchewan feedlot reported that from December to February (mean monthly temperature -17 ° C), ADG decreased 30% compared to the remainder of the year (Milligan and Christison, 1974). Regression equations relating mean air temperatures and climatic stress to relative performance indicate that 40 to 60% of the seasonal variation in feedlot performance can be accounted for by climatic variables (Young, 1981). Cattle likely inherently alter their behavior to combat these environmental challenges.

Feeding high-quality and energy-dense feed sources are essential to meet energy demands for feedlot cattle at northern latitudes. Corn has traditionally been the most popular grain source in the U.S. (Samuelson et al., 2016); however, barley is commonly fed to beef cattle in the northern U.S. and Canada due to its adaptation to the environmental conditions at northern latitudes (Bowman, 2001). Although the National Research Council reports lower energy values for barley than corn (NRC, 2016), work by Bowman et al. (2019) suggests that barley and corn often have similar net energy values. However, utilization of these different feedstuffs has been shown to yield differences in performance (Nichols, 1988; Dion and Seoane, 1992; DelCurto-

Wyffels et al., 2021) and digestive utilization in feedlot steers (Ørskov, 1986; Surber et al., 1998a).

Feeding behavior and activity are frequently monitored to evaluate cattle well-being and health status (Weary et al., 2009; Wolfger et al., 2015a). However, limited work has been conducted in regard to cattle behavioral changes, both feeding and activity behavior, when fed differing basal diets and under variable environmental conditions. Feed intake and subsequent utilization by the animal involve complex biological processes, as well as interactions with environmental factors (Arthur et al., 2004). The influence of environmental conditions and differing finishing diets on cattle feedlot behavior remains to be fully defined. Therefore, the objectives of this study were to evaluate the effects of changing environmental conditions at northern latitudes on feeding behavior and activity of steers fed corn- or barley-based finishing diets. We hypothesized that steer behavior is affected by both diet and environmental conditions.

Materials and Methods

All protocols and procedures were approved by the Agriculture Animal Care and Use Committee of Montana State University (#2016-AA26). This study was conducted at the Northern Agricultural Research Center in Havre, Montana (48.5500° N, 109.6841 ° W). All animals were provided by the Montana Agricultural Experiment Station.

Angus-based yearling steer calves were fed in a feedlot trial from February to June (105 days) for two consecutive years (year 1, 427.3 ± 3.7 kg, n = 48; year 2, 406.8 ± 3.4 kg; n = 47). All steers were implanted with a Synovex One Feedlot Implant (Zoetis, Parsippany-Troy Hills, NJ) at the initiation of the study. In addition, steers were stratified by body weight (BW) and assigned to one of two primary basal grain dietary treatments: 1) Number 2 feed corn or 2)

Hockett barley. Hockett barley is a two-rowed dry-land malting variety of barley, that is often fed to livestock when malting parameters are not met (Barley Breeding Program, 2008). Both barley and corn were dry-rolled, and diets contained 80% grain, 12% barley straw, 3% canola oil, and 5% supplement averaging 10.28 % crude protein and 0.24 Mcal · kg^{-1} net energy gain. Supplements consisted of vitamin/mineral packages for feedlot steers and protein sources, including wheat middlings and canola meal. Steers were acclimated to their respective diet for 14 days prior to the start of the data collection period. Steers were fed their respective diets once daily at 0800 and managed to allow for maximum individual intake without excessive feed refusals. Bunks were read at 1200 daily, and when clean for two consecutive days, rations were increased by 0.23 kg per head. Feed refusals were removed weekly. All animals had ad libitum access to water throughout the study period.

Steers were fitted with an electronic identification ear tag and allotted to one of 12 pens (6 pens per treatment; 4 steers per pen) measuring 5 × 11 m in size. A total of 24 GrowSafe (GrowSafe Systems Ltd., Airdrie, AB, Canada) electronic feed bunks (12 per treatment; 2 per pen) were used in this study. Steers were adapted to the GrowSafe system for 14 days prior to the start of the study. Each GrowSafe feed bunk was equipped with an antenna to detect animal presence and neck bars that allowed for only one animal to enter the feed bunk. Load cells then measured feed disappearance. Individual animal intake was recorded daily via wireless transfer to a data-acquisition computer. The GrowSafe system monitored unaccounted feed disappearance daily, and when over 5% of the feed disappearance was unaccounted for, the GrowSafe system automatically deemed the 24-hour period as failed. In our study, 8.54% of the dry matter intake data failed in year 1, and 10.92% failed in year 2, with an average fail rate of

9.73% across both years. Prior research validating the use of GrowSafe has demonstrated that the accuracy of dry matter intake was not impacted when up to 30% of the data were missing (Wang et al., 2006).

Steer weights were obtained at the beginning and every 28 days throughout the study until the end of the feeding trial. Feeding behavior measurements: daily dry matter intake (DMI, $kg \cdot d^{-1}$), intake ($g \cdot kg\ BW^{-1} \cdot d^{-1}$), time spent eating ($min \cdot d^{-1}$) and eating rate ($g \cdot min^{-1}$) were all calculated from GrowSafe data for each individual steer on a daily basis. Daily intake variation, measured as coefficient of variation (CV, %), was based on daily intake estimates for individual animals.

To determine time spent lying ($min \cdot d^{-1}$), frequency of lying bouts ($bouts \cdot d^{-1}$), and duration of lying bouts ($min \cdot bout^{-1}$); HOBO accelerometers (HOBO Pendant G acceleration data logger, Onset Corp., Pocasset, MA) were fitted to 12 steers per treatment group. Accelerometers were attached for 15-day increments at the beginning, middle, and end of the trial. These devices were programmed to record g-force on the x, y, and z-axes at 1-minute intervals and were attached to the front leg above the pastern, as described by Ito et al. (Ito et al., 2009). The data loggers were removed from the steers after the 15-day data collection periods and downloaded using Onset HOBO ware software (Onset Corp., Pocasset, MA). From the data, the degree of vertical tilt (y-axis) was used to determine whether the animal was lying or standing. Readings $< 60°$ indicated steers were standing, whereas readings $\geq 60°$ indicated steers were lying down.

An Onset HOBO U30-NRC Weather Station (Bourne, MA) was placed near the feedlot and programmed to collect air temperature, relative humidity, wind speed, and direction data

every 10 minutes for the entirety of the finishing period. Temperatures adjusted for windchill were calculated using the National Weather Service formula modified for cattle (Osczevski and Bluestein, 2005; Tucker et al., 2007; Graunke et al., 2011). Daily average temperatures adjusted for windchill were calculated for the entirety of the finishing period. Short-term relative temperature changes were then derived by subtracting daily average temperatures from a rolling previous 10-day average. Relative temperature change from a rolling 10-day average was used as previous research results suggest cattle behavior response to short-term thermal stress was most likely to occur when environmental conditions differ from the 9 to 14-day average (Senft and Rittenhouse, 1985). Daily relative temperature change was then paired with daily intake and activity readings for each individual animal for the duration of the finishing period each year. Each day was then classified as colder than the 10-day average ($\leq$ -1 SD from the mean), average ($\pm$ 0.5 SD from mean), or warmer than the 10-day average ($\geq$ 1 SD from the mean) temperature, adjusted for windchill, within each year of the finishing period to evaluate relative temperature change on steer intake behavior and activity.

Daily individual intake ($kg \cdot d^{-1}$ and $g \cdot kg\ BW^{-1} \cdot d^{-1}$), the coefficient of variation of intake, time spent at the feeder, eating rate, and steer lying activity were analyzed using ANOVA (car; (Fox and Weisberg, 2011) with a generalized linear mixed model (lme4; (Bates et al., 2014) including diet, relative temperature change class and the interaction of diet and relative temperature change class as fixed effects, with year and individual steer as random intercepts. Individual steer was used as a random intercept to account for autocorrelation of multiple measurements for each individual. Individual steer was considered the experimental unit. Data were plotted and log transformed if needed to satisfy assumptions of normality and homogeneity

of variance. An alpha ≤ 0.05 was considered significant, and an alpha ≤ 0.10 was considered a tendency. Orthogonal polynomial contrasts were used to determine linear and quadratic effects of relative temperature change for each analysis, and means were separated using the Tukey method when $P < 0.05$ (emmeans; (Lenth et al., 2019)). All statistical analyses were performed in R (R Core Team, 2017).

Results

Steer daily intakes displayed a diet by temperature class interaction ($P = 0.05$; Figure 3). Barley-fed steers did not alter daily intakes in response to relative temperature change ($P \geq 0.44$). However, there was a tendency ($P = 0.08$) for corn-fed steers to alter intake in response to daily temperatures, where intakes decreased linearly ($P = 0.04$) with decreases in relative temperature. Additionally, corn-fed steers had greater ($P \leq 0.03$) intakes than barley-fed steers on days with average and above average temperature but did not differ ($P = 0.71$) on days below the 10-day average temperature. Steer daily intake expressed as $g \cdot kg\ BW^{-1} \cdot d^{-1}$ also displayed a diet by temperature class interaction ($P = 0.04$; Figure 4). There was a quadratic effect ($P < 0.01$) of relative temperature change on intake $g \cdot kg\ BW^{-1} \cdot d^{-1}$ for barley-fed steers, where intake increased ($P = 0.01$) on days colder than the 10-day average and tended to increase ($P = 0.08$) on days warmer than the 10-day average. There was a linear effect ($P = 0.03$) of relative temperature change on intake $g \cdot kg\ BW^{-1} \cdot d^{-1}$ for corn-fed steers, where intake increased with increases in relative temperature. Diet did not have an effect ($P = 0.84$) on intake $g \cdot kg\ BW^{-1} \cdot d^{-1}$ on days colder than the 10-day average; however, corn-fed steers tended ($P = 0.06$) to have greater intakes than barley-fed steers on average and warmer than average days. Relative temperature change had no effect ($P = 0.60$) on variation in intake, expressed as the coefficient

of variation. However, diet influenced ($P < 0.01$) variation of intake, where corn-fed steers had a greater CV than barley-fed steers (21.89 ± 1.46 vs. 18.72 ± 1.46%).

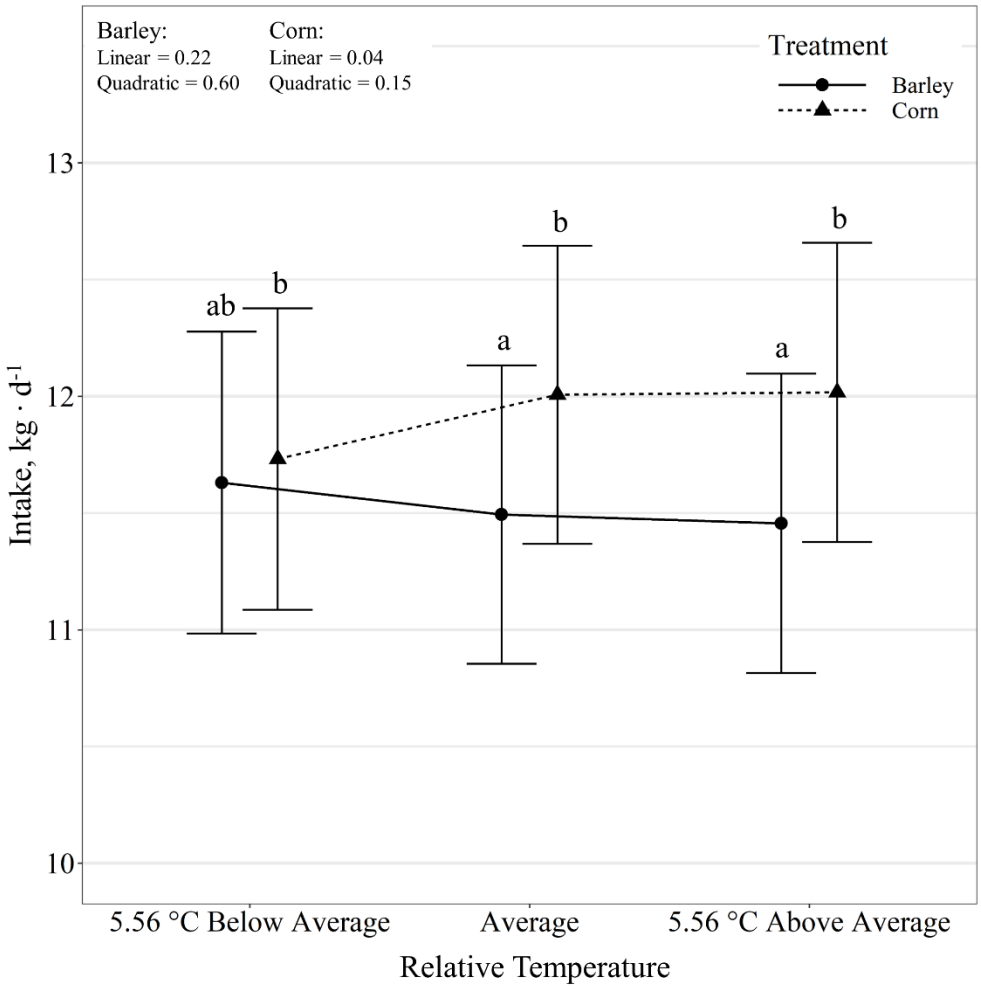


Figure 3. Influence of relative temperature change × diet ($P = 0.05$) on average daily intake (expressed as kg · d-1) by beef steers consuming either barley or corn-based feedlot diets at the Northern Agricultural Research Center, Havre, Montana, USA.

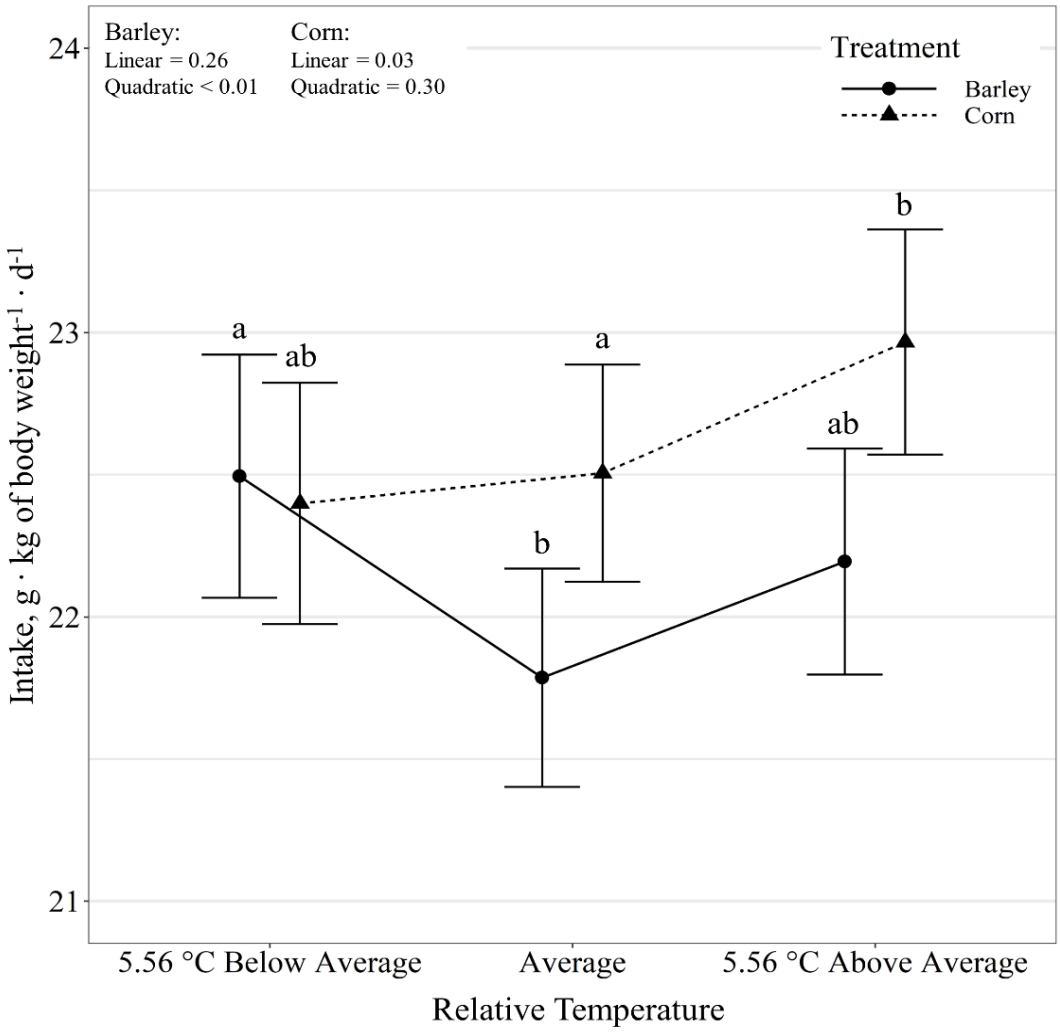


Figure 4. Influence of relative temperature change × diet (P = 0.04) on average daily intake (expressed as g · kg of body weight^{-1} · d^{-1}) by beef steers consuming either barley or corn-based feedlot diets at the Northern Agricultural Research Center, Havre, Montana, USA.

Time spent eating per day also displayed a diet by temperature class interaction (P < 0.01; Figure 5). Relative temperature changed displayed a quadratic effect of time spent eating per day for barley-fed steers (P < 0.01), where time at the feeder increased (P < 0.01) on days colder than the 10-day average, however, did not differ (P = 0.89) between days with average

and above average temperatures. Corn-fed steers tended ($P = 0.06$) to decrease time at the feeder linearly ($P = 0.02$) as relative temperature increased. Diet had no effect ($P \geq 0.40$) on time spent eating within each temperature class. Additionally, steer eating rate displayed a diet by temperature class interaction ($P = 0.04$; Figure 6). Relative temperature change displayed a quadratic effect ($P < 0.01$) on eating rate for barley-fed steers, where eating rate decreased ($P < 0.01$) on days colder than the 10-day average, with no differences ($P = 0.95$) observed between days with average and above average temperatures. Corn-fed steers decreased eating rate linearly ($P < 0.01$) with decreasing relative temperatures. Diet had no effect ($P \geq 0.33$) on eating rate for days with average and below average temperature, but corn-fed steers tended ($P = 0.09$) to have greater eating rates than barley-fed steers on days warmer than the 10-day average.

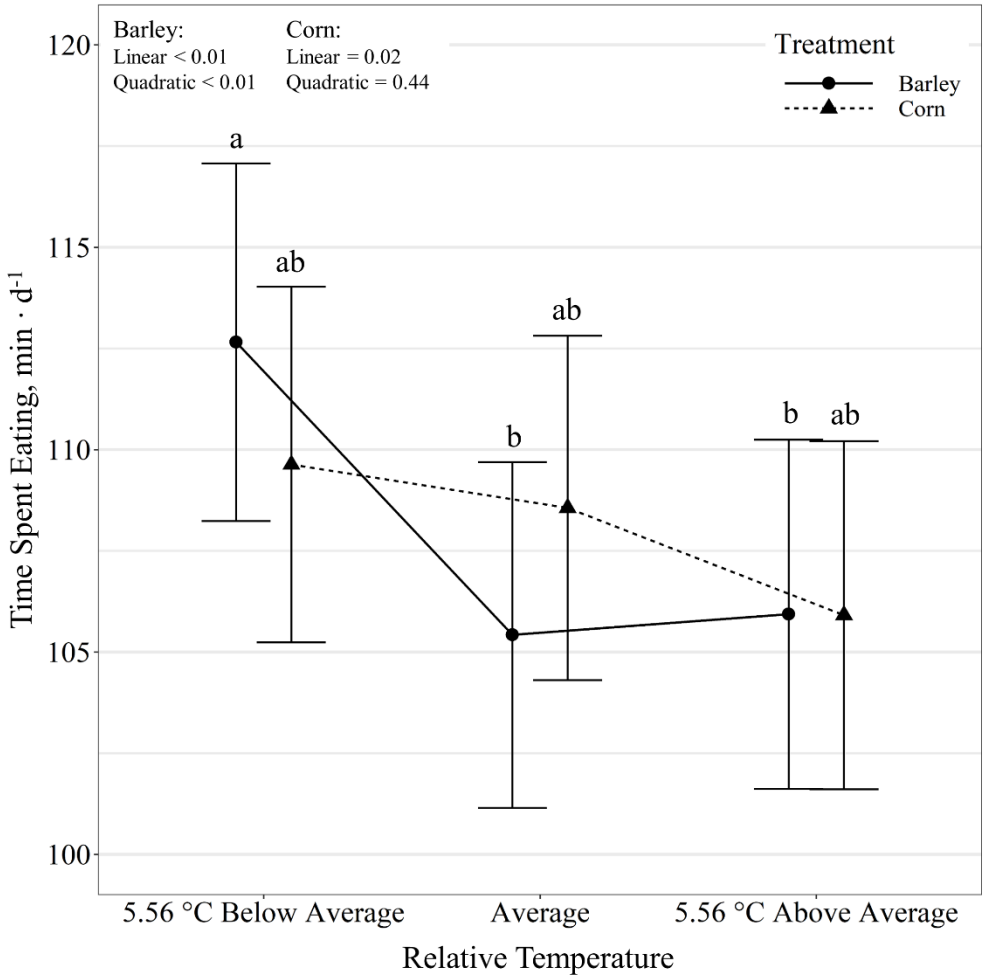


Figure 5. Influence of relative temperature change × diet ($P < 0.01$) on time spent eating (expressed as min · d^{-1}) by beef steers consuming either barley or corn-based feedlot diets at the Northern Agricultural Research Center, Havre, Montana, USA.

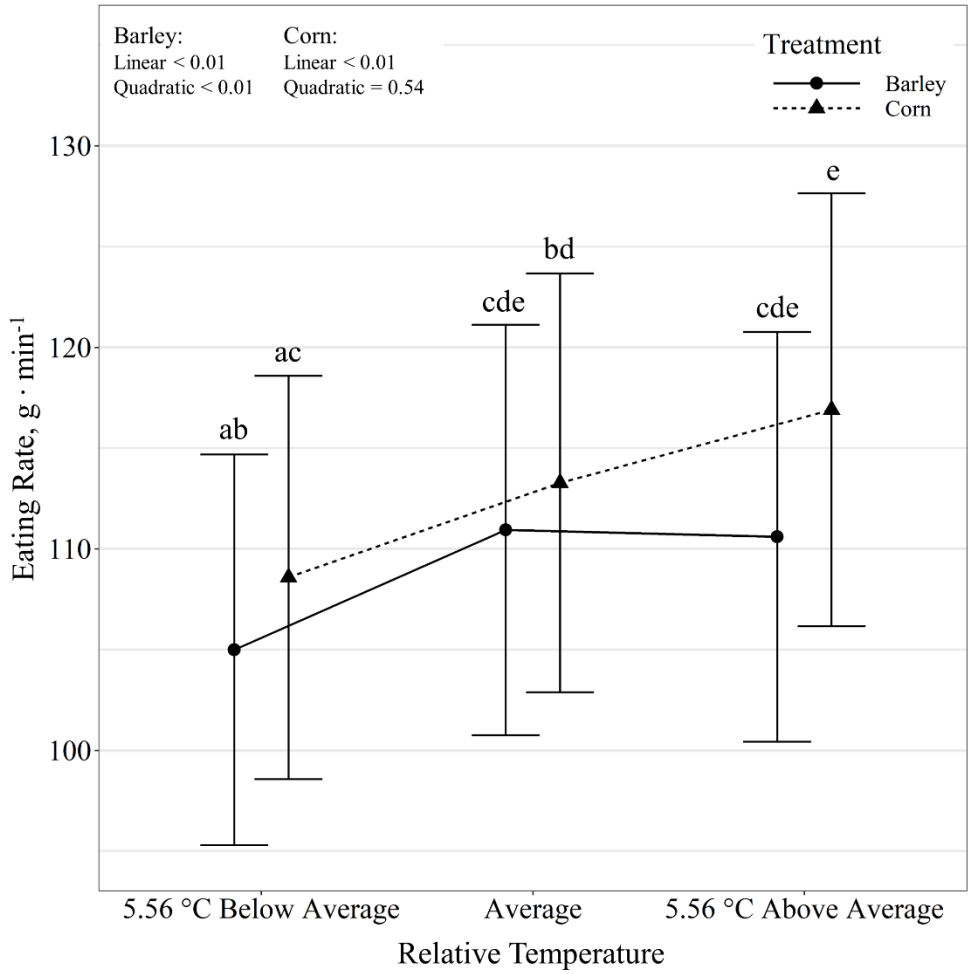


Figure 6. Influence of relative temperature change × diet ($P = 0.04$) on eating rate (expressed as $g \cdot min^{-1}$) by beef steers consuming either barley or corn-based feedlot diets at the Northern Agricultural Research Center, Havre, Montana, USA.

Diet had no effect ($P \geq 0.12$) on steer lying activity, however, temperature class influenced all lying activities ($P < 0.01$). There was a quadratic effect ($P < 0.01$) of relative temperature change on lying time per day, where, regardless of diet, lying time decreased ($P < 0.01$) on days colder than the 10-day average but did not change ($P = 0.47$) between days with average and warmer than the 10-day average temperature (Figure 7). Lying bouts per day was also quadratically influenced ($P < 0.01$) by relative temperature change, where lying bouts

decreased ($P < 0.01$) on days colder than the 10-day average but did not change ($P = 0.90$) between days with average and warmer than the 10-day average (Figure 8). Additionally, duration of lying bouts, minutes per day, was quadratically influenced ($P < 0.01$) by relative temperature change, where duration of lying bouts increased ($P < 0.01$) on days colder than the 10-day average temperature but did not differ ($P = 0.93$) between days with average and warmer than the 10-day average temperature (Figure 9).

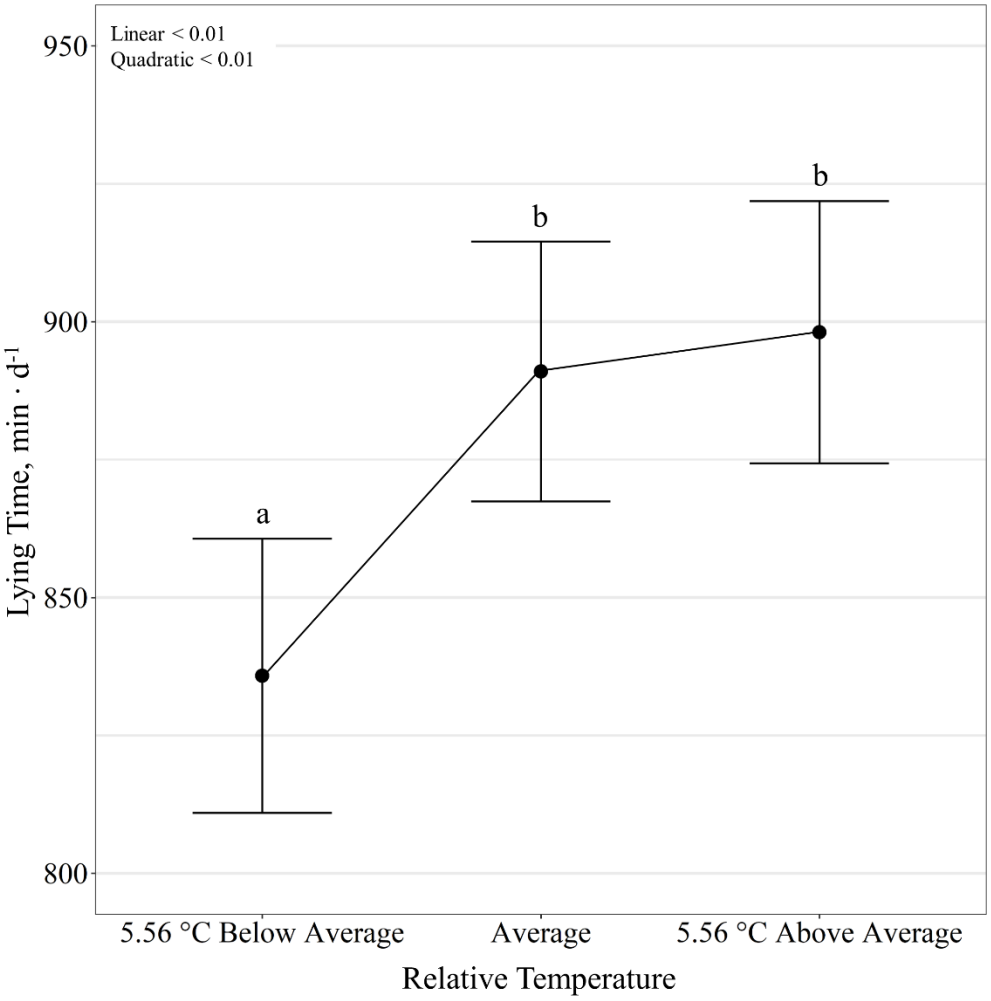


Figure 7. Influence of relative temperature change on lying time ($P < 0.01$; expressed as min · d^{-1}) by beef steers consuming either barley or corn-based feedlot diets at the Northern Agricultural Research Center, Havre, Montana, USA.

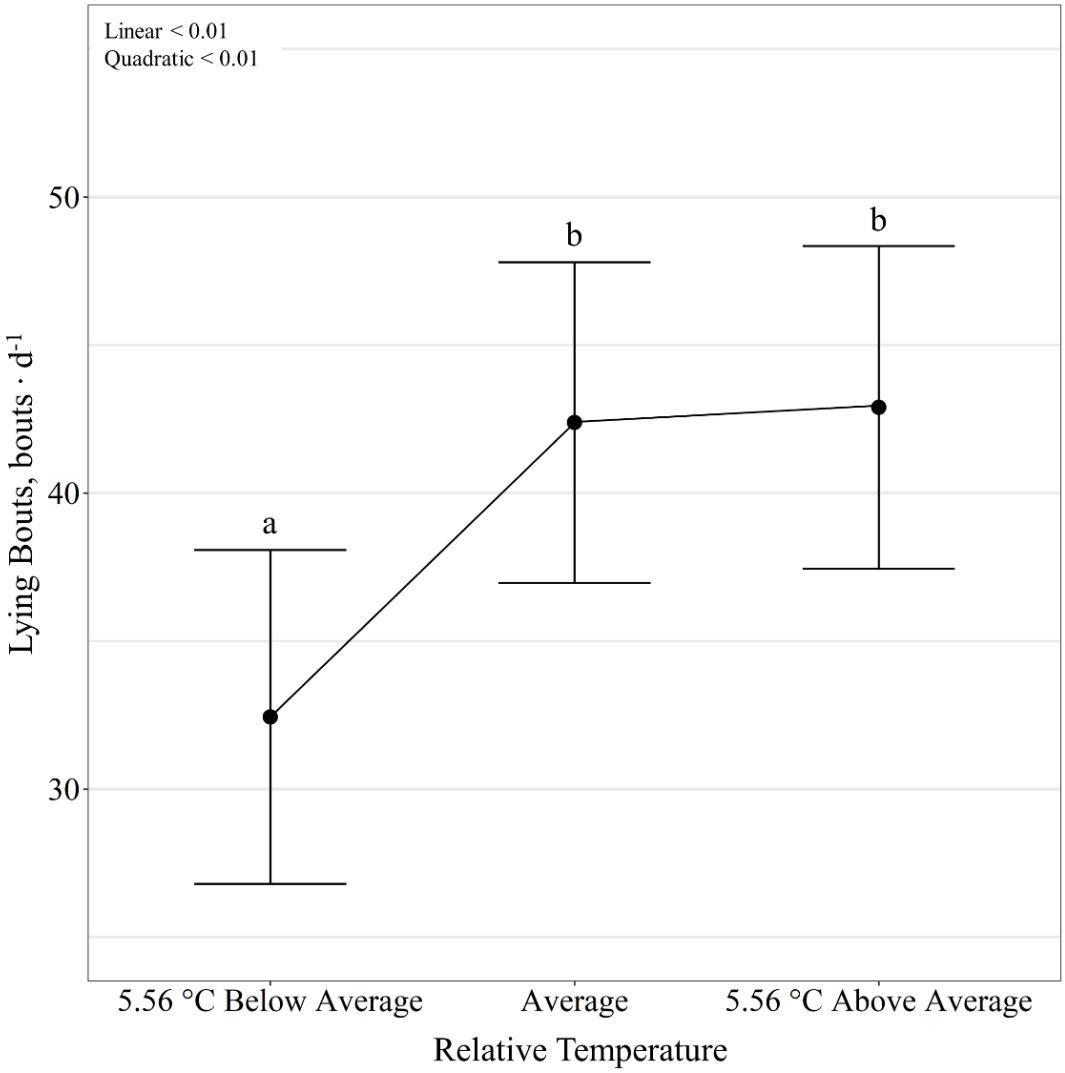


Figure 8. Influence of relative temperature change on lying time ($P < 0.01$; expressed as bouts · d^{-1}) by beef steers consuming either barley or corn-based feedlot diets at the Northern Agricultural Research Center, Havre, Montana, USA.

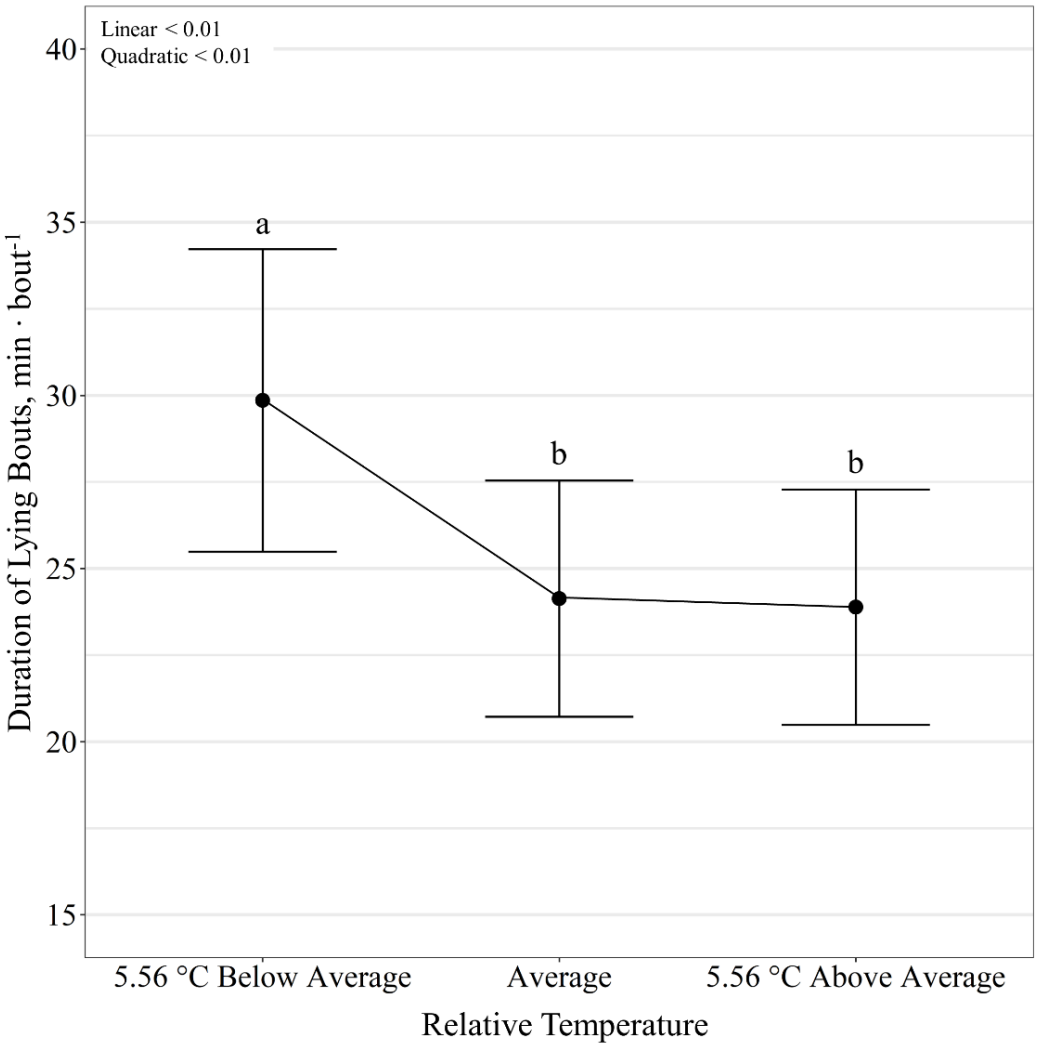


Figure 9. Influence of relative temperature change on lying time ($P < 0.01$; expressed as min · bout^{-1}) by beef steers consuming either barley or corn-based feedlot diets at the Northern Agricultural Research Center, Havre, Montana, USA.

Discussion

Variation in beef cattle performance may be attributed to individual feeding behavior and activity (Golden et al., 2008; Schwartzkopf-Genswein et al., 2011; Richeson et al., 2018). Changes in environmental conditions have been related to changes in the individual animal's overall behavior, and environmental shifts are frequently cited as the cause of corresponding alteration in feed consumption, occurrence of ruminal acidosis, and metabolic disorders (Streeter et al., 1999). In addition, grain sources (corn and barley) can influence feedlot steer behavior (Milner et al., 1995). Our results suggest intake expressed on a $g \cdot kg\ BW^{-1} \cdot d^{-1}$ basis increased on days colder than the 10-day average for barley-fed steers. However, for corn-fed steers intake only increased on days above the 10-day average. In grazing beef cattle, mean daily forage intake expressed as % of BW increased when temperature deviated (either increase or decrease) from temperature averages (Beverlin et al., 1989). Senft and Rittenhouse (1985) concluded that short-term behavioral responses in extreme weather conditions may be critical to the energy balance of domestic animals in both grazing and feedlot scenarios. In feedlot cattle trials, intake increased linearly from 10 °C to -10 °C, however, at temperatures below -10 °C variation of intake among animals was high, likely due to difference in individual response to cold temperatures (NRC, 1981). In contrast, our results suggest relative temperature change did not influence variation in intake. This observation could potentially be due to the uniformity of steers in this study and prior acclimation to the local environment.

It has also been observed that cattle decreased time spent feeding in response to cold temperature (Malechek and Smith, 1976; Adams et al., 1986). Specifically, intake declined in extremely low temperatures because of behavioral patterns, such as standing to shiver, which led to less time eating (NRC, 1981). Hepola et al. (2006) found that low temperatures decreased the

time spent eating and growth rate in dairy calves. In our study, time spent eating per day was influenced by temperature change and diet where barley-fed steers increased time at the feeder on colder than average days, and corn-fed steers tended to linearly increase time at the feeder as temperatures decreased. Interestingly, the eating rate of cattle fed both corn and barley-based diets declined when temperatures were below the 10-day average. While limited work has been conducted on eating rate in relationship to environmental changes, increased eating rate has been demonstrated to be associated with increased performance by cattle (Frisch and Vercoe, 1969; Prawl et al., 1997), which may aid in explaining reduction in cattle performance in northern latitudes during winter months (Milligan and Christison, 1974).

In addition to feed intake, cattle behavioral activity is used as an indication of animal comfort and well-being. Specifically, lying behavior is often a sign of cattle well-being (Robert et al., 2009; Rutten et al., 2013; Chapa et al., 2020). Lying and resting behavior are important for cattle, and longer lying times are often associated with better welfare (Tullo et al., 2019). Periods of rumination are also associated with time spent lying (Schirmann et al., 2012). Conversely, extended lying behavior, > 14 hour/day, may be a sign of illness, lameness, or disease (Solano et al., 2016). Limited work has been conducted specifically evaluating lying response to environmental changes in beef cattle (Richeson et al., 2018). Tullo et al. (2019) recently developed a model that predicted lying behavior in dairy cows based on temperature-humidity index, solar radiation, air velocity and rainfall. Additionally, dairy cattle have been found to decrease daily lying time, number of lying bouts, and lying bout duration with decreased air temperature (Hendriks et al., 2020). In grazing cattle, shorter lying times have also been reported when cattle experience colder or inclement weather conditions (Tucker et al., 2007). Our study

found that feedlot beef cattle also decreased lying time and lying bouts per day on days colder than the 10-day average. Conversely, other authors have found cattle exposed to cold temperatures and winter weather conditions increased time spent lying down as temperature decreased; however, cattle in these studies had access to bedding (Gonyou et al., 1979; Redbo et al., 2001). Thus, it has been suggested frozen ground conditions underfoot may impact standing and lying time (Hendriks et al., 2020), specifically with a wet or frozen surface contributing a reduction in the time cattle lie down (Tucker et al., 2007; Schütz et al., 2010; Hendriks et al., 2020). Additionally, the conflicting results of the above studies may be due to differences in micro-climates associated with wind and temperature. Increasing wind speed is correlated to convection heat loss, which reduces the temperature an animal experiences (Osczevski and Bluestein, 2005; Graunke et al., 2011; Wyffels et al., 2020). Therefore, wind can have a profound effect on effective environmental temperature, which could relate to differing animal behavioral responses.

Conclusions

We found that short-term temperature changes impacted feedlot beef cattle intake behavior and activity. Differing basal diets interacted with short-term environmental changes to influence animal feeding behavior, but diet had limited impact on cattle lying behavior. Overall, environmental shifts and cold temperature conditions could result in greater energetic needs and ultimately impact steer behavior. By providing information related to beef cattle feedlot behavior, we can more effectively manage cattle feeding systems at northern latitudes to improve feed efficiency.

CHAPTER FOUR

DIURNAL RUMINAL PH AND TEMPERATURE PATTERNS OF STEERS FED CORN OR BARLEY-BASED FINISHING DIETS

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Animals

Status of Manuscript:

____ Prepared for submission to a peer-reviewed journal

____ Officially submitted to a peer-reviewed journal

____ Accepted by a peer-reviewed journal

_X__ Published in a peer-reviewed journal

MDPI

(submitted manuscript – 15 August 2021)

(accepted work – 24 September 2021)

(published work – Animals 2021, 11(10), 2809)

doi:10.3390/ani11102809

CHAPTER FOUR

DIURNAL RUMINAL PH AND TEMPERATURE PATTERS OF STEERS FED CORN OR BARLEY-BASED FINISHING DIETS

Abstract

This study evaluated the effects of corn or barley finishing diets on ruminal pH and temperature and their relationship to feed intake events using continuous reticulorumen monitoring of feedlot steers. Average daily ruminal pH and temperature were not impacted ($P \geq 0.17$) by diet. However, diet did affect daily variation of ruminal pH and temperature ($P < 0.01$). Average hourly ruminal pH displayed a diet by hour post-feeding interaction ($P < 0.01$), where barley-fed steers had greater ($P < 0.01$) ruminal pH than corn-fed steers at 0-, 1-, 18-, 19-, 20-, 21-, 22-, and 23-hours post-feeding, but had lower ($P \leq 0.05$) ruminal pH than corn-fed steers at 6-, 7-, and 8-hours post-feeding. Variation in ruminal pH hour post-feeding also displayed a diet by hour post-feeding interaction ($P < 0.01$), where barley-fed steers had greater ($P \leq 0.03$) variation in ruminal pH at hours 1 – 17 post-feeding but did not differ ($P \geq 0.16$) at 0-, 18-, 19-, 20-, 21-, 22-, and 23-hours post-feeding. Additionally, average hourly ruminal temperature exhibited a diet by hour post-feeding interaction ($P < 0.01$). In summary, basal grain interacted with time post feeding influencing ruminal pH and temperature in feedlot steers.

Keywords: barley, corn, intake, ruminal pH, ruminal temperature, steer

Introduction

Feedlot cattle are often fed a diet with a high proportion of cereal grains to meet the energy requirements necessary for targeted growth and performance. Numerous grains may be

utilized in cattle feedlot rations. In the United States, corn is the most common grain ingredient in feedlots (Samuelson et al., 2016). However, barley is more adapted to the growing conditions of northern regions and, as a result, is a common feed grain in finishing rations in Canada and the Pacific Northwest (Bowman, 2001).

While feeding high concentrate-based rations of rapidly fermentable carbohydrates favors growth and performance, it does come with the challenge of increased likelihood of metabolic disorders such as acidosis (Owens et al., 1998). Digestive disorders account for approximately 25% to 33% of deaths in the feedlot and can have a marked impact on cattle health and efficiency of production (Galyean and Rivera, 2003). The grain source used in feedlot rations can have an influence on both rumen environment and function (Owens et al., 1997). In particular, barley starch is more rapidly fermented and digested to a greater extent in the rumen compared to corn (Ørskov, 1986; Herrera-Saldana et al., 1990). Thus, the use of barley in finishing rations has been criticized due to the increased likelihood of metabolic disorders and reduced performance (Owens et al., 1997; Owens et al., 1998).

In an ideal rumen environment for grain-fed cattle, ruminal fermentation is stable and mean ruminal pH is generally greater than 5.5, often ranging from 5.8 to 6.5 (Nagaraja and Titgemeyer, 2007). Typically, ruminal pH of grain-fed cattle follows a diurnal pattern in which ruminal pH is often high before the morning feeding and declines after feeding through peak fermentation (Nocek et al., 2002). However, the extent of ruminal pH decline is dependent on the size and fermentability of the meal (Beauchemin, 2000; Nocek et al., 2002). Ruminal pH is a critical factor for rumen function due to the impact of pH on microbial populations, products of fermentation, as well as the physiological function of the rumen including motility and

absorption (Elam, 1976; Nagaraja and Titgemeyer, 2007). When ruminal pH drops below 5.6 there is often a shift in microbial populations toward lactic acid production, which will continue to reduce ruminal pH resulting in acidosis (Nagaraja and Titgemeyer, 2007). Recent research has demonstrated that low ruminal pH is also associated with increased ruminal temperature (AlZahal et al., 2008; Wahrmund et al., 2012) establishing an importance for monitoring rumen temperature for determining animal health and early detection of disease (Rose-Dye et al., 2011). Diet composition and ruminal microbial populations play a large role in digestion and therefore, the efficiency of cattle performance (Nagaraja and Titgemeyer, 2007). The digestive characteristics of barley and corn grains could potentially influence ruminal environment and cattle dry matter intake. However, the effects of intake on gastrointestinal function in cattle are less understood (Moya et al., 2014). Moreover, information relating individual intake to ruminal environment of animals on barley or corn-based diets is limited. Therefore, the objective of this study was to evaluate the effects of corn or barley finishing diets on ruminal pH, temperature, and feed intake events of feedlot steers using continuous rumen monitoring.

Materials and Methods

All animals used in this study were provided by the Northern Agricultural Research Center, a unit of the Montana Agricultural Experiment Station, (Havre, MT, USA; 48.5500° N, 109.6841 ° W). Experimental design and procedures were approved by the Agriculture Animal Care and Use Committee of Montana State University (#2016-AA26).

Experimental design and diets have been published previously in DelCurto-Wyffels et al. (2021). Briefly, Angus-based yearling steer calves were fed in a feedlot study from February 27, 2017, to June 12, 2017 (105 days; 427.3 ± 3.7 kg; n = 48) in year 1, and February 26, 2018, to

June 11, 2018 (105 days; 406.8 ± 3.4 kg; n = 47) in year 2. All steers were implanted at the initiation of the study (Synovex One Feedlot Implant; Zoetis, Parsippany-Troy Hills, NJ). Upon entry to the feedlot, steers were stratified by body weight (BW) and, within stratum, randomly assigned to one of two primary basal grain dietary treatments, including: 1) Grade 2 feed corn or 2) Hockett barley. Hockett is a two-row malting barley that is very stable under dryland conditions and often used as a livestock feed source when malting parameters are not met (Barley Breeding Program, 2008). Both barley and corn grains were dry-rolled and provided as a total mixed ration (Table 8). The diets averaged 10.28% crude protein and 0.24 Mcal · kg^{-1} net energy gain. Prior to the data collection period, steers were acclimated to their respective diet for 14 days. Steers were fed once daily at 0800 and rations were provided to attain maximum individual intake without excessive wastage. Diets were increased by 0.23 kg per head after clean bunks had been present by mid-day for two consecutive days. Feed refusals were weighed and removed weekly. All animals had ad libitum access to water for the entirety of the trial.

Table 8. Ingredient composition of finishing diets containing corn or Hockett barley as basal grains**.**

	Barley	**Corn**
Ingredient		
Corn, %	-	80.00
Barley, %	80.00	-
Barley straw, %	12.00	12.00
Canola oil, %	3.00	3.00
Supplement, % [1]	5.00	5.00

[1] The supplement composition was formulated based on initial basal grain nutrient analysis and designed to make diets similar in crude protein, minerals and vitamins

Steers were fitted with an electronic identification ear tag and were adapted to a GrowSafe system (GrowSafe Systems Ltd., Airdrie, AB, Canada) for 14 days prior to the start of the study. A total of 24 GrowSafe electronic feed bunks (12 per treatment; 1 per 2 steers) were used in this study, each equipped with an antenna to detect animal presence. Neck bars on feed bunks only allowed for one animal entry to a bunk at a time. Individual animal intake was continuously recorded with load cell measurements via wireless transfer to a data-acquisition computer. The system was monitored daily for unaccounted feed balance. Whenever unaccounted feed disappearance was greater than 5% the GrowSafe system deemed the 24-hour data collection period as failed. In our study, 8.54% and 10.92% of the dry matter intake data failed in year 1 and 2, respectively. Previous research with GrowSafe technology has suggested that the accuracy of dry matter intake was not impacted when up to 30% of the data was missing (Wang et al., 2006).

To determine ruminal pH and temperature, an indwelling wireless data transmitting system (SmaXtec® Animal Care GmbH, Graz, Austria) was used (Gasteiner et al., 2012). A SmaXtec bolus was administered to 12 steers per treatment group for each year of the study. The pH probes were calibrated using pH 4 and pH 7 buffer solutions. According to directions of the manufacturer, the boluses were inserted into the reticulorumen of the steers at the initiation of the study. SmaXtec animal care technology® enables the continuous, real-time display of data such as ruminal pH and temperature. The data was read every 10 minutes throughout the entirety of the study and all data was obtained by smaXtec messenger® computer software.

Average daily intake and intake behavior are presented in a companion study (DelCurto-Wyffels et al., 2021). GrowSafe data was used to calculate intake for each individual steer each

hour post-feeding on a daily basis. The length of time between intake readings that constitute a new intake event was predetermined as 300 seconds (Sowell et al., 1998; Schwartzkopf-Genswein et al., 2002; Parsons et al., 2004). Hourly intake and intake event data was then paired with the ruminal pH and temperature readings for each individual steer for the duration of both study years. Daily and hourly variation in ruminal pH and temperature, measured as coefficient of variation (CV, %), was based on SmaXtec bolus data for each individual. Data was then used to evaluate ruminal pH and temperature change post-feeding and post-intake event and the variation of ruminal pH and temperature post-feeding.

All statistical analyses were performed in R 4.0.3 (R Core Team, 2017). Average daily ruminal pH, temperature, and coefficient of variation (CV, %) of daily ruminal pH and temperature were analyzed using ANOVA (the car package; (Fox and Weisberg, 2011) with a generalized linear mixed model (the lme4 package; (Bates et al., 2014) including diet as the fixed effect, with year and individual steer as random intercepts. Prior to evaluating the effects of diet on diurnal ruminal pH and temperature change, we conducted a Pearson's correlation test to evaluate the relationship between ruminal pH and temperature. However, preliminary results suggest that there was little relationship between ruminal pH and temperature for both barley- and corn-fed steers (r^2 = -0.02 and -0.01, respectively). Therefore, ruminal pH and temperature were both included in the final analysis and analyzed independently. Post-feeding hourly intake and ruminal pH, pH CV, ruminal temperature and temperature CV were analyzed using ANOVA (the car package; (Fox and Weisberg, 2011) with a generalized linear mixed model (the lme4 package; (Bates et al., 2014) including diet, hour post-feeding and the interaction of diet and hour post-feeding as fixed effects, with year and individual steer as random intercepts. Ruminal

pH and temperature post-feed intake event were analyzed using ANOVA (the car package; (Fox and Weisberg, 2011) with a generalized linear mixed model (the lme4 package; (Bates et al., 2014) including fixed effects of diet, minutes post-intake event and the interaction of diet and minutes post-intake event and random intercepts of year and individual steer. To account for autocorrelation of repeated measurements, individual steer was used as a random intercept in all analyses. To satisfy assumptions of normality and homogeneity of variance, data were plotted and log transformed if needed. Significance was considered at an alpha ≤ 0.05 and tendencies were considered at an alpha ≤ 0.10. Mean separation was conducted using the Tukey method when $P < 0.05$ (the emmeans package; (Lenth et al., 2019)). Experimental unit was individual steer.

Results

Average daily ruminal pH and temperature were not impacted ($P \geq 0.17$; Table 9) by diet. However, diet did affect daily variation of ruminal pH and temperature ($P < 0.01$), where barley-fed steers exhibited 1.74 and 0.25% greater daily variation of pH and temperature, respectively, compared to corn-fed steers. Average hourly intake (kg) post-feeding displayed a diet by hour post-feeding interaction ($P < 0.01$; Figure 10), where corn-fed steers consumed more feed ($P \leq 0.01$) than barley-fed steers at 0-, 1-, 2-, 5-, and 6-hours post-feeding and tended ($P \leq 0.08$) to consume more feed than barley-fed steers at hours 3 and 4 post-feeding. However, barley-fed steers consumed more feed ($P \leq 0.03$) than corn-fed steers at 10-, 11- and 22-hours post-feeding.

Table 9. Daily dry matter intake, ruminal pH and temperature of steers consuming diets containing corn or Hockett barley as basal grains.

Item	**Barley**	**Corn**	**SEM[1]**	**P-Value**
Average daily intake, kg[2]	11.30	11.72	0.52	0.06
Average daily ruminal pH	6.46	6.43	0.14	0.46
Daily ruminal pH CV, %[3]	5.63	3.89	0.14	< 0.01
Average daily ruminal temperature, °C	39.22	39.35	0.08	0.17
Daily ruminal temperature CV, %	2.37	2.12	0.10	< 0.01

[1]SEM = standard error of the means.
[2]Average daily intake (kg) originally presented in (DelCurto-Wyffels et al., 2021)
[3]CV = coefficient of variation

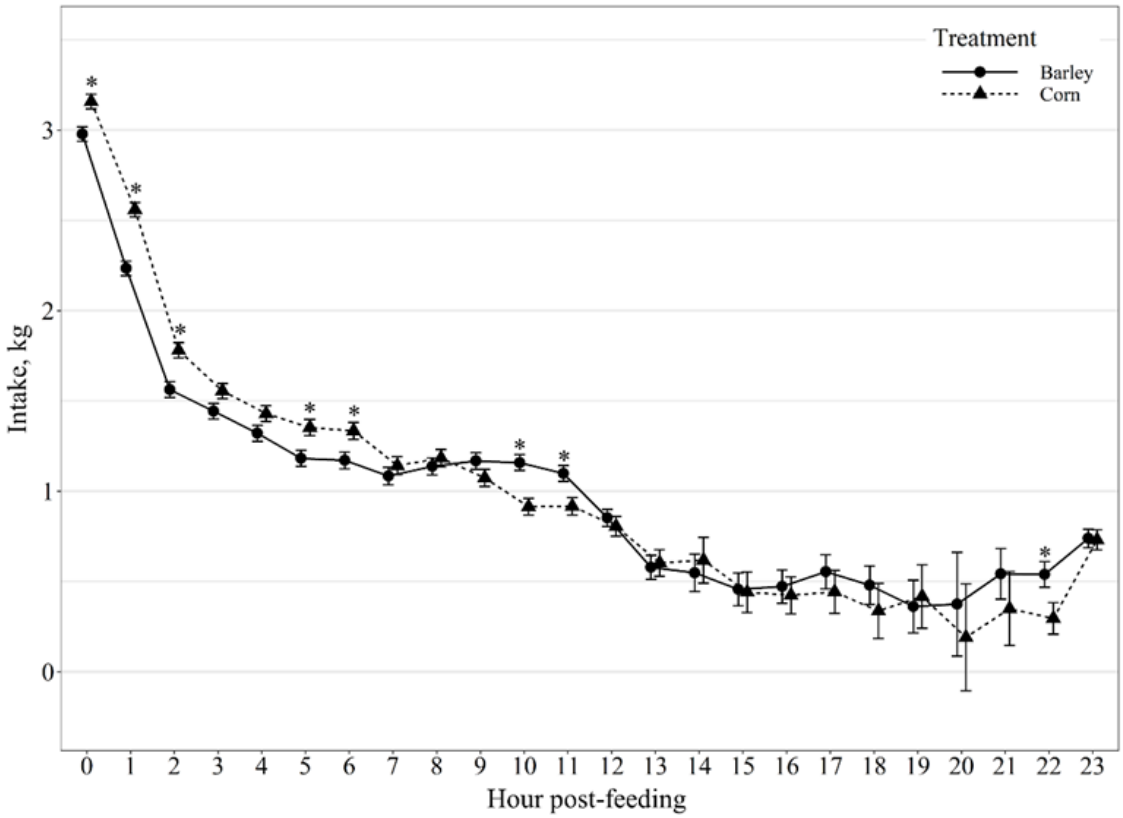


Figure 10. Diurnal dry matter intake patterns of beef steers fed once daily (0800) barley or corn-based feedlot diets. Intake was influenced by diet × hour post-feeding interaction ($P < 0.01$) and differences ($P \leq 0.05$) within hour post-feeding are denoted by *

Average hourly ruminal pH displayed a diet by hour post-feeding interaction ($P < 0.01$; Figure 11). Barley-fed steers had greater ($P < 0.01$) ruminal pH than corn-fed steers at 0-, 1-, 18-, 19-, 20-, 21-, 22-, and 23-hours post-feeding and tended ($P = 0.07$) to be greater than corn-fed steers 2-hours post-feeding, but had lower ($P \leq 0.05$) ruminal pH than corn-fed steers at 6-, 7-, and 8-hours post-feeding and tended ($P = 0.06$) to be lower than corn-fed steers at 9-, 10-, and 11-hours post-feeding. Additionally, variation in ruminal pH hour post-feeding also displayed a diet by hour post-feeding interaction ($P < 0.01$; Figure 12), where barley-fed steers had greater ($P \leq 0.03$) variation in ruminal pH at hours 1 – 17 post-feeding but did not differ from corn-fed steers ($P \geq 0.16$) at 0-, 18-, 19-, 20-, 21-, 22-, and 23-hours post-feeding. Suggesting that barley-

fed steers had greater decline in pH post-feeding and greater variation in ruminal pH than corn-fed steers.

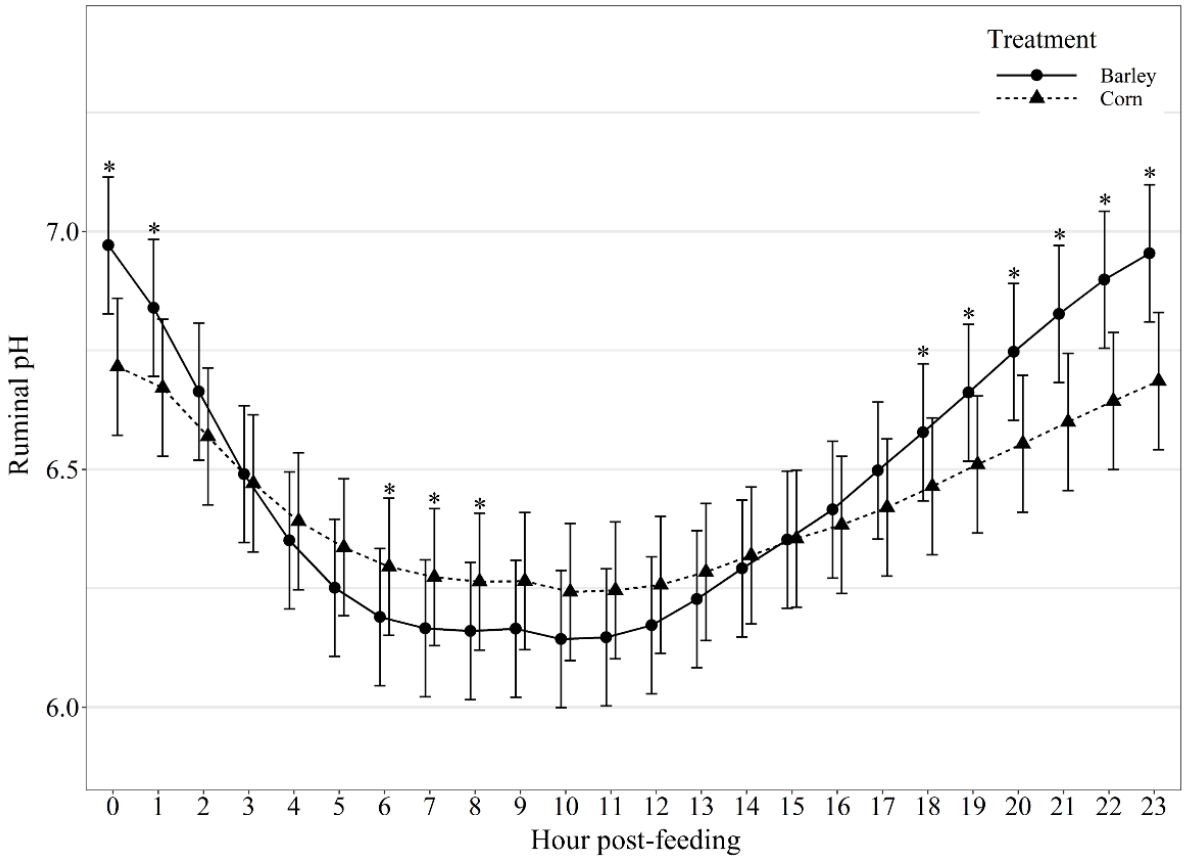


Figure 11. Diurnal pH patterns of beef steers fed once daily (0800) barley or corn-based feedlot diets. Ruminal pH was influenced by diet × hour post-feeding interaction ($P < 0.01$) and differences ($P \leq 0.05$) within hour post-feeding are denoted by *.

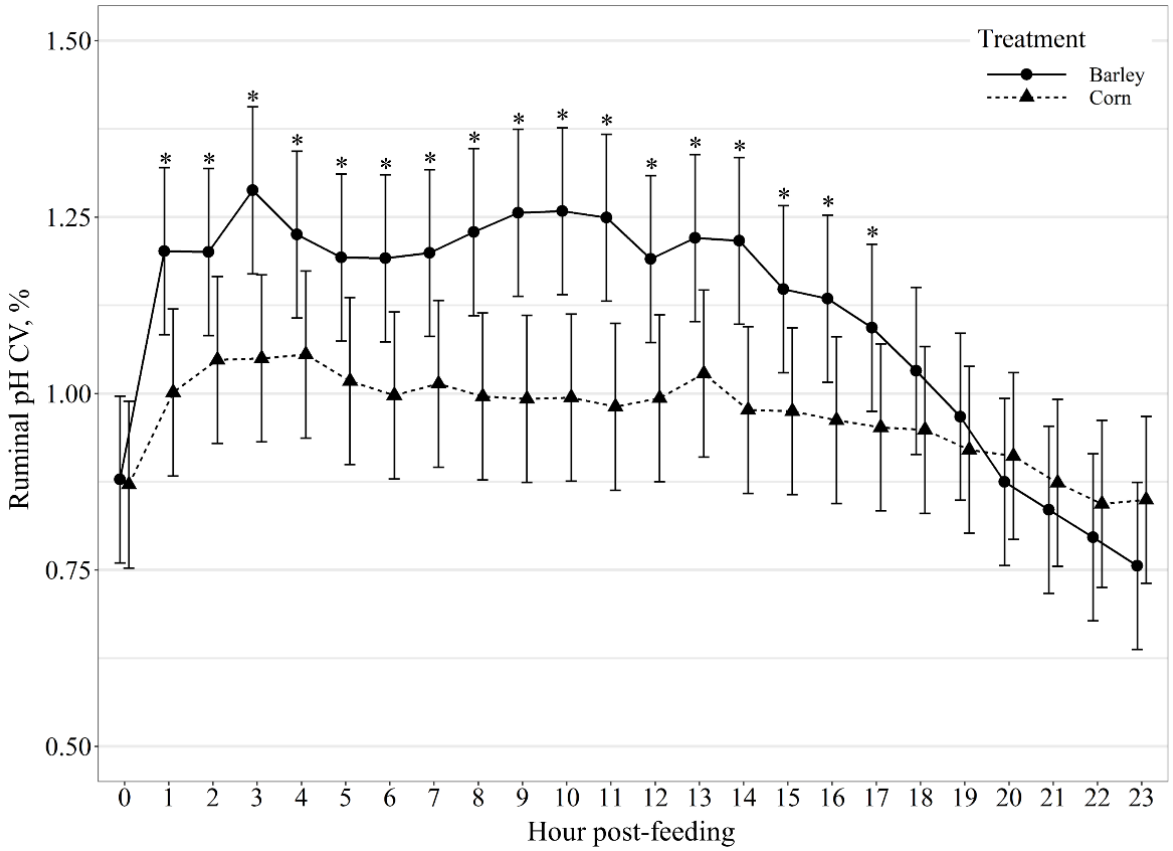


Figure 12. Diurnal pH coefficient of variation (CV, %) patterns of beef steers fed once daily (0800) barley or corn-based feedlot diets. Ruminal pH CV was influenced by diet × hour post-feeding interaction ($P < 0.01$) and differences ($P \leq 0.05$) within hour post-feeding are denoted by *.

Average hourly ruminal temperature exhibited a diet by hour post-feeding interaction ($P < 0.01$; Figure 13), with corn-fed steers having greater ($P \leq 0.01$) ruminal temperature at 0-, 1-, and 23-hours and tended ($P \leq 0.10$) to have greater ruminal temperature at 4-, 18-, 21- and 22-hours post-feeding. Variation in ruminal temperature hour post-feeding also displayed a diet by hour post-feeding interaction ($P < 0.01$; Figure 14), where corn-fed steers had greater ($P = 0.02$) variation in ruminal temperature at 2-hours post-feeding than barley-fed steers, however, barley-

fed steers had greater ($P \leq 0.02$) variation in ruminal temperature than corn-fed steers at 3-, 4-, 5-, 7-, 8-, 9-, 10-, 11-, 15-, 16-, 17-, and 18-hours post-feeding.

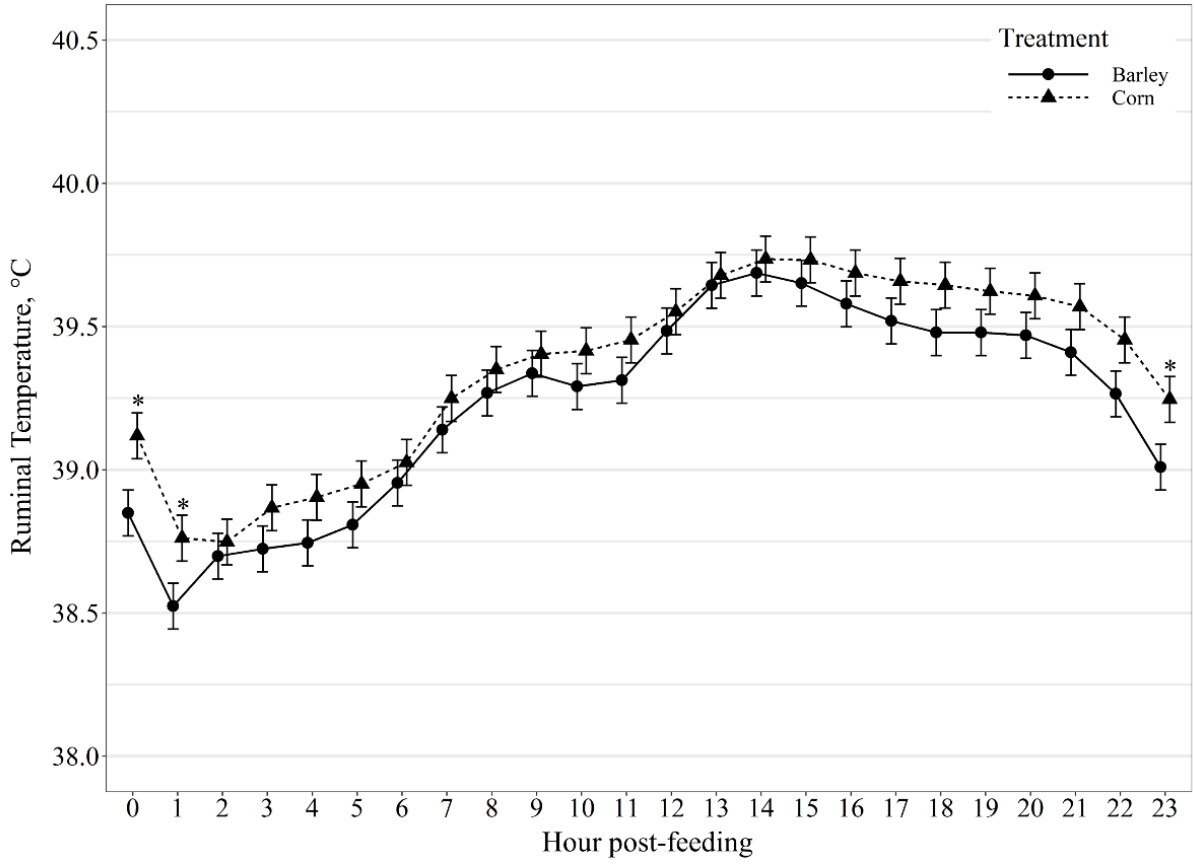


Figure 13. Diurnal ruminal temperature (°C) patterns of beef steers fed once daily (0800) barley or corn-based feedlot diets. Ruminal temperature was influenced by diet × hour post-feeding interaction ($P < 0.01$) and differences ($P \leq 0.05$) within hour post-feeding are denoted by *.

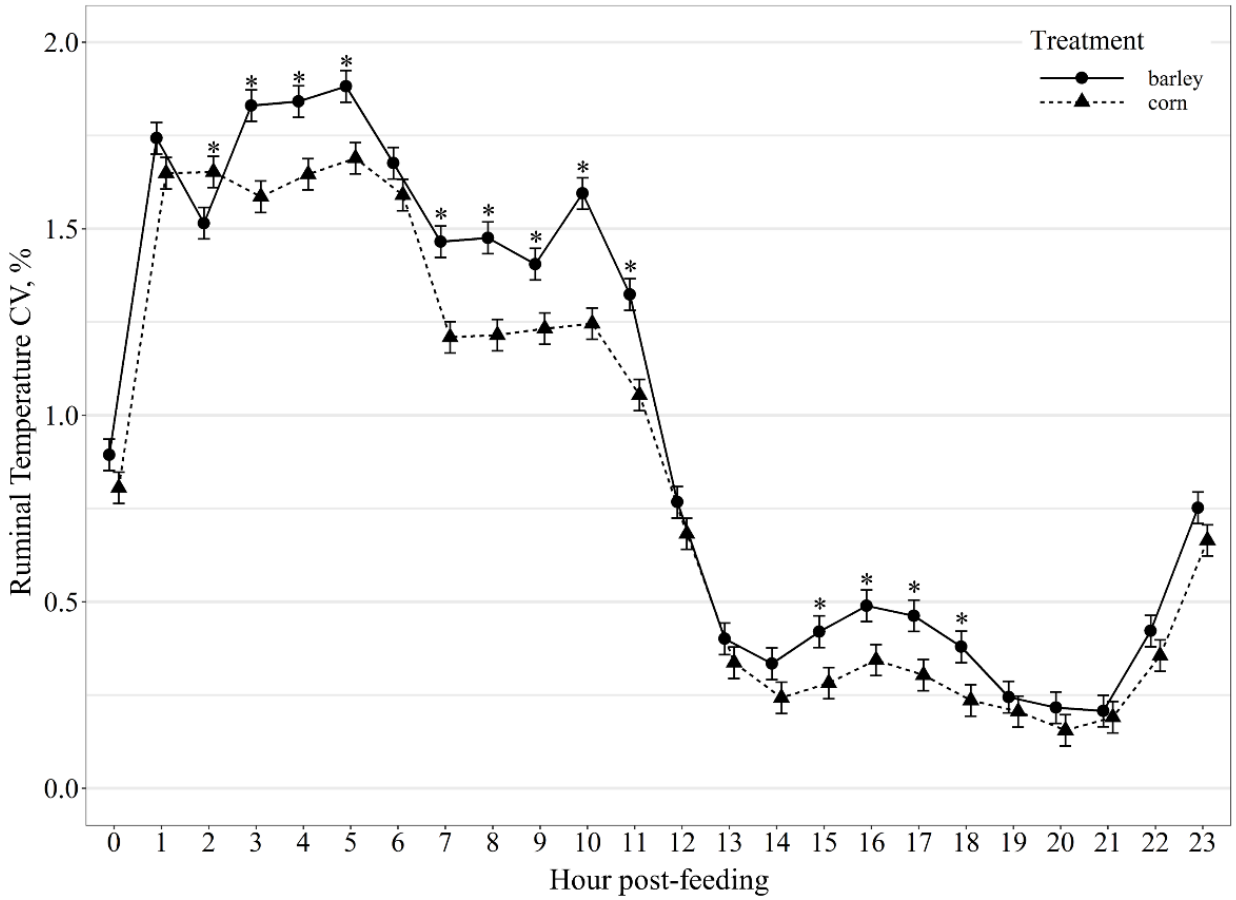


Figure 14. Diurnal ruminal temperature coefficient of variation (CV, %) patterns of beef steers fed once daily (0800) barley or corn-based feedlot diets. Ruminal temperature CV was influenced by diet × hour post-feeding interaction ($P < 0.01$) and differences ($P \leq 0.05$) within hour post-feeding are denoted by *.

Ruminal pH post-intake event displayed a diet by minute post-intake event interaction ($P < 0.01$; Figure 15), however, post-hoc mean separation displayed no diet effects ($P \geq 0.63$) on ruminal pH within minute post-intake event. Similarly, ruminal temperature post-intake event also exhibited a diet by minute post-intake event interaction ($P < 0.01$; Figure 16), however, post-hoc means separation displayed no diet effects ($P \geq 0.11$) on ruminal temperature within minute post-intake event.

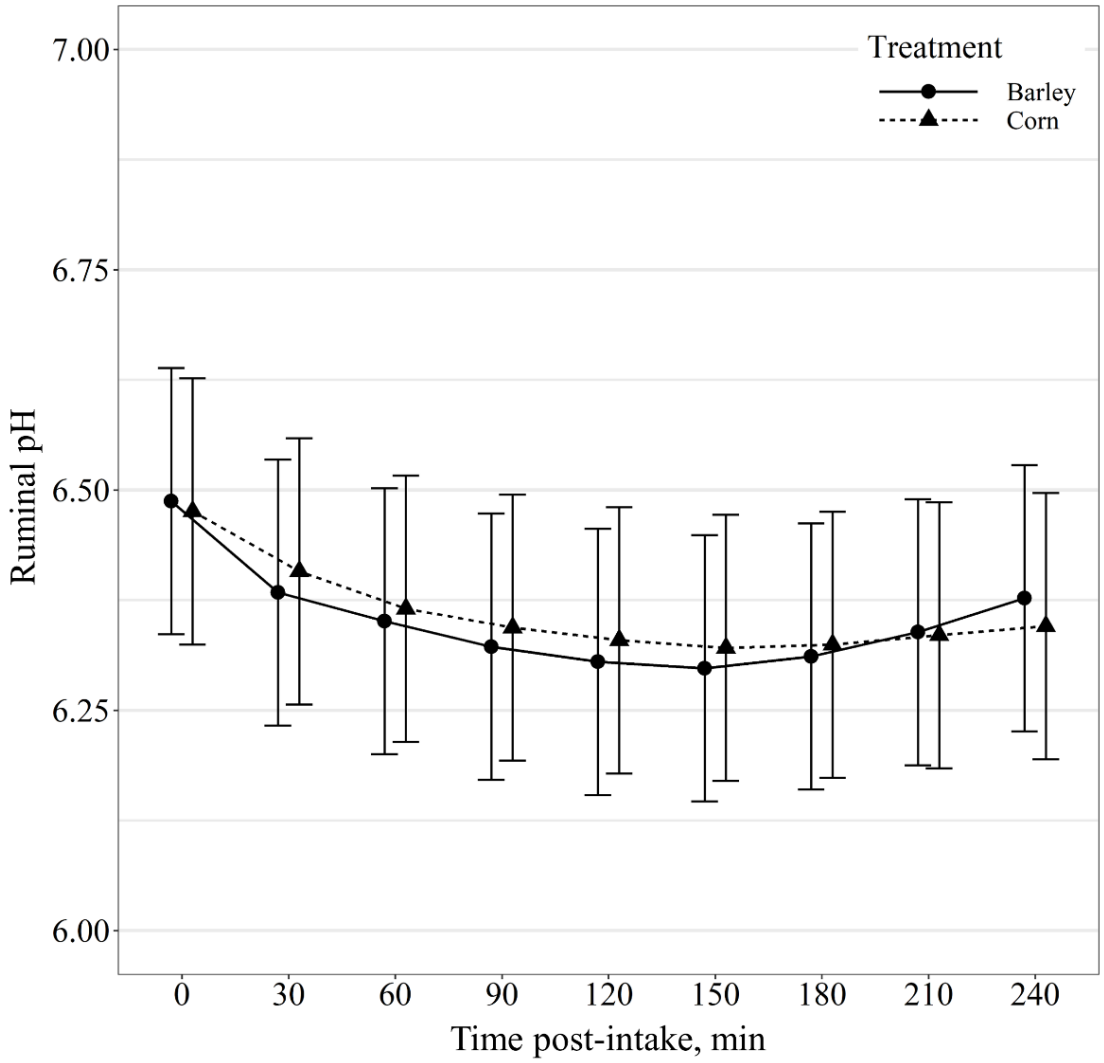


Figure 15. Ruminal pH change as a function of time (min) relative to intake event of beef steers provided barley or corn-based feedlot diets. Ruminal pH was influenced by a diet × minute post-intake event interaction ($P < 0.01$), however, no differences ($P \geq 0.63$) were observed between diets within post-intake event time periods.

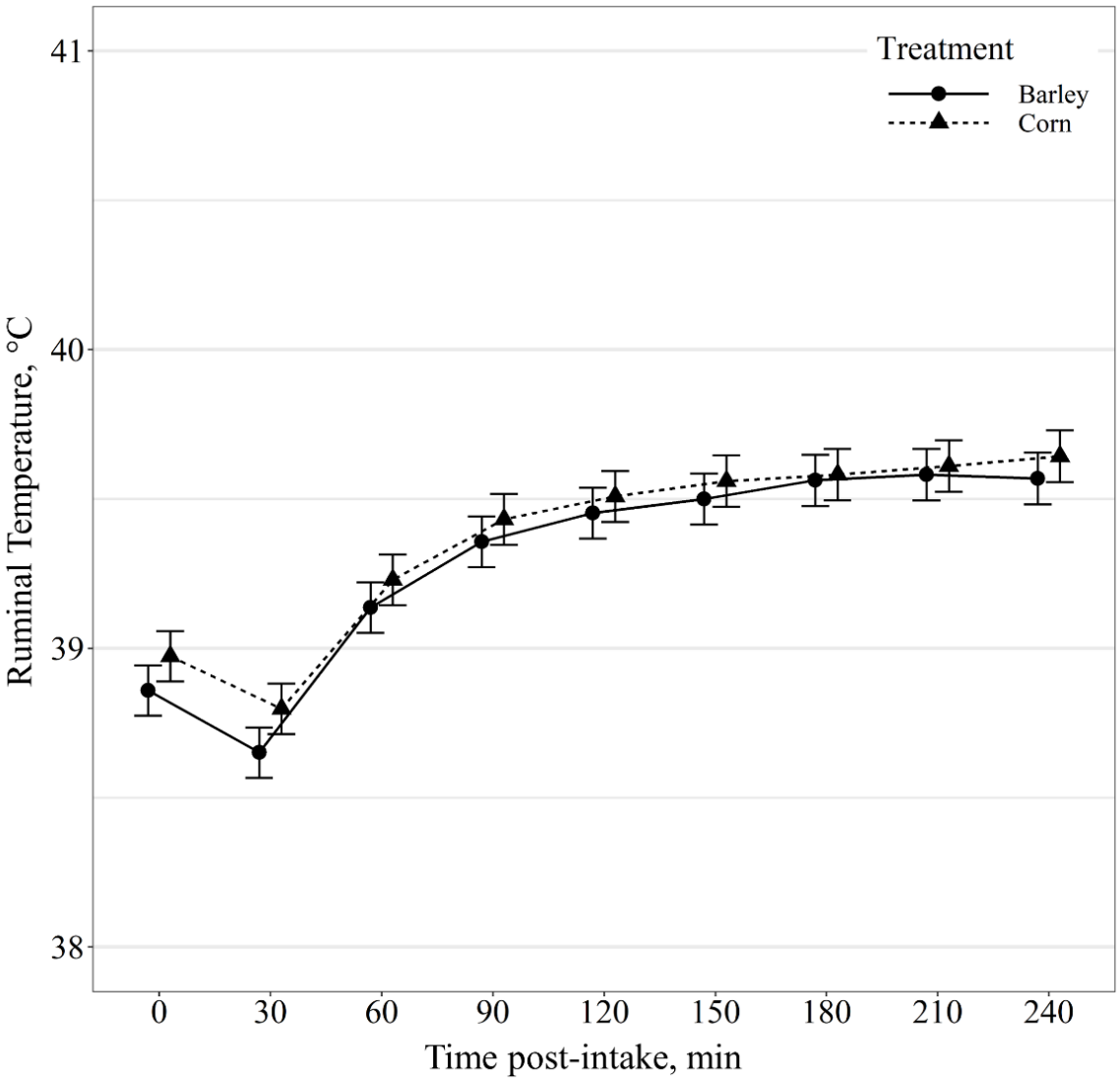


Figure 16. Ruminal temperature (°C) change as a function of time (min) relative to intake event of beef steers provided barley or corn-based feedlot diets. Ruminal temperature was influenced by a diet × minute post-intake event interaction ($P < 0.01$), however, no differences ($P \geq 0.11$) were observed between diets within post-intake event time periods.

Discussion

In the United States, the majority of cattle in feedlots are fed a grain-based diet (Samuelson et al., 2016). The feedstuff utilized can impact cattle performance, rumen dynamics, and digestive efficiency. In addition, the intake of fermentable carbohydrates coupled with the rate of fermentation can impact ruminal pH. Barley and corn are two commonly used feeds for cattle; however, the digestive utilization of each grain can be quite different. Generally, corn has a greater starch content than barley and the starch is more likely to escape ruminal digestion and be absorbed in the small intestine (Ørskov, 1986). Because starch digestion in the rumen is greater for barley than corn it has been demonstrated that cows fed diets containing barley tend to have a ruminal pH 0.2 units lower than cows fed corn when fed the same amount of forage fiber (Beauchemin, 2000). In our study, we did not observe a difference in daily mean ruminal pH between barley and corn-fed steers and mean ruminal pH for steers fed both diets were well above acidotic conditions. However, nutritionists commonly attribute metabolic disturbances to large daily shifts in feeding behavior and erratic feed intake by cattle (Cooper et al., 1999; Schwartzkopf-Genswein et al., 2003). The size, number, and frequency of meals can have a large effect on ruminal pH (Schwartzkopf-Genswein et al., 2003) with low ruminal pH further contributing to erratic intake patterns (Fulton et al., 1979). A companion study evaluating the effect of corn and barley-based diets on intake behavior and performance using the same steers, demonstrated a tendency for corn-fed steers to consume more feed per day and have greater variation in intake per day than barley-fed steers, but showed no differences in number and frequency of meals (DelCurto-Wyffels et al., 2021). However, the differences in regard to intake patterns were not manifested in average daily ruminal pH.

Generally, ruminal pH is highest just before the morning feeding. After feeding, the pH drops in relationship to fermentation of dietary carbohydrates (Beauchemin, 2000; Schwartzkopf-Genswein et al., 2003). Although we did not observe a difference in mean daily pH between barley- and corn-fed steers, barley-fed steers displayed greater variation in daily ruminal pH and greater variation in ruminal pH for the majority of hours-post feeding (hours 1 – 17) compared to corn-fed steers. These findings could be due to the difference in starch availability and rate of fermentation between the two feedstuffs. Corn starch is less ruminally digestible (Ørskov, 1986) with up to 30% of corn starch escaping ruminal fermentation. Corn also has a slower rate of in situ dry matter and starch disappearance (Surber et al., 1998). The slower rate of ruminal digestion of corn-based diets reduces the risk of low reticulorumen pH and may allow for the more stable diurnal pH observed in our study.

Previous research has reported a strong correlation between feed intake of feedlot cattle and the lowest daily ruminal pH on the previous day (Brown et al., 2000). Yang et al. (1997) observed that ruminal pH was higher in cows fed a corn-based diet compared to barley throughout the early portions of the day post-feeding. However, the magnitude of difference in ruminal pH between barley and corn-based diets were relatively small (Overton et al., 1995; Yang et al., 1997). In our study, both corn and barley-fed steers exhibited the majority of daily intake the first 12 hours post-feeding, with corn-fed steers consuming or tending to consume more feed than barley-fed steers within the first 6 hours post-feeding, however, barley-fed steers consumed more feed than corn-fed steers at hour 10 and 11 post-feeding and immediately prior to the next feeding event at 22-h. Additionally, we found a diurnal difference in ruminal pH between barley and corn-fed steers in which ruminal pH was higher in barley fed steers 0- and 1-

hour post-feeding, as well as, 18 – 23 hours post-feeding and lower than corn-fed cattle at hour 6, 7, and 8 post-feeding. Thus, the ruminal pH for barley-fed steers had greater daily ruminal pH declines compared to corn-fed steers. Previous research has found that cattle consuming high levels of barley alter feeding behavior in a manner that reduces the risk of acidosis (Moya et al., 2011). These findings suggest that animals may adjust their intake when pH is low, presumably in an attempt to limit consumption of fermentable carbohydrates and restore pH conditions to a more comfortable level (Schwartzkopf-Genswein et al., 2003). This may explain why diet had an effect on diurnal ruminal pH patterns but was not a factor influencing ruminal pH post-intake event out to 240 minutes.

Previous research has demonstrated ruminal temperature to be a reliable measure of body temperature in both dairy cows and beef steers (Bewley et al., 2008; Rose-Dye et al., 2011). Thus, monitoring ruminal temperature could aid in detecting adverse health events in cattle (Rose-Dye et al., 2011). Additionally, a correlation has been observed between rumen temperature and pH (Wahrmund et al., 2012; Mohammed et al., 2014). The strength of this relationship, however, appeared to be influenced by diet composition and individual animal variability (Mohammed et al., 2014). In the current study, rumen temperature responded similarly in both barley and corn-fed cattle apart from the hour before and after feeding. There was no difference in ruminal temperature post-intake events between barley and corn-based diets. However, for steers fed barley- or corn-based diets, rumen temperatures declined 30 minutes post-intake event. Rumen temperatures are impacted by other factors such as water intake (Brod et al., 1982; Dye and Richards, 2008). Presumably, the reduced temperatures observed 30 minutes post-intake could be due to cattle consuming water after feeding. Previous

research has predicted watering events based on ruminal temperature change recorded with rumen boluses, however, this comes with a large margin of error (Vázquez-Diosdado et al., 2019). Therefore, the relationship of rumen pH and temperature with water intake and intake behavior warrants further investigation.

Conclusions

Barley and corn are two commonly used grain sources in beef cattle diets. However, digestive utilization of each feedstuff and subsequent rumen environment of cattle fed barley or corn-based diets can be markedly different. While mean ruminal pH was not different between corn or barley-fed steers, barley-fed steers had greater ruminal pH change throughout a 24-hour period. Additionally, barley-fed steers had greater diurnal variation in ruminal pH up to hour 17 post-feeding. These findings are likely due to differences in starch content and rate of fermentation of the grains. Intake patterns were also unique in corn and barley-fed steers in which corn-fed steers consumed more feed the first 6 hours directly after feeding. Barley-fed steers, however, consumed more feed later in the day. Presumably these intake patterns could be influenced by ruminal pH. Our research suggests that evaluating intake and ruminal fermentation characteristics need to be conducted at a diurnal scale to optimize beef cattle performance and efficiency.

CHAPTER FIVE

CONCLUSIONS AND MANAGEMENT CONSIDERATIONS

Feeding cattle at northern latitudes can present challenges. While interest exists in growing the backgrounding, feedlot, and packing sectors of the cattle industry in Montana, upper mid-west, and the Pacific Northwest; feed availability, cost, as well as environmental extremes can limit production efficiency. Thus, our research sought to further our understanding of finishing cattle at northern latitudes. Our objectives were to 1) evaluate the effect of corn and barley-based diets on steer performance and eating behavior, 2) evaluate the influence of environmental conditions on intake behavior and activity for steers fed both corn- and barley-based diets, and 3) evaluate diurnal ruminal pH and temperature of steers fed corn- and barley-based diets. With a better understanding of the influence of grain source and environmental conditions on beef cattle behavior we hope that our research will aid producers in making informed nutritional and management decisions when feeding cattle at northern latitudes.

Feed is one of the most significant expenses in livestock production. In general, feedlots often select feedstuffs based on the cost of grain, cost of processing, and availability (Owens et al., 1997). One of the challenges of feeding cattle in the Northwest is our limited growing season and relative distance from large grain resources. Barley is more adapted to the climatic conditions of northern latitudes (Bowman, 2001). Thus, barley is a common grain alternative to corn that has been successfully fed to feedlot cattle (Boss and Bowman, 1996; Surber et al., 1998; Johnson et al., 2020). In our first study, we evaluated the impact of corn and barley-based diets on steer performance and intake behavior. In this study we found corn-fed steers had greater gains and heavier final live weights than barley-fed steers, however, this tended to be

accompanied by greater daily intake. No differences in animal behavior were observed between barley or corn-fed steers (DelCurto-Wyffels et al., 2021b). Thus, depending on the difference of costs associated with feeding corn or barley in a given year, barley could be a potential high-quality feed source in beef cattle finishing rations.

Montana and the Pacific Northwest are prone to environmental extremes and seasonal variations. Climatic conditions have a major influence on performance, health, and overall well-being of cattle and seasonal variations of climatic conditions have been documented to impact feedlot cattle performance (Elam, 1971; Milligan and Christison, 1974). Thus, in our second study, we evaluated the influence of diet and environmental changes on intake behavior and activity (lying time) of feedlot steers. Short-term temperature changes impacted both beef feedlot cattle intake behavior and activity. The steers' diet, whether they were fed corn or barley, interacted with short term environmental changes to influence animal feeding behavior, but diet had limited impact on cattle lying behavior. Lying behavior was influenced by short-term temperature changes in which cattle spent more time lying down on relatively cold days (DelCurto-Wyffels et al., 2021a). Overall, environmental shifts and cold temperature conditions could result in greater energetic needs and ultimately impact feedlot steer intake behavior and activity.

Different feedstuffs have unique digestive utilization which may lead to different cattle performance outcomes. Barley is fermented to a greater extent in the rumen, compared to corn, and can lead to an increased likelihood of digestive disorders (Ørskov, 1986). In our third study, we evaluated the effects of corn and barley diets on ruminal pH, temperature and feed intake events using continuous rumen monitoring technology. While mean ruminal pH was not

different between corn or barley-fed steers, barley-fed steers had greater ruminal pH change throughout a 24-hour period. Barley-fed steers also exhibited greater variation in ruminal pH. Additionally, intake patterns were different between corn and barley-fed steers in which corn-fed steers consumed more feed the first 6 hours directly after feeding while barley-fed steers consumed more feed later in the day. Presumably, these intake patterns could be influenced by differences in the diurnal patterns of ruminal pH between corn and barley.

In conclusion, our studies evaluated several aspects of feeding cattle corn and barley-based diets at northern latitudes and the impacts that these environmental factors and feed grains may have on steer performance, behavior and digestive utilization. Both corn and barley-fed steers exhibited similar behavior and performance outcomes. However, steers fed different diets responded uniquely to environmental changes. Additionally, each diet yielded differences in diurnal patterns of ruminal pH and temperature. Presumably these ruminal differences were driven by the digestive utilization of barley and corn grains and contributed to the differences we observed in diurnal eating behavior.

These studies utilized advanced technologies in animal science to address beef cattle management considerations of feeding cattle at northern latitudes. During this exciting time in animal science, we have more technology than we ever have before. These technological tools give us the opportunity to address questions in new ways. The use of continuous rumen monitoring, activity monitors, GrowSafe feed bunks that allow for the study of individual animal feed intake, as well as numerous others are all unique tools to address modern problems and questions.

Future research is warranted to further evaluate the impacts of environmental conditions on cattle performance and behavior. Additionally, our research suggests that when evaluating intake and ruminal fermentation characteristics data needs to be conducted at a diurnal scale. Within these studies we characterized the differences that could be observed in cattle performance, behavior and ruminal profiles when cattle are fed corn or barley-based diets at northern latitudes. By providing information related to individual feeding behavior and performance we can more effectively manage cattle feeding at northern latitudes to improve overall efficiency in beef cattle production systems.

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APPENDIX A

CORRECTED TEXT FOR CHAPTER TWO

Carcass data was collected by a private entity, not an USDA grader.