NUTRITIONAL MANAGEMENT STRATEGIES TO ALTER PERFORMANCE, HEALTH, AND RUMINATION CHARACTERISTICS DURING THE FEEDLOT RECEIVING PERIOD

by

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ABSTRACT

Feeder cattle procured through auction market channels experience multiple stressors prior to feedlot arrival. Once at the feedlot, cattle enter a novel environment where they are exposed to new feedstuffs and water sources and are frequently comingled. These environmental factors contribute to physiological stress, which is associated with low feed intake and is a predisposing factor to bovine respiratory disease. Through this process cattle can become dehydrated and may enter a negative energy balance. Addressing hydration and energy requirements more rapidly at feedlot arrival may reduce morbidity and improve performance. Therefore 3 studies were conducted to evaluate 2 management strategies. Study 1 evaluated the effect of oral hydration therapy at feedlot arrival on health and performance during a 56-d receiving period. In study 1, experiment 1 (n=664 high-risk heifers,197.1 ± 5.8 kg) and experiment 2 (n= 297 high-risk bulls and steers, 188.9 ± 19.1 kg) assessed oral hydration therapy (0.57 L of water/ 45.4 kg BW) at feedlot arrival compared to a negative control. This study suggested improved performance and DMI in cattle receiving oral hydration therapy, however health outcomes were not improved. In study 2 a sub set of the cattle from experiment 2 were fitted with a 3-axis accelerometer collar (n = 58) and rumen bolus (n = 33) to quantify oral hydration therapy effects on activity, rumination, rumen pH and rumen temperature. Oral hydration therapy cattle had an earlier peak rumen temperature suggesting a physiological modification enabling a more pronounced inflammatory response. From this sub-set, cattle treated at least once for bovine respiratory disease (BRD) were

retrospectively compared to non-treated cohorts. Cattle treated for BRD had reduced activity and rumination, as well as increased rumen temperatures and altered rumen pH. Differences in activity and rumination may be useful for early BRD detection. In study 3, 36 auction derived steers (284 ± 11 kg) were used to compare 3 receiving period nutritional management strategies including a traditional lower energy density diet, a high energy density diet, or a high energy density diet supplemented with long stem hay every 3rd day. There were no differences in performance due to nutritional management strategy. Cattle fed the high energy density ration had a greater rumen temperature following initial viral vaccination, and decreased rumination compared to the lower energy density ration treatment. There were minimal differences in rumen pH likely due to large animal to animal variation. These results suggest feeding higher energy density diets upon feedlot arrival may be a viable option, however this needs to be validated in a pen fed setting where greater daily intake variation is probable.

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INTRODUCTION

The most prevalent disease in North American feedlots is bovine respiratory disease (BRD). In feedlots with a capacity of 8,000 or more, 19.0% of cattle that arrive weighing less than 318 kg are treated for BRD. Average treatment cost for respiratory disease has been estimated at $23.60 per treatment (USDA-APHIS, 2011), and the total cost across the U.S. feedlot industry has been estimated at $54.12 million not including decreased performance associated with morbidity and mortality (Johnson and Pendell, 2017). Others estimate the annual economic cost of BRD to approach $1 billion (Griffin, 1997).

Diagnosing BRD is difficult because it is currently done subjectively and cattle, being prey animals, inherently disguise illness behavior. At commercial feedlots, a skilled pen rider will observe cattle daily for clinical signs of BRD. In the research setting, multiple scoring systems have been utilized to standardize this practice. Some of the scoring systems include the clinical illness score or depression score (Pillen et al., 2016). A more elaborate scoring system has been used in diagnosing dairy calves which considers ocular and nasal discharge as well as cough frequency (McGuirk, 2008). Despite these efforts, the correlation between BRD treatments and lung lesion presence is low. Wittum et al. (1996) reported out of 469 feedlot steers, 35% were treated for BRD, but pulmonary lesions were present for 72% of the steers at slaughter. Furthermore, 68% of untreated steers had pulmonary lesions. The poor association between clinical BRD treatment in

the feedlot and lung lesions at slaughter has been documented not only in the U.S. (Tennant et al., 2014), but also Italy (Caucci et al., 2018) and South Africa (Thompson et al., 2006). The presence of pulmonary lesions at slaughter was associated with decreased ADG of 0.076 kg/d (Wittum et al., 1996) and 0.088 kg/d (Thompson et al., 2006). Holland et al. (2010) preconditioned auction sourced feeder heifers for 63 d prior to sorting by number of BRD treatments. Heifers were then followed through slaughter which was targeted at a common compositional endpoint based on BW and LM area determined via ultrasound. Finishing phase ADG increased with increasing BRD treatments suggesting compensatory gain following a BRD event; however, ADG decreased with increasing BRD treatments over the entire feeding period. Heifers treated less than 3 times for BRD were finished in the same number of days. Heifers requiring 3 BRD treatments required 19 additional days to reach suitable finish, further supporting decreased performance associated with BRD even through the end of the finishing period. Incidence of BRD is frequent and costly, and solutions to this challenge have been elusive because it is a multifactorial disease involving viral and bacterial pathogens. These pathogens attempt to survive in spite of the host's immune system, which is often compromised during the transition through the marketing system from the ranch of origin to the feedlot. This literature review will outline the pathogenesis of BRD and the homeostatic regulatory systems in bovine. Finally, the current body of literature pertaining to nutritional and health management strategies for high-risk feeder calves will be reviewed.

BOVINE RESPIRATORY DISEASE COMPLEX

Bovine respiratory disease is often referred to as a disease complex because it is multifaceted. Initially, immunosuppression induced by stressors encountered through the beef marketing system reduces the ability to resist infection (Carroll and Forsberg, 2007). Increased viral replication in the upper respiratory tract further suppresses immune function by damaging tracheal cilia, reducing their pathogen clearing activity (Yates, 1982). A secondary bacterial infection occurs when otherwise commensal bacteria of the upper respiratory tract migrate to the lungs and further stimulate the host's immune system (Hodgson et al., 2005).

Bovine respiratory disease viral pathogens

The 5 viruses most commonly associated with BRD are bovine herpesvirus-1 (BHV-1), bovine viral diarrhea virus (BVDV) types 1 and 2, parainfluenza-3 virus (PI3V), and bovine respiratory syncytial virus (BRSV). Infectious bovine rhinotracheitis virus is another common name for BHV-1. Most commonly, BHV-1 is considered a pathogen of the upper respiratory tract and a predisposing infectious agent to bronchopneumonia, but it can also be responsible for abortion and genital infections in breeding cattle (Kahn, 2005b). Bovine herpesvirus-1 can contribute to BRD through reducing mucosal clearing, allowing migration to the lung causing subsequent alveolar macrophage inhibition. Furthermore, BHV-1 becomes latent in neural tissues and can recrudesce during times of host immunosuppression (Muylkens et al., 2007). Transmission of BHV-1 occurs primarily through nose to nose contact, but can also occur via aerosol over short distances (Ellis, 2009).

Bovine viral diarrhea virus has been reported to be the most common virus isolated from young beef cattle (Fulton et al., 2002), but its involvement in BRD is controversial (Hodgins et al., 2002; Kahn, 2005b). There are multiple ways BVDV is categorized including type (1 or 2) and cytopathology (Fulton et al., 2009). Using 313 feeder calves, Fulton et al. (2002) compared BVDV seroconversion between healthy calves and those being treated for BRD. There was a greater percentage of sick cattle which were treated for BRD that seroconverted than there were healthy animals. An increase in BVDV-specific antibodies at BRD treatment compared to arrival is suggestive of BVDV contributing to respiratory disease. Additionally, Welsh et al. (1995) used 12 cross-bred calves to evaluate BVDV effects on alveolar macrophage functionality. Calves were challenged intranasally and intratracheally with BVDV. Then macrophages were collected via bronchoalveolar lavage. Macrophages from cattle challenged with BVDV had decreased phagocytic and microbicidal activity suggesting BVDV has an immunosuppressive effect. The other two viruses associated with BRD are PI3V and BRSV. Both are difficult to detect unless sampling occurs during the incubation or acute phases of infection (Kahn, 2005b). Replication of BRSV occurs in the cytoplasm of the host cell where transcription errors occur more frequently (Ellis, 2009). For this reason, BRSV has low fidelity increasing its chance of survival. Both ciliated and non-ciliated epithelial cells have been demonstrated to be infected with BRSV, predisposing the host to BRD (Hodgins et al., 2002). Infections with PI3V often occur concurrently with BHV-1 and BVDV and have been reported to decrease immune function in alveolar macrophages (Hodgins et al., 2002). The primary function of these viruses is to sustain themselves. This is accomplished through impairing the immune function of the upper

respiratory tract initially, which increases migration of other pathogens to the lungs. Bacterial pneumonia is often a consequence of a viral infection in the upper respiratory tract.

Bovine respiratory disease bacterial pathogens

The 3 primary causative agents of bronchopneumonia in cattle are *Mannheimia haemolytica* (MH), *Pasteurella multocida* (PM), and *Haemophilus somnus* (HS). Additionally, *Mycoplasma Bovis* (MB) is often isolated in BRD cases (Hodgins et al., 2002). Upon necropsy of 68 BRD mortalities, prevalence of bacteria detected via polymerase chain reaction was 77%, 33%, 35%, and 51% for MH, PM, HS, and MB respectively, from both nasopharyngeal swabs and lung tissue concurrently. *M. haemolytica* was cultured from 81% of lung tissue samples, while PH (12%), and HS (15%) were recovered in culture less frequently (Klima et al., 2014).

The primary virulence factors of MH are lipopolysaccharide (LPS) expression and secretion of leukotoxin. Alveolar macrophage exposure to LPS stimulates the synthesis of the proinflammatory cytokines tumor necrosis factor-α (TNF-α) and interleukin-1β (IL-1 β). In vitro production of TNF-α was more rapid than IL-1β, peaking at 4 h post inoculation and returning to baseline at 8 h. A more delayed, longer-term production of IL-1β occurred following LPS inoculation in vitro (Yoo et al., 1995). These proinflammatory cytokines increase recruitment of bovine immune cells to the lungs. Incubation of bovine leukocytes with leukotoxin caused increased plasma membrane disruption and chromatin collapse in neutrophils, alveolar macrophages and circulatory monocytes. Both of these traits are characteristic of cell apoptosis (Stevens and Czuprynski, 1996). Tissue damage associated with MH in the lung includes interstitial

edema, necrosis of alveolar septae, and infiltration of neutrophils. More extensive alveolar lesions in neutrophil sufficient calves compared to calves with induced neutropenia demonstrates the further tissue damage caused by the hosts immune system (Breider et al., 1988).

The primary virulence factors for PM are LPS and a capsule with antiphagocytic properties (Dabo et al., 2007). Different from the previous 2 bacteria, HS expresses lipooligosaccharide rather than LPS. This bacteria is also non-encapsulated but has various outer membrane proteins (Confer, 2009). All 3 of the primary pathogenic bacteria associated with BRD are gram-negative and commensal (Griffin et al., 2010). In BRD mortalities, *M. bovis* has been isolated with greater frequency than PM and HS (Klima et al., 2014). This pathogen is a mollicute, which are a class of bacteria lacking a cell wall. These are prokaryotes which evolved from gram-positive *Clostridium*-like bacteria. Rather than a cell wall, MB has a tri-layered cell membrane, which cause many of the commonly used antimicrobials in the feedlot to be ineffective in treating it (Caswell and Archambault, 2007).

Viral and bacterial presence in BRD mortalities

It is rare for a BRD morbidity or mortality event to be uncomplicated involving only a single pathogen. Several research trial results have been published screening for the pathogens associated with the BRD complex. Cattle arriving at feedlots in Western Canada were followed for the initial 60 days on feed (DOF). Immunohistochemistry and histopathology were used to detect pathogens in 90 BRD mortalities and 9 feedlot moralities due to other complications. In peracute, acute, and subacute BRD, MH was the most prevalent bacterial culprit, while MB was most common in chronic BRD.

Additionally, 96% of BVDV positive mortalities were also MH positive, and 80% of HS positive mortalities were also MB positive (Booker et al., 2008).

Fulton et al. (2009) collected lung tissue samples from 237 BRD mortalities between May 2002 and May 2003 on a single feedlot in Oklahoma. The mortality rate was 1.3% over the entire year and 53.8% of those mortalities were associated with BRD. Samples were cultured for the bacteria MH, PM, HS, *Arcanobacterium pyrogenes*, and *Salmonella* spp. Virus isolation was conducted for BVDV, BRSV, and *Bovine coronavirus.* Additionally, MB was also cultured. From culture, 25% of cases were MH positive, 24.5% were PM positive, 10.0% were HS positive and 71.4% were MB positive. Similar to Booker et al. (2008), MB positive mortalities had more treatments with more antibiotics, and MH presence was positively correlated with BVDV isolation. Booker et al. (2008) focused on cattle arriving at feedlots in Western Canadian in the fall and moralities had to occur during the first 60 DOF. Mortalities found to harbor MB may be less prevalent in cattle that arrive at the feedlot in the fall season that have been at the feedlot less than 60 d.

More recently, scientists have investigated antibiotic resistance profiles in the feedlot due to increasing scrutiny from consumers. Using 43 BRD mortalities classified as acute, subacute or chronic from the Willard Sparks Beef Research Center at Oklahoma State University, antimicrobial susceptibility patterns were characterized from bacteria cultured from lung tissue. Of these mortalities, 60% were MH positive, 74% were MB positive and 77% had multiple non-viral pathogens present. In this study, initial BRD treatment was tilmicosin, the second BRD antibiotic treatment was enrofloxacin and the third BRD treatment was ceftiofur. The majority of bacterial isolates were susceptible to

enrofloxacin and ceftiofur even following antemortem treatment with these drugs, suggesting other mechanisms in addition to antibiotic resistance contributing to these BRD mortalities (Lamm et al., 2012). Klima et al. (2014) evaluated 68 BRD mortalities from Alberta (n=42), Texas (n=6), and Nebraska (n=20). Nasopharyngeal swabs and lung tissue samples were collected. Colonies were cultured and their identities were confirmed using polymerase chain reaction (PCR). Again, MH (91%) and BVD (69%) were the most prevalent with co-infection occurring frequently (63%). Antibiotic resistance was more common than reported by Booker et al. (2008), possibly because this study utilized PCR. Detection of antibiotic resistance at the gene level reveals the potential for the cell to be resistant; however, this may not be reflected in the phenotype because the gene may not be actively expressed.

Ruminal acidosis

The clinical signs of ruminal acidosis are similar to those of BRD and include inappetence and rapid, shallow respiration (Kahn, 2005a); for this reason there is potential for misdiagnosing acidosis as BRD. Cattle most likely consume a primarily forage-based diet prior to feedlot arrival. Over consumption of a ration containing high-levels of readily fermentable carbohydrates leads to acid production greater than the rumen epithelium can absorb and the ruminal microbes can utilize (Owens et al., 1998). Ruminal acid accumulates, usually in the form of lactate, causing a reduction in rumen pH. In such a scenario, there is a subsequent shift in rumen microbial population towards acid tolerant microbes such as *Megasphaera elsdenii*. Acid accumulation is propagated by the increase in amylolytic, lactate producing bacteria including *Streptococcus bovis* and *Lactobacillus spp*. There is a lag in the growth of *M. elsdenii* which allows lactate to

accumulate to sufficient levels to cause ruminal acidosis (Yokoyama and Johnson, 1988). Ruminal acidosis has been differentiated into subacute and acute based on rumen pH thresholds. Bevans et al. (2005) used 12 beef heifers to compare rapid and gradual high concentrate ration adaptation strategies. These authors defined subacute acidosis as a ruminal pH less than 5.6 for ≥12 h in a day, and acute acidosis was a pH less than 5.2 for ≥6 h in a day. Results revealed a high level of animal to animal variation in rumen pH and therefore, their ability to tolerate ration changes. This presents a challenge in the feedlot setting were cattle are typically fed in groups of 100 or more animals. Variations in animal to animal intake exist within a pen, allowing aggressive cattle to consume more feed than their less aggressive pen mates, potentially leading to acidosis in the more aggressive eaters. Strategies to manage ruminal acidosis include limit feeding, gradual adaptation to high-grain diet, and oral administration of *M. elsdenii* (Pritchard and Bruns, 2003; Brown et al., 2006; Miller, 2013). Acidosis may be occurring more frequently during the receiving and transition period, but disease is likely undetected or misdiagnosed as these cattle can be treated for BRD due to the similarity of clinical signs between acidosis and BRD.

The BRD complex is initiated by stress and viral pathogens allowing initial migration of the bacterial pathogens into the lungs. Secondary infections caused by MH, PM, HS and MB propagate the assault further. Interactions of the viral, bacterial, and *Mycoplasma spp.* pathogens comprise the infectious aspect of the BRD complex. The challenge of BRD is further complicated by the interaction with the hosts own immunological defenses and their regulation by other physiological mechanisms.

HOMEOSTATIC REGULATION SYSTEMS

The host's primary defense against BRD pathogens is the immune response, which seeks to maintain the host in a state of immunologic and physiologic homeostasis. Other systems, including the stress response and thirst signaling system, contribute to homeostasis maintenance as well. The immune response is divided into innate and adaptive immunity. Inducers of the stress response or stressors are classified by their type, duration, and intensity. These differences impact how the stress response influences the immune system. Finally, thirst signaling is essential to maintain adequate hydration status for a host to carry out necessary biological functions for survival.

Immune response

The innate immune response is an ancient host mechanism which is activated by pathogen associated molecular patterns (PAMP). The innate portion of the immune system can rapidly and non-specifically respond to pathogens and is a fixed component of the bovine genome. Alternatively, adaptive immunity has a delayed, yet extremely specific response of effector cells and the genetic code must be rearranged from gene segments. Adaptive immunity recognizes specific proteins, carbohydrates, lipids, or nucleic acids to target a specific antigen. These specific molecules are presented to naïve T-cells by antigen presenting cells. Upon subsequent recognition of these structures by the adaptive immune system, effector cells are produced from the adaptive immune system or recruited from the innate immune system. Having both innate and adaptive immune systems allows for rapid response to initial infection which can signal for a subsequent more specific response when the pathogen's virulence is greater than the innate response alone can control (Janeway and Medzhitov, 2002).

White blood cells of the immune system are called leukocytes; these can be further classified based on the cell's lineage from the hematopoietic tree. All originate from self-renewing multipotential stem cells of bone barrow. Monocytes, neutrophils, eosinophils, and basophils are derived from common myeloid progenitor cells located in bone marrow. While the lymphocytes (T-cells, B-cells, and natural killer (NK) cells) originate from common lymphoid progenitors found in lymph nodes and the spleen (Metcalf, 2007).

In a healthy bovine, the monocyte concentration in blood is between 25 and 840 cells/µl which is only 2.0 to 7.0% of the total white blood cell count (Jones and Allison, 2007). After migration into tissue, monocytes differentiate primarily into macrophages, but can also become dendritic cells (Geissmann et al., 2010). Macrophages are classified based on their location in the body and functional phenotype. Their primary function in tissue is to engulf and digest foreign molecules, dead cells, and infectious pathogens. Pathogen recognition receptors on the surface of leukocytes enable pathogen binding and initiation of phagocytosis; a cellular process of engulfing and digestion of antigens. Pathogen processing activates gene transcription to produce pro-inflammatory cytokines, signaling the pathogenic invasion and recruiting other immune cells such as neutrophils (Murray and Wynn, 2011).

Neutrophils are the most common leukocyte present in bovine blood. Reference ranges for neutrophils in healthy cattle are between 1,000 and 6,300 cells/µl or 15 to 45% of total leukocytes (Jones and Allison, 2007; George et al., 2010; Roland et al., 2014). Immature band neutrophils have horseshoe shaped nuclei rather than lobular nuclei. Band neutrophils are rare in circulation except in the case of acute inflammation (Jones and

Allison, 2007) and their presence may indicate such. In circulation, these combination phagocyte/granulocyte cells remain inactive until recruited in response to signals from macrophages (Borregaard, 2010). Their migration is enhanced through selectin-mediated rolling, where selectin ligand is expressed on the neutrophil surface and binds with low affinity to L-selectin on endothelial cells. Subsequently, integrin on the neutrophil cell surface binds with high affinity to integrin ligand on endothelial cells to stop cellular movement and allow translocation to complete. Cytokines, such as tumor necrosis factor-α (TNF-α), increase neutrophil recruitment and translocation to infected areas by increasing receptor expression and relaxing tight junctions between endothelial cells (Abbas et al., 1997; Ley et al., 2007). Similar to macrophages, bacterial pathogens are ingested by neutrophils in a process called phagocytosis, subsequent bacteria killing is accomplished through the reactive oxygen intermediates in the phagosome (Hampton et al., 1998). Neutrophils have been reported to secrete hydrogen peroxide in response to TNF-α exposure *in vitro* after a 27 min delay in the absence of phagocytic activity (Nathan, 1987). Reactive oxygen intermediates do not differentiate between pathogens and self, which can cause unwanted tissue damage in the host (Nathan, 2006). Secretion of hydrogen peroxide and other antimicrobial compounds by neutrophils *in vivo* is a mechanism for further host tissue damage carried out by their own immune system.

Eosinophils and basophils have receptors for the IgE antibody class (Abbas et al., 1997) and exist in relatively low concentrations in the blood with reference ranges often including 0 as the lower limit. Basophils are granulocytes which play a role in allergic responses mediated through heparin or histamine (Jones and Allison, 2007). Eosinophils have antiparasitic features mediated through IgE (Abbas et al., 1997). Despite their low

concentration in the blood, reduced eosinophil counts have been associated with subsequent BRD risk (Richeson et al., 2013). Eosinopenia is induced by stress, specifically when stress is associated with a bacterial infection. Abidi et al. (2008) observed eosinopenia to be useful in differentiating systemic inflammatory syndrome from sepsis in human medicine. Eosinophils are indicative of bacterial infections; however further research is warranted to elucidate an appropriate cut off value.

The cells maturing in lymphoid tissue are NK cells, B cells, and T cells. Natural killer cells are the only lymphoid immune cells included in innate immunity. Different from other cells of innate immunity, NK cells are activated by decreased expression or absence of major histocompatibility complex-1 (MHC-1) rather than expression of MHC-2. Decreased MHC-1 expression is characteristic of virus-infected and cancerous cells (Moretta and Moretta, 2004). The non-specificity of this signaling mechanism enables NK cells to respond to various pathogens and explains their classification as part of innate immunity. Cell destruction is carried out through granule exocytosis or signaling through the TNF death receptor family. Exocytosis mechanisms include perforin, a cell membrane disrupter, and granzymes, which directly cause apoptosis or act to signal it through caspase dependent pathways. Tumor necrosis factor-related apoptosis-inducing ligand on NK cell surface interacts with receptors on tumor and pathogen receptor cells to induce cell death (Smyth et al., 2005).

Two additional lymphocytes are T cells and B cells; these differ from NK cells in that they are part of adaptive immunity because they have pathogen specific memory, allowing the host to have a more rapid and robust immune response to a subsequent infection compared to a novel one (Fearon et al., 2001). Maturation and differentiation of

T cells occurs in the thymus. Many T cell precursors are generated and enter the cortex, but the majority are eliminated due to non-expression of T cell receptors (TCR). As T cells mature, they move through the medulla, where positive selection occurs; this allows only T cells capable of recognizing host MHC to mature. Negative selection eliminates T cells reactive to non-pathogenic antigens present in high concentrations in the thymus. In the medulla, remaining T cells are differentiated into T helper lymphocytes ($CD4^+/CD8^-$) and cytotoxic cells ($CD4^-/CD8^+$). These cell surface proteins are expressed prior to being released into the periphery (Abbas et al., 1997). The mature T cells are activated through the binding of TCR with antigens presented in conjunction with MHC-II, which are used for extracellular antigen presentation. The $CD4^+$ T cells are MHC-II specific and secrete cytokines to regulate other aspects of the immune response. Both intra- and extra-cellular antigens can be presented by MHC-I which stimulate the activity of cytotoxic $CD8^+$ T cells (Guermonprez et al., 2002). Helper T cells ($CD4^+$) are further categorized by the cytokines they produce. Mosmann et al. (1986) initially investigated this by stimulating antigen specific T helper cell clones and quantified subsequent cytokine production. This and other research elucidated that type 1 (TH_1) T cells produce IFN-γ, TNF-α, granulocyte-macrophage colony-stimulating factor and IL-2, while type 2 (TH_2) produce IL-4, IL-5, IL-6, IL-10 and IL-13 (Mosmann et al., 1986; Swain, 1995). Pathogen type can influence the cytokine produced by T helper cells. Intracellular pathogens, which are eliminated by inflammation and infected cell destruction, activate TH_1, while extracellular pathogens activate TH_2 to increase antibody response and granulocyte activation. Activation of one type also has a negative feedback to down regulate its counterpart (Swain, 1995). Traditionally, there has been a dichotomous classification of

$CD4^+$ signaling T helper cells or $CD8^+$ cytotoxic types. However, $CD8^+$ types also produce cytokines with similar profiles to either TH_1 or TH_2 cells (Kelso et al., 1991; Croft et al., 1994; Swain, 1995). As an infection is resolved, memory T cell production increases and effector cell synthesis decreases. Memory T cells have decreased levels of CD45RB and L-selectin expression and greater CD44 compared to effector T cells (Croft et al., 1994). Memory T cells are categorized as effector memory (T_{EM}) or central memory (T_{CM}). Protective memory is carried out by T_{EM} through migration to infected tissues and subsequent cytotoxic function, whereas T_{CM} must first mobilize from secondary lymphoid organs and differentiate to have effector functions (Sallusto et al., 2004).

Another component of the adaptive immune response is B cells. All B cells originate as non-Ig producing stem cells committed to the B cell lineage in bone marrow. As B cells mature, they begin expressing IgM on their cell surface and can be found in both bone marrow and the periphery. In circulation and lymphoid tissues mature B cells can be activated by encountering their specific antigen leading to decreased membrane bound antibodies and increased concentrations of secreted antibodies (Abbas et al., 1997). As infections are resolved differentiation between memory B cells and plasma cells is at least partially controlled by CD40L (Arpin et al., 1995).

Humoral antibody production is a process unique to B cells. Antibodies control and neutralize pathogens in various ways. Mechanisms of action for pathogen neutralization prior to host tissue interaction include aggregation of infecting agent or binding to pathogen ligands blocking their attachment. After pathogen attachment, antibodies can block fusion of virus and host membranes, or act as opsonin with

cytotoxic cells (Forthal, 2014). Antibodies comprise amino acids chains of specific structure. The smaller sequences, or light chains, bind with longer heavy chain via disulfide bonds, then two heavy chain pairs attach; resulting in the classic Y shape of antibodies. The variable region, also call the Fab region, exists near the N terminal end of the light chain-heavy chain bond and changes to enable antigen specificity, while the carboxyl end is highly conserved across antibodies (Abbas et al., 1997). Antibodies are classified as 5 types based on their heavy chain. The most common are IgG, IgA, and IgM; 2 other antibodies exist (IgD, and IgE) in low concentrations. The largest immunoglobulin, IgM, is a pentamer, IgG is a monomer, and IgA can be a monomer, dimer (most common), or trimer (Williams et al., 1990; Abbas et al., 1997).

The multiple immune cell types exist to control the diverse types of antigens encountered. Coordination of the immune response is carried out through exocrine molecules called cytokines. The immune response is initiated by resident macrophages releasing pro-inflammatory cytokines, primarily TNF-α, IL-1 and IL-6 (Guha and Mackman, 2001). Furthermore, chemokines are a type of cytokine that increase leukocyte recruitment to infected tissue (Romano et al., 1997; Roach et al., 2002). In addition to chemotactic signals, cytokines signal hepatocytes to increase acute phase protein (APP) production (Samols et al., 2002; Petersen et al., 2004). In bovine research haptoglobin is the most commonly measured APP (Gånheim et al., 2003; Roberts et al., 2015; Ball et al., 2018; Roberts et al., 2018). It binds hemoglobin, sequestering iron available for bacteria use, which reduces their growth rate (Eaton et al., 1982). Other APP include LPS binding protein and ceruloplasmin. The LPS binding protein is specifically beneficial in bovine for contributing to the immune response to MH infection. By binding to LPS,

affinity between CD14 on surface of macrophages and the LBP-LPS complex increases (Tobias et al., 1986; Wright et al., 1990; Hailman et al., 1994). The primary proposed functions of ceruloplasmin include Cu transport and antioxidant activity (Stabel et al., 1993; Spears and Weiss, 2008). As an infection or tissue damage is resolved, there is an increase in the anti-inflammatory cytokine IL-10 from macrophages, which inhibit macrophage cytokine production and T cell activation.

In addition to the cellular and humoral aspects of the inflammatory response, systemic activation has consequences on feed intake, altering energy balance and tissue accretion. Inappetence is a normal response during immune system activation (Hutcheson and Cole, 1986; Fantino and Wieteska, 1993). The reasoning for this mechanism is unknown but has been hypothesized to reduce host energy requirements, pathogen energy supply and exposure to additional antigens in feed (Hart, 1988; Exton, 1997; Wang et al., 2016). Metabolism is shifted during an immune response such that growth is impaired (Garcia et al., 2010; Holland et al., 2010). Skeletal muscle growth is hindered through its catabolism as well as an increase in AA uptake by hepatocytes which is signaled by proinflammatory cytokines. In the liver more AA are used to synthesize APP (Andus et al., 1991) contributing to the decreased AA availability for growth. There are both quantitative and qualitative differences between the AA profile of skeletal muscle and proteins synthesized during an inflammatory response requiring greater skeletal muscle mass catabolism than the mass of final protein synthesized. This mismatch increases the need to eliminate N through urine (Obled, 2003; Le Floc'h et al., 2004). An alternative use for some AA, such as glutamine, is energy. Lymphocytes and macrophages can oxidize glutamine, utilizing it as an energy source (Caldwell, 1989). In mammals the

cytokines TNF-α and IL-1 increase hepatic lipid synthesis and reduce lipoprotein clearance. The inhibition of lipoprotein lipase decreases fatty acid uptake into tissue as triglycerides causing a net increase in circulatory lipid levels (Klasing and Johnstone, 1991). In LPS challenge models, cattle enter a transient hyperglycemia followed by an insulin spike about 2 h post challenge and then hypoglycemia compared to baseline (Elsasser et al., 1996; Rumsey et al., 1999; Bernhard et al., 2012). While the immune response primarily alters immune cells, there are also metabolic consequences associated with its activation.

A systemic inflammatory response extends beyond altering immune cells and metabolism to even influencing cattle behavior. More specifically meal and water consumption frequency and duration are impacted. Sowell et al. (1999) conducted two 32 d receiving trials where individual feed and water consumption behavior was monitored in 150 kg cross-bred feeder calves. Steers in trial 1 were received at a feedlot in Wellton, Arizona in July 1996 where the average daily ambient temperature was 36.2 ºC. In this trial 57 of 108 steers were classified as morbid. By d 3, 100% of healthy cattle had visited the feed bunk at least once, while only 91% of the morbid cattle had. Trial 2 initiated on November 12, 1996. During this trial the mean daily ambient temperature was 16.8 ºC and 117 of 143 steers were classified as morbid. All healthy cattle had visited the feed bunk by d 4, but only 76% of morbid steers had. This is comparable to Hutcheson and Cole (1986), who report 89% of healthy calves and 76% of morbid calves consuming feed by d 4. Morbid cattle also had fewer eating and drinking bouts compared to their healthy counterparts (Sowell et al., 1999). Buhman et al. (2000) followed cattle with an overall BRD morbidity rate of 25% for 58 d following arrival and documented feeding

and drinking behavior. Morbid cattle had more water tank visits and drinking duration on d 4 and 5, but had reduced drinking visit and duration during d 11 to 27. Feeding frequency and duration were also reduced in sick cattle from d 11 to 27 (Buhman et al., 2000). In a retrospective analysis using 3 axis-accelerometers placed on auction-sourced feeder steers, morbid calves took fewer steps and had decreased activity index values during the 4 d prior to antimicrobial treatment. There were no statistical differences in lying bouts per day between morbid and healthy cattle. There was an interaction between BRD status and day prior to antibiotic treatment for daily standing time; where morbid cattle had decreased standing time the day prior to antibiotic treatment, but no statistical difference for d 6 to 2 prior to treatment (Pillen et al., 2016). Based on anecdotal observation, the authors suggest this interaction may be due to inconsistencies in sick cattle behavior. Some morbid cattle prefer to stand to facilitate respiration, while others tended to spend more time lying down to spare energy. These differences in standing, lying and activity may be useful tools for identify BRD cases prior to the expression of clinical signs in the future. However further research is need to define appropriate cutoff values to differentiate healthy and morbid cattle. Assuming morbid cattle are in a pro-inflammatory state, inflammation reduces feed and water intake as well as overall activity levels.

The innate and adaptive arms of the immune system play important roles in controlling pathogenic infections. Innate immunity provides a rapid, more general response, while adaptive immunity has greater specificity but is more delayed in responding to infection. Coordination of these systems is carried out through signaling molecules called cytokines. Communication and coordination between innate and

adaptive immune components are key for an effective response. When the response becomes systemic, cattle behavior is altered. In addition to interacting with behavior, the immune system can itself be influenced by other conditions such as physiological stress.

Stress response

Stress was first described as a typical syndrome whose symptoms are independent from the damage inflicted, either physical or chemical, by Selye (1936). Stress encountered by bovine can be categorized as psychological, physiological, or physical (Grandin, 1997). Psychological stress is usually associated with fear and can be caused by commingling with other cattle, exposure to novel environments, or handling by human caretakers. Physiological stress is manifested by deviations from basal endocrine levels. Finally, physical stress may be caused by injury, ambient temperatures outside the bovine thermoneutral zone, or hunger and thirst (Carroll and Forsberg, 2007). Stress can also be further classified based on duration. Selye (1936) published the first paper differentiating acute and chronic stress. This author reported decreased thymus, spleen, lymph glands, and liver size; and release of cortical lipoids (cortisol) and chromaffin substance (catecholamines) from the adrenal during the first 6 to 48 h after injury. At 48 h post injury, the adrenals are greatly enlarged, body growth is inhibited, and milk production is reduced in lactating animals (Selye, 1936). In a subsequent review, the stress response was coined general adaptation syndrome (Selye, 1946).

Protection against unfamiliar stimuli is modulated physiologically through the hypothalamic-pituitary-adrenal (HPA) axis and the sympathetic nervous system. The hypothalamus releases corticotropin-releasing hormone (CRH) and vasopressin (VP) in response to stressful stimuli. In this scenario, CRH is always secreted; however, VP

secretion may or may not occur depending on the severity of the stressor. Subsequently, CRH and VP stimulate secretion of adrenocorticotropic hormone (ACTH) from corticotrophs of the anterior pituitary. The adrenal gland is stimulated by ACTH to produce glucocorticoids; primarily cortisol in bovine (Carroll and Forsberg, 2007). The HPA axis is controlled via negative feedback mechanism. Most frequently, cortisol's inhibitory effect on ACTH production by the pituitary has been reported as the primary component of negative feedback (Liberzon et al., 1997; Gómez et al., 1998). Additional feedback pathways for ACTH and CRH have been proposed (Ono et al., 1985; Calogero et al., 1988; Liberzon et al., 1997), but are less clear due to challenges associated with quantification.

The stress response is important in cattle because of its impact on immune function, specifically during the feedlot receiving period when cattle are at greatest risk for BRD. Acute stress has been reported to increase leukocyte migration to affected tissues (Dhabhar and McEwen, 1999), and chemotaxis and cellular adhesion molecule expression (Redwine et al., 2003). In chronic stress models, pharmacological cortisol and dexamethasone treatments reduced affected tissue inflammation (Dhabhar and McEwen, 1999) and chemotaxis (Redwine et al., 2004), resulting in immunosuppression.

Viral shedding and antibody and APP responses were measured using an *in vivo* stress model. Using 32 beef steers, acute stress was modelled as a single dexamethasone intravenous injection at 0.5 mg/kg BW (ACU), and chronic stress was induced using the same dexamethasone dose repeated for 4 consecutive days (CHR). All steers were administered a pentavalent modified-live virus respiratory vaccine and a non-replicating MH toxoid (Richeson et al., 2016). Results suggest an enhanced antibody response to

replicating vaccines when cattle are stressed, likely due to immunosuppression enabling increased viral replication in stressed cattle compared to non-stressed counterparts. However, when a non-replicating vaccine was administered, the antibody response by CHR was blunted compared to ACU or negative control (Richeson et al., 2016). Immunosuppression induced by chronic stress is further supported by decreased levels of APP because their production is signaled by pro-inflammatory cytokines (Richeson et al., 2016). Pro-inflammatory cytokine production would be reduced during immunosuppression, resulting in reduced APP concentration.

Classification of stress events can help to understand their effects on the body and specifically the immune system. Type, duration, and intensity have all been used to better describe stressors and the disruption they cause to homeostasis. Stressors activate the HPA axis, which is controlled by negative feedback properties. Differentiating between acute and chronic stress is beneficial in determining the events overarching effect on a host's immune system.

Thirst signaling

Another system seeking to maintain physiological homeostasis is thirst signaling. Water is an often over looked essential nutrient in livestock. Approximately 70% of live weight of cattle is water (Macfarlane and Howard, 1972). Maintaining adequate hydration is essential for biological functions to perform properly. In the feedlot, cattle have constant access to water tanks to allow *ad libitum* intake. The first compilation of water requirements for beef cattle was published by Winchester and Morris (1956). These authors note free water and moisture in feed both contribute to meeting daily water requirements. Many factors influence water intake (WI) including stage of production,

DMI, and ambient temperature. At temperatures below 4.4 ºC WI is minimally influenced by ambient temperature, but as ambient temperature increases above this threshold, WI increases at an increasing rate relative to DMI (Winchester and Morris, 1956). Hicks et al. (1988) reported WI to increase 2.43 L/d with every 1 kg increase in DMI, and a 1 ºC increase in maximum daily temperature increased WI by 0.71 L/d. A limitation to this WI data is the non-existence of treatment replication. The was no replication within experimental treatments because water tanks in this study were shared between 2 adjacent pens and flow meters measured water supplied to the tank. The reported impacts of DMI and temperature affects are across all 3 dietary sodium treatments. In a meta-analysis combining 7 studies, Arias and Mader (2011) established increased WI in the summer months. Across all seasons the best fit model ($R^2 = 0.65$) was WI = 5.92 + (1.03*DMI) + (0.04*SR) + (0.30*THI) where WI is L/d, DMI is kg/d, SR is solar radiation (W/m^2), and THI is the temperature humidity index (Arias and Mader, 2011). In a more recent publication, Ahlberg et al. (2018) reported DMI, BW, SR, and ambient temperature to have a positive correlation with WI, while relative humidity and wind speed were inversely correlated.

Williams et al. (2016) conducted a meta-analysis using a systematic literature review of restricted water access to evaluate its effect on water intake, DMI, and live weight gain. Due to limited published literature meeting the criteria for meta-analysis inclusion, the authors were unable to make statistical comparison, but did report descriptive statistics. Reducing water access frequency reduced water intake and DMI. At the time of publication, there were 5 previous beef cattle experiments reporting water access frequency and live weight gain, which yielded inconsistent responses (Williams et

al., 2016). Water access was restricted for the 48 h prior to shipment, alternating 24 h periods for 7 d prior to shipment, or only during transport. Restricting water access prior to shipment caused negative BW shrinkage during transport compared to unrestricted calves, likely due to greater water losses during transport. At arrival all animals had access to hay and water prior to BW recording (Kaufman et al., 2017). Water restricted calves were able to compensate for gut fill difference overnight, while unrestricted calves were not. Furthermore, there was no difference in ADG during the receiving period suggesting water restriction does not influence subsequent performance

Fluid balance is maintained in the body by antidiuretic hormone (ADH), which may also be called arginine vasopressin (Dousa and Valtin, 1976). Elevated plasma osmolality increases plasma ADH concentrations which signals the kidneys to increase water retention by reabsorbing water through the kidney, concentrating urine (Miller et al., 1970). This response is reduced with injury to lamina terminalis and subfornical organ in the brain suggesting these regions of the brain control its secretion (McKinley et al., 2004). Permeability to water of renal cells is increased by exocytosis of intracellular vesicle into the apical membrane which is signaled by ADH. These vesicles contain aquaporins which are water selective channels in highly water-permeable cells (Nielsen et al., 1995). This reabsorbed water reduces plasma osmolality to maintain biologically functional ranges.

Another hormonal fluid balance control system is the renin-angiotensin system (RAS). Traditionally RAS is associated with blood pressure regulation, but also influences thirst signals. Renin, from juxtaglomerular cells in the kidney, cleaves angiotensinogen to angiotensin-1 during times of decreased fluid volume causing

vasoconstriction. Subsequent cleavage by the enzyme ACE produces the most biologically active peptide of RAS (Sparks et al., 2011). In rat models, increased angiotensin-II has been associated with increased water intake in hydrated rats (Antunes-Rodrigues et al., 1985). Additionally, intracerebroventricular infusion of an angiotensin-2 antagonist reduced water consumption in cattle, sheep, rabbits, and mice (Blair-West et al., 1994).

Interactions between RAS and the stress response have been investigated. Dexamethasone has been shown to blunt this response in rats via interactions with glucocorticoid receptors (Liu et al., 2016). Parker et al. (2004) deprived *Bos indicus* steers of water for 90 h and reported increased plasma vasopressin concentration with increasing duration of water deprivation. Additionally, angiotensin-II was not different between steers administered 0.01 mg hydrocortisone intravenously/kg BW per h. Steers deprived of water but not administered hydrocortisone had increasing concentrations of angiotensin-II with increasing time of water deprivation.

In dairy cows, the periparturient period is associated with a transition from gestation to lactation. This transition alters the dam's nutrient requirements, including water. Additionally, parturition has been associated with dehydration (Klinkon and Zadnik, 1999). To address this water deficit and supply additional nutrients it is common practice on dairies to orally drench cows during the transition period of the milk production cycle. Using 210 multiparous non-lactating Holstein dairy cows, Tankersley et al. (2007) compared 3 oral drenching treatments (water, a commercially available yeast and mineral supplement drench, or ruminal transfaunation) against a negative no drench control. All treatments were applied within 24 h of parturition. There were no differences

due to treatment for milk production, milk quality or blood metabolite parameters indicating no benefit from this supplement or rumen transfaunation. Additionally, drenching with water alone did not impact dairy cow milk production.

The inclusion of glucose precursor in oral drenches has been investigated (Stokes and Goff, 2001; McFadden et al., 2010). In a field study, periparturient cows were drenched within 4 h of parturition and again 24 h later with their respective treatments; which were 9.5 L of water, 9.5 L of water with propylene glycol (PG), or 9.5 L of water with calcium propionate. These authors report greater average milk production using PG compared to water only, with calcium propionate being intermediate. There were no treatment differences for plasma glucose; however, PG reduced plasma NEFA, water only was intermediate, and calcium propionate had the greatest plasma NEFA. The calcium propionate treatment supplied 14.6 mol of glucose precursor and PG supplied 8.2 mol (Stokes and Goff, 2001). Energy status would be hypothesize to improve with greater glucose precursor supply; however, the NEFA results reported in Stokes and Goff (2001) do not support this. McFadden et al. (2010) administered a single drench treatment of water, water with propylene glycol, or a commercial drinkable drench product within 24 h of parturition. There were no treatment differences in milk production. Blood was collected and analyzed every 2 h for the first 10 h post-treatment administration. There was no treatment effect for plasma glucose; however, plasma NEFA and BHBA concentrations were greater from 6 to 10 h post-treatment for the water only treatment suggesting improved energy status with glucose precursor inclusion in oral drenches (McFadden et al., 2010).

Suppling energy in a drench as lipid was investigated using 48 Holstein cows (Pickett et al., 2003). Treatments were applied for 3 consecutive days in a 2 x 2 factorial of 500 ml of PG and 454 g of fat delivered in 1.9 L of water. In agreement with previous research, PG reduced plasma NEFA, but had no effect on plasma glucose. Overall, oral dosing with water and PG appears to reduce plasma NEFA concentrations, while other drench additives had little effect on the plasma metabolites measured in the periparturient dairy cow. Mobilization of energy stored in fat increases plasma NEFA levels. Decreased NEFA concentrations suggest reduced mobilization of lipid due to improved energy status. There has been no published work on drenching feedlot cattle at arrival with water or water containing PG or other additives. High-risk calves procured through auction market channels may be dehydrated. Additionally, elevated serum NEFA levels have been reported at arrival with sharp decreases by d 14 (Richeson et al., 2015). This suggests the marketing system may induce a negative energy balance in these calves. Drenching at arrival with water, PG, or both may be beneficial in addressing dehydration and energy deficit.

Biological systems including the immune response, stress response, and thirst signaling require energy. These systems work to maintain homeostasis in the animal. The immune response contributes to this through innate and adaptive mechanisms. Stress response can be activated by psychological, physiological, or physical stimuli, altering the body to irregular conditions. Finally, thirst signaling seeks to maintain fluid balance within the body to support biological functions.

RECEIVING PERIOD MANAGEMENT STRATEGIES

After feedlot arrival most managers allow the cattle to rest for 12 to 24 h to aid in recovery from transportation (Samuelson et al., 2016). Newly received cattle will then be processed and assigned a feeding program designed to assist the animal in returning to homeostasis as rapidly as possible, optimizing their production potential. Initial processing protocols are developed by the attending or consulting veterinarian and may include a combination of antimicrobial metaphylaxis, various vaccinations, anthelmintic, and hormonal growth promoting implant. The feeding program is typically determined by a nutritional consultant and includes the ration formulations, and bunk management and ration transition strategies.

In designing a processing protocol, newly received cattle are often categorized according to BRD risk level (high-, medium-, or low-risk). According to the most recent feedlot nutritionist survey, 83.3% of their clients used metaphylaxis on high risk calves, 39.5% mass medicated medium risk calves, and 6.1% administered an antimicrobial at initial processing in low risk cattle (Samuelson et al., 2016). Metaphylaxis was administered to 39.2% of cattle weighing less than 320 kg at arrival to feedlots with a capacity greater than 1000 animals. In cattle greater than 320 kg at arrival from the same feedlots surveyed, 5.2% were administered an injectable antibiotic as a group (USDA-APHIS, 2011). Abell et al. (2017) conducted a meta-analysis of published literature on antimicrobials approved for parenteral metaphylaxis in feeder and stocker calves to compare their effects on BRD morbidity and mortality. Antimicrobials were ranked into tiers based on ability to reduce the odds of BRD morbidity occurrence. If one of the upper tier antimicrobials (tulathromycin, gamithromycin, or tilimicosin) were

administered to a group of feeder cattle expected to have a BRD morbidity rate of 30% in the first 60 d without metaphylaxis, then this model predicts the BRD morbidity incidence to be between 4 and 8%. Alternatively, if a lower tier antimicrobial, such as oxytetracycline, were used this reduction in BRD incidence would less (Abell et al., 2017). The modern consumer has scrutinized antimicrobial use in food animals. However, the use of antimicrobial metaphylaxis is an extremely important facet of cattle health management. It was estimated that if metaphylaxis were eliminated as a BRD management tool, net returns to cattle feeding would be reduced between $532 million and $680 million per year (Dennis et al., 2018).

Vaccination is another common practice associated with arrival processing. Most commonly viral respiratory vaccines are administered. According to USDA data 95.1, 93.2, 61.4, and 55.1% of cattle are vaccinated at feedlot arrival against BVDV, IBRV, BRSV, and PI3V, respectively. Additionally, clostridial vaccines were administered at arrival to 62.4% of cattle (USDA-APHIS, 2011). Vaccination timing has been debated because efficacy hinges on adequate immune response and subsequent natural challenge. Delaying vaccination for 14 d after arrival has been reported to be beneficial for high risk feeder calf performance (Richeson et al., 2008), while some investigations have reported no performance differences (Richeson et al., 2009; Poe et al., 2013). Reduced BRD retreatment rates have also been reported with delaying vaccination until 30 d from arrival (Rodgers et al., 2016). For parasite control, 75.8% of feedlot cattle are administered an anthelmintic at arrival (USDA-APHIS, 2011) . Subsequent control is unnecessary because the feedlot environment disrupts the parasitic lifecycle (Craig, 1988). Hormonal implants are administered to more than 90% of cattle placed in the

feedlot for the purpose of increased growth performance (Duckett et al., 1996; USDA-APHIS, 2011). After cattle have been processed, they are relocated to a home pen to be acclimated to novel feedstuffs which are likely more energy dense than previous diets.

Nutritional management

In a series of experiments conducted by Lofgreen et al. (1975), receiving ration energy density was evaluated for its impact on health, performance, and DMI. The energy densities in the receiving diets for the first experiment were 0.84, 1.01, or 1.10 Mcal NE_g /kg (20, 55, and 72% concentrate, respectively). The greatest energy density was selected based on previous unpublished findings where calves self-selected a ration with an energy density of 1.10 Mcal NE_g / kg from three individual ingredients offered "cafeteria" style. Greater energy density reduced the number of days required to regain purchase weight and improved ADG and DMI during the 29 d receiving trial. In Exp. 2, the lowest energy density diet was replaced with a diet containing 1.19 Mcal NE_g / kg. Gain was not improved with dietary energy density greater than 1.10 Mcal NE_g / kg. This data suggests increasing dietary energy concentration improves performance up 1.10 Mcal NE_g / kg, but there is no additional improvement above this level of dietary energy. A limitation to Lofgreen's research is that it does not report the protein concentration in the diet, but reported ingredient composition indicates that the diets compared were not isonitrogenous. The gain could potentially be limiting in the 1.19 Mcal NE_g / kg treatment due to a lack of crude protein. In Exp. 1, there was no clear relationship between increasing energy density and BRD incidence. In Exp. 2, 10, 12, and 18 calves were treated for BRD during the first week for 0.84, 1.01, or 1.10 Mcal NE_g / kg treatments, respectively. Although not statistically significant, the total number of calves in Exp. 2

requiring BRD treatment was increased numerically with increasing dietary energy density supporting the hypothesis of increased energy density increases morbidity rate. A notable limitation to this health data is the small population of calves in each treatment. The 1.10 Mcal NE_g / kg treatment had 10% morbidity rate, yet this only represents 4 treated animals. A larger sample size would provide more confident conclusions regarding morbidity differences among cattle consuming diets of different energy concentration. Regardless, increased energy density up to 1.10 Mcal NE_g / kg improved performance, but numerically increased BRD morbidity (Lofgreen et al., 1975).

In a subsequent experiment, isonitrogenous (16% CP) rations with energy density ranging from 1.15 Mcal NE_g / kg to 1.30 Mcal NE_g / kg were fed to 60 individually housed steers during a 28 d receiving trial (Fluharty and Loerch, 1996). There was a linear increase in ADG and DMI with increasing energy level (Fluharty and Loerch, 1996). This data supports the hypothesis that performance increases with increasing energy density. Contrary to Lofgreen et al. (1975), these authors report improved performance at energy densities above 1.10 Mcal NE_g / kg. This may be due to differences in the genetic potential of the cattle, or greater dietary CP availability to support the increased performance. In a second experiment Fluharty and Loerch (1996) fed two energy density levels (1.17 Mcal NE_g / kg or 1.32 Mcal NE_g / kg) and 3 different CP levels. The CP treatments were 12.5%, 16% or phase feeding where CP was 23%, 17%, 14%, and 12.5% for wk 1 thru 4 respectively. There was no interaction between energy density and CP level. During wk 1, increased energy density improved DMI, ADG, and G:F, and increased CP concentration increased ADG and G:F. The lack of differences after cattle had been on feed for more than 2 wk suggests the observed

improvement in performance is likely due to a more rapid recovery from the nutrient deficit the calves were exposed to during their transition through the marketing system. There was no difference in morbidity due to energy or protein concentration in the ration for either experiment. The overall morbidity rate was comparable to morbidity rates reported by Lofgreen et al. (1975). Both Fluharty and Loerch (1996) and Lofgreen et al. (1975) utilized small sample sizes which limited their ability to detect statistical differences in BRD morbidity outcomes.

Berry et al. (2004b) fed two dietary energy concentration levels and 2 starch levels in a 2 x 2 factorial arrangement to investigate the effect of energy level and energy source. Dietary energy concentrations were 0.85 or 1.07 Mcal NE_g / kg and dietary starch levels were 34 or 48%. There were no interactions detected between energy concentration and starch concentration. Additionally, there was no difference for any performance measured during the 42 d trial. This data contradicts the improved performance reported by Lofgreen et al. (1975) when dietary energy density was increased from 0.84 Mcal NE_g/ kg to 1.10 Mcal NE_g/ kg. There were no statistical differences in morbidity due to treatment except cattle on greater starch concentration treatment had numerically greater morbidity (68.8 vs. 59.4% of calves were treated). Starch is a rapidly fermentable energy source that can promote ruminal acidosis. Numerically increased BRD morbidity rates in this study may be due to misdiagnosing ruminal acidosis as a respiratory infection.

Increasing dietary energy density diets were fed at reducing quantities resulting in isocaloric energy intake (Spore et al., 2018). There was no dietary treatment effect on any outcome variable suggesting performance and morbidity are not influenced by energy

source but rather the total amount of energy (starch) consumed. These papers collectively suggest an improvement in performance with increasing energy density in receiving rations. The increased performance may come at the cost of an increased morbidity level. Small pen and individual animal feeding research may not represent the population as well as a study that use a larger number of sampling units (cattle) typical in a commercial feedlot pen.

A meta-analysis is an alternative method to evaluate energy density in receiving rations and its impacts on performance and health. Rivera et al. (2005) compiled data from 6 feeding trials conducted at the Clayton Livestock Research Center in Clayton, NM. These data were used to evaluate the relationship between energy density in the receiving ration and morbidity, DMI, and ADG. These were receiving studies using primarily auction sourced calves with purchase weights between 160 and 250 kg. The regressions from this analysis suggested increasing energy density in the receiving ration increase DMI, ADG, and BRD morbidity. The authors cautioned about potential confounding due to unaccounted CP differences between dietary energy treatments. Their model accounts for random variation between trials, but does not account for potential "systematic bias introduced by confounding factors" so the regression models should not be used as predictor equations. An economic component was used to project the financial return in comparing a 60 vs. 0 % concentrate diet. From their equations, a 60% concentrate ration would result in losing $5.11 per calf, while a 0% concentrate ration would lose $29.44 per calf. This supports conclusions from Fluharty and Loerch (1996) and Lofgreen et al. (1975) that increased energy density in receiving rations increases performance and morbidity.

Cellular impacts

Pen level results suggest increased performance and BRD morbidity as dietary energy level increases; however, these data are not conclusive. A better understanding of responses at the cellular level may be beneficial in elucidating the driving factors for these potential differences. Alternative indicators for response to receiving ration energy density treatments could be the bacterial load within the animal, the robustness of the acute phase response or circulatory cytokine concentration in response to an immunological challenge.

Two dietary energy densities were compared to quantify the immune response to bacterial pathogens. Increased energy concentration had no effect on antibody titers for MH, PM, or HS. In this study, calves were nasal swabbed during BRD treatment events to culture for bacterial prevalence in the upper-respiratory tract. Increased energy density in the receiving ration decreased PM prevalence in calves during the initial BRD treatment, and tended to decrease HS prevalence during primary and secondary BRD treatments. This suggests that increased energy density improves immune function against PM and HS during a BRD event (Berry et al., 2004b). However, there were no differences in fibrinogen, haptoglobin or serum amyloid-A between dietary treatments. Although dietary treatments did not impact APP concentrations there were day effects relative to BRD events. The serum concentrations decreased with increasing days on feed, and haptoglobin concentration was greater on the day of antimicrobial treatment than during recovery (7-d post antimicrobial treatment). Serum haptoglobin concentration may be useful as a BRD diagnostic tool (Berry et al., 2004a).

Reuter et al. (2008) conducted research comparing a 70% concentrate ration fed *ad libitum* (1.19 Mcal NE_g /kg, 70AL), a 30% concentrate ration fed *ad libitum* (0.75 Mcal NE_g /kg, 30AL) or a high concentrate ration restricted to match energy intake of the low energy ration (70RES). Steers were challenged with *Escherichia coli* LPS and intensively blood sampled for analysis of cytokine concentrations post-challenge. Blood was sampled every 2 h starting 2 h prior to and continuing through 24 h post LPS challenge. There was an increase in maximum concentration of the pro-inflammatory cytokines IFN- γ, TNF-α, and IL-6 with the lower energy density ration. For the measured pro-inflammatory cytokines, 30AL had the greatest peak concentration, 70AL had the least, and 70RES was intermediate. Greater peak pro-inflammatory cytokine concentration in the 30AL suggest a more robust immune response to the LPS challenge, which is a potential mechanism for the reduced BRD morbidity incidence reported with decreased energy density in receiving rations. Additionally, the anti-inflammatory cytokine IL-4 was reduced to a concentration of 1 pg/mL in the 30AL treatment (Reuter et al., 2008). This low concentration may also contribute to a more robust immune response by reducing the inhibitory signal for leukocytes, allowing them to be more available to control pathogenic challenges such as those associated with BRD morbidity events.

Contrary to Reuter et al. (2008), increased TNF-α production has been reported with increasing energy density in the ration (Schwertner et al., 2011). Peripheral blood mononuclear cells were isolated and cultured to measure TNF-α secretion. Reuter et al. (2008) used an in vivo model, while Schwertner et al. (2011) measured TNF-α production ex vivo as amount secreted from individual macrophages. An in vivo model

would be influenced by other systemic signaling molecules. Alternatively, ex vivo would be representative of the local response by the macrophages. The opposing results are potentially due to these differences. Schwertner et al. (2011) reported no differences in neutrophil oxidative burst activity or MH killing ability by cells in whole blood due to energy density. These results suggest there is an alternative mode of action in the systemic immune response than circulating leukocytes driving the differences in BRD morbidity associated with increased energy density in receiving rations.

A limitation to these challenge models is that healthy, non-stressed cattle are often used. The responses in these studies represent a subset within a load of high-risk calves; likely not representing the ones at greatest risk for BRD. There is variation in the nutrition, hydration, and health status between high-risk calves within a truckload upon arrival to the feedlot. Healthy, early respiratory infected, and clinical BRD calves are present on these truckloads at feedlot arrival. A challenge model including a chronically stressed treatment would represent feeder calves that have been subjected to the marketing process for extended time periods. Continued consumer pressure to reduce antibiotic use may alter this in the future, but currently metaphylaxis is the best tool available for controlling BRD in the feedlot. Increasing energy density appears to have differing impacts on pro-inflammatory responses (Reuter et al., 2008; Schwertner et al., 2011), depending on where it is measured, and may decrease the pathogen load in the upper respiratory tract (Berry et al., 2004b).

Nutrient digestibility

Digestibility of nutrients may also be altered during the receiving period and influenced by diets differing in energy density. Improvements in digestibility may

contribute to improved nutrient availability to the animal to support an immune response and growth. High (1.19 Mcal NE_g /kg) and low (0.90 Mcal NE_g /kg) energy diets were fed in a 2 x 2 factorial with 2 protein sources. There was an increase in apparent dry matter digestibility (DMD) at the greater energy density level on d 14 and d 42 of the trial and numerically increased DMD on all other sample days except d 7 (Fluharty et al., 1994b). Neutral detergent fiber digestibility was reduced with greater energy density and this may be due to the rumen microbial population shifting towards increased amylolytic rather than cellulolytic bacteria due to low NDF levels in the more energy dense treatment. While apparent DMD does not account for endogenous losses, this measurement is still valuable for comparison between the 2 treatments. In this trial, there was a reduction in DMI with increased energy density but energy intake was improved (3.10 vs 2.23 Mcal / d, higher vs low energy density, respectively) suggesting increased energy density during the receiving period as a practical way to improve energy supply to the high-risk feeder calf.

Ruminal digestibility was measured *in situ* in a study using the same dietary treatments from the previous study (Fluharty et al., 1994a). Crossbred beef steers were fitted with ruminal cannulas 3 wk prior to weaning. Calves were weaned and transported 8 h to an auction market facility where they were penned over night before being transported back to the research facility to simulate the stress associated with the current beef marketing system. The NDF disappearance of orchard grass (18.1% CP, 62.4% NDF) was greater in the lower energy density treatment. The lower energy treatment had greater NDF concentration likely supporting a greater concentration of cellulolytic bacteria which explains the improved ruminal NDF disappearance. Increased dietary

energy density resulted in decreased ammonia in the rumen. The authors hypothesize increased microbial activity supported by increased energy supply improved N uptake by the bacteria in the rumen, further suggesting increased microbial activity in the rumen. Increasing dietary energy density decreases NDF digestibility, but has resulted in greater energy intake and potentially greater ruminal bacterial activity.

Processing protocols are altered based on the cattle type, which are usually based on BRD risk. Metaphylaxis is a key tool in controlling BRD (Ives and Richeson, 2015). Vaccination against viral pathogens, administration of anthelmintic, and hormonal growth implants commonly occurs at feedlot arrival processing. These processes are intended to improve health, growth, and value of feedlot cattle. Increased dietary energy concentration improves performance during the receiving period for high-risk calves. The improvement in performance with increased energy density must be supported by increasing protein suppled to the animal. Rapidly digestible non-structural carbohydrates may support increased energy intake and improve rumen microbial activity. Increasing dietary energy density will improve performance during the receiving period. The improvement in performance must be considered relative to BRD and acidosis risks.

CONCLUSIONS FROM THE LITERATURE

The current feeder calf marketing system often increases the incidence of BRD by combining weaning, transport, and commingling stressors into a single event. The BRD complex is initiated through stress-induced immunosuppression enabling viral pathogens to infect, replicate and further suppress innate immune function. This allows commensal bacterial of the upper respiratory tract to migrate into the lungs where they become pathogenic. Biological systems work within the animal to attempt maintenance of

homeostasis during this process. The inflammatory response uses both innate and adaptive immune systems to protect the host from pathogens, such as bacteria invading the lung. The initial inflammatory response relies on cytokines for recruitment of additional leukocytes, which eventually signal the adaptive immune system if an infectious pathogen remains present. The stress response can be initiated by a variety of stimuli, and has been reported to be beneficial in the short term. As the duration of stress increases, host immunocompetence is decreased. Thirst signaling pathways work to maintain the fluid balance enabling the inflammatory and stress responses to operate efficiently. Processing and nutritional management protocols are designed to optimize cattle health and performance following arrival and throughout the feeding period, but these methods will require refinement as our understanding of stress, nutrition, BRD and their interactions evolves.

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Chapter II: Oral hydration therapy with water affects health and performance of high-risk, newly received feedlot cattle

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ABSTRACT

Our objective was to evaluate the impact of oral hydration therapy with water during initial processing of high-risk crossbred beef calves on health and performance during a 56-d feedlot receiving period. In Exp. 1 (**EXP1**), 6 arrival blocks of heifers (n = 664, initial BW = 197.1 ± 5.8 kg) were randomized to treatment pens (n = 6/treatment). In Exp. 2 (**EXP2**), 3 arrival blocks (initial BW = 188.9 ± 19.1 kg) of bulls (n = 242) and steers (n = 55,) were stratified by sex and purchase BW and randomly assigned to treatment pens (n = 15/treatment) before initial processing. In both experiments, calves received either 0.57 L water/45.4 kg BW from a modified oral drenching apparatus (**H2O**) or no water administration (**CON**) at initial processing. Treatment-blinded technicians evaluated calves daily and assigned a clinical illness score for bovine respiratory disease (**BRD**). Cattle qualifying for BRD treatment were administered an antimicrobial. In EXP1, BW, ADG and G:F did not differ ($P \geq 0.63$); however, H2O numerically increased DMI (5.29 vs. 5.09 kg/d; $P = 0.12$) and tended to increase BRD morbidity (29.0 vs. 21.5%; $P = 0.07$). There was no difference ($P \geq 0.39$) in second or third BRD morbidity rate or mortality rate. In EXP2, final BW (256.8 vs. 248.7 kg) and overall ADG (1.19 vs. 1.07 kg/d) tended to increase ($P = 0.08$) and DMI from d 42 to 56 (7.54 vs. 6.85 kg/d) was greater ($P < 0.01$) for H2O vs. CON. However, BRD-associated mortality was greater ($P = 0.05$) in H2O (8.1%) vs. CON (2.7%). Increased performance and DMI was observed for H2O; but health outcomes were not improved.

Key words: Bovine Respiratory Disease, High-risk Feeder Calves, Hydration, Performance

INTRODUCTION

Stimulating feed intake and managing health in newly received calves are long standing challenges faced by the feedlot sector of the beef industry (Lofgreen et al., 1975; Duff and Galyean, 2007). Stressors associated with weaning, marketing, and transport, coupled with the inability to provide feed and water during transport may cause moderate to severe dehydration and other metabolic or immunologic dysfunction in newly received calves (Loerch and Fluharty, 1999). Physiological stress is also known to promote diuresis, which may further exacerbate dehydration (Parker et al., 2003). Chronic stress and dehydration encountered during relocation predisposes cattle to bovine respiratory disease (BRD) because innate and adaptive immune functions are altered. Specifically, the immune response is suppressed, reducing host resistance to pathogens and the efficacy of health products used for BRD prevention and control (Carroll and Forsberg, 2007; Taylor et al., 2010). In dairy cattle, oral drenching with water during the transition period has been evaluated (Tankersley et al., 2007; McFadden et al., 2010) and results suggest improved energy balance following treatment when water drenches included propylene glycol (Stokes and Goff, 2001; Pickett et al., 2003). In contrast, using beef cattle and the same administration technique as the current study, Lopez et al. (2018) drenched high-risk calves at arrival with water or water-based solution containing 200 or 400 g/L glycerin and reported no differences in BW, DMI or ADG. Nevertheless, addressing dehydration in high-risk beef calves via oral water drench has been minimally investigated, and we are unaware of previous studies conducted in the large pen setting.

We hypothesized that an oral water drench administered upon feedlot arrival would improve DMI, performance, and health of newly received calves. The study objective was to evaluate DMI, gain performance, and health impacts of oral hydration therapy with water upon initial processing of high-risk calves monitored during a 56-d receiving period.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at West Texas A&M University (WTAMU) approved animal procedures in experiment 1 (#01-08-16) and 2 (#02-05-17). Two experiments were conducted using cattle acquired from the same order buyer facility located in central TX. Both experiments were randomized complete block designs with cattle being randomly allocated to oral hydration therapy treatment (**H2O**) at initial processing or a negative control (**CON**).

Experiment 1

In Exp. 1 (**EXP1)**, 6 arrival blocks of high-risk beef heifers (n = 664, initial BW = 197.1 ± 5.8 kg) were received (block 1 and 2, October 2016, 20.4 ºC, 3.1 cm; block 3 and 4, May 2016, 30.6 ºC, 11.43 cm; block 5 and 6, July 2017, 30.7 ºC, 23.5 cm; arrival month and year, average maximum temperature and cumulative rain fall for each block, respectively) at a commercial feedlot near Hereford, TX. At arrival, heifers were randomized to treatment pen using a 2 × 2 gate sort where every other heifer pair was sorted into 1 of 2 receiving pens upon exiting the trailer (6 blocks, 6 pens/treatment, 55 ± 3 heifers/pen). Initial processing occurred the same morning cattle arrived at the feedlot, beginning at approximately 0800 h.

For all blocks, heifers were administered antimicrobial metaphylaxis with tilimicosin phosphate (Micotil 300, Elanco Animal Health, Greenfield, IN) with a 3-d post metaphylactic interval (PMI), doramectin anti-parasitic (Dectomax, Zoetis, Kalamazoo, MI), a subcutaneous autogenous bacterin (*Histophilus somni*, *Mannheimia haemolytica, Mycoplasma bovis,* and *Pasteurella multocida* antigens), and a trivalent (infectious bovine rhinotracheitis virus, bovine respiratory syncytial virus, and parainfluenza-3 virus) intranasal vaccine (Inforce 3, Zoetis) during initial processing. Growth promoting implants, clostridial, and other parenteral respiratory vaccinations varied between blocks as recommended by the consulting veterinarian, but all processing was identical within block except for the experimental treatment. Heifers were revaccinated on d 15 with the same parenteral viral respiratory vaccines as initial processing. In EXP1, heifers within a treatment pen were weighed as a group using a platform scale (± 2.27 kg readability; Cardinal 220; Webb City, MO) at arrival (d 0), and on d 15 and 56. Pens used in EXP1 measured 13.7 m × 36.6 m, which provided 9.1 m^2 pen space and 0.27 m linear bunk space per heifer. Water tanks were located in the fence line (Johnson Concrete, Hastings, NE), however every other pen was vacant, so only 1 treatment pen had access to a water tank. Heifers were initially offered a grower diet before transitioning to a finishing diet (Table 1). This transition started on d 5 for blocks 1, 2, and 6 and on d 6 for blocks 3, 4, and 5. There were 2 intermediate diets used. The initial transition diet was fed for 11.3 ± 2.4 d. The secondary transition diet was fed for 18 d to blocks 1 and 2. For blocks 3 through 6 the secondary transition diet was fed for 3.3 ± 1.5 d. Diet transition duration varied slightly between blocks (20.3 ± 5.2 d) but was the same between treatments within block.

Experiment 2

In Exp. 2 (**EXP2**), 3 arrival blocks of high-risk beef bull (n= 242) and steer (n = 55) calves (initial BW = 188.9 ± 19.1 kg) were at the WTAMU Research Feedlot (Canyon, TX) on 9 June 2017, 17 August 2017 and 26 September 2017. The average maximum temperature and cumulative rain fall was 33.8 ºC and 15.3 cm, 27.7 ºC and 14.9 cm, and 21.3 ºC and 7.5 cm for the 56 d of blocks 1, 2, and 3; respectively

At the order buyer facility, before transport to the WTAMU Research Feedlot, cattle were tagged in the ear with a unique visual identification number, ear notched for testing of persistent infection (PI) with bovine viral diarrhea virus (BVDV; Cattle Stats, Oklahoma City, OK), and sex (bull or steer) was determined. Cattle were stratified by sex and purchase BW, then assigned randomly to treatment pens within block. Each arrival block resulted in 10 pens (n = 5 pens/treatment) with 10 calves per pen. There were 2 PI-BVDV positive calves in the second arrival block that were quarantined on d 0 and excluded from the study.

Upon arrival (d 0) to Canyon, TX, cattle were individually weighed and sorted into treatment pens. Bulls were orally administered a nonsteroidal anti-inflammatory drug (meloxicam, 1 mg/kg BW, Unichem Pharmaceuticals, Hasbrouck Heights, NJ), and surgically castrated using aseptic technique. Additionally, cattle were administered antimicrobial metaphylaxis (block 1 and 2: tilimicosin phosphate, Micotil 300, Elanco Animal Health, 3-d PMI; block 3: tulathromycin, Draxxin, Zoetis, 7-d PMI), anthelmintic treatment with ivermectin (Noromectin, Norbrook, Overland Park, KS), a growth promoting implant (Component-ES with Tylan, Elanco Animal Health), and a

Mannheimia haemolytica leukotoxoid (Nuplura, Elanco). On d 28, steers were administered a pentavlent modified-live virus vaccine (Titanium 5, Elanco).

Steers were a fed a common growing ration throughout EXP2 (Table 2). In blocks 1 and 2 of EXP2, residual feed in the bunk was observed daily at 0700 h before feed delivery. The feed offered was increased 0.31 kg DM per steer if there was no residual feed for 2 consecutive days. This protocol was modified for block 3 to add an additional evening bunk read. The first bunk observation occurred at 0700 h, and the second at approximately 1800 h. For block 3, the amount of feed offered was increased 0.61 kg DM per steer if there was no residual feed at 1800 h or 0.31 kg DM per steer following 2 consecutive d of no residual feed at 0700 h. Study pens in EXP2 measured 6.1 m × 27.4 m and provided 16.7 m^2 pen space and 0.6 m of linear bunk space per steer. Each pen contained its own automatic waterer (WaterMatic 150, Ritchie Inc., Conrad, IA).

Every 14 d throughout the 56-d receiving study individual BW were recorded and any residual feed was weighed and sampled for DM determination (60°C in a forced-air oven for 48 h) then discarded. Pen average BW and ADG were calculated from individual BW. Orts were deducted from feed offered to calculate interim DMI and G:F.

Treatment administration

Oral hydration therapy with water was administered to chute restrained calves during arrival processing via a modified oral drenching apparatus (Figure 1) attached to a garden hose and water faucet located in the processing facility. To assemble the drenching apparatus the tip of an oral deworming device was bored using a 4.8 mm drill bit to increase water volume and decrease water pressure. Water pressure was adjusted before administration such that the water stream flowed upward 15 to 20 cm when

directed perpendicular to gravity. The hose was fitted with an in-line shutoff valve and digital water meter (Model 825, Sotera Systems, Fort Wayne, IN) to measure water offered according to the targeted consumption. In EXP1 block 1, water was offered to target 0.76 L water /45.4 kg of BW, but hydration therapy was terminated when heifers began refusing treatment. Upon completion of block 1, it was determined that heifers were more receptive to 0.57 L/45.4 kg of BW on average; therefore, this smaller amount was utilized as the maximum water volume for all remaining calves administered oral hydration therapy in EXP 1. For blocks 2 to 6 in EXP1, heifers were delivered at least 1.1 L through the modified drenching apparatus, then oral water administration continued until treatment refusal or a maximum of 0.57 L/45.4 kg of BW (mean = 0.42 L/45.4 kg BW, mode = 0.57 L/45.4 kg BW). The minimum water delivery threshold of 1.1 L was observationally determined to be the maximum amount of water before a heifer would begin voluntarily consumption and become receptive to the treatment. In EXP2, calves were offered 0.57 L water/45.4 kg of BW, regardless of receptivity to the treatment application. The water drenching device was placed in an anti-septic bath containing chlorhexidine solution between each treated animal. A water consumption score (**WCS**) was assigned to H2O-treated calves to document differences in receptivity to the oral hydration therapy. The ordinal scale ranged from 1 to 3 and was assigned subjectively by the same investigator in both experiments. Calves consuming < 25% of offered water volume were scored a 1, those consuming between 25 and 75% of the targeted water volume were scored a 2, and those consuming > 75% of water offered were assigned a score of 3.

BRD case definition

Cattle were observed and assigned a BRD-associated clinical illness score (CIS) daily by treatment-blinded personnel as described by Pillen et al. (2016) and presented in Table 3. In EXP1, heifers observed by pen riders to be CIS ≥ 2 were considered a BRD case. A morbid heifer was removed from their home pen and relocated to the hospital for antimicrobial treatment. After antimicrobial treatment, heifers were returned to their original treatment pen, except chronically ill cattle, which were placed in a recovery pen adjacent to their treatment pen. In EXP2, steers assigned a CIS ≥ 2 were removed from their treatment pen for further evaluation. Steers with a rectal temperature ≥ 40.0°C or assigned a CIS ≥ 2 for 2 d regardless of rectal temperature were administered antimicrobial treatment. All calves in EXP2 were immediately returned to their home pen. Cattle in both experiments were eligible for up to 3 antimicrobial BRD treatments following post-treatment interval expiration of the previously administered antimicrobial.

For all blocks in EXP 1, initial BRD treatment was florfenicol (40 mg/kg BW; Nuflor, Merck Animal Health) and ceftiofur crystalline free acid (6.6 mg/kg BW; Excede, Zoetis). In EXP 1, secondary BRD treatment included penicillin G procaine (33,000 units/kg BW; PenOne Pro, Norbrook) for all blocks. Additionally, at secondary BRD treatment heifers in block 1 and 2 were administered tulathromycin (2.5 mg/kg BW; Draxxin, Zoetis). For blocks 3 through 6 in EXP1, secondary BRD treatment also included tildipirosin (4 mg/kg BW; Zuprevo, Merck Animal Health). Tertiary and final BRD treatment was oxytetracycline (22 mg/kg BW; Liquamycin LA-200; Zoetis). In EXP 1, there was a 4-d post treatment interval (PTI) following initial BRD treatment and a 5-d PTI following secondary BRD treatment. In EXP 2, initial BRD treatment was

ceftiofur crystalline free acid (6.6 mg/kg BW, 6-d PTI; Excede, Zoetis) secondary BRD treatment was florfenicol (40 mg/kg BW, 3-d PTI; Nuflor, Merck Animal Health); tertiary and final BRD treatment was enrofloxacin (11 mg/kg BW; Baytril 100, Bayer, Shawnee Mission, KS). Cattle treated at least once for BRD were considered BRD1, cattle treated at least twice for BRD are included in BRD2, and those receiving 3 treatments were also included in BRD3.

Statistical analysis

Data from EXP1 and EXP2 were analyzed independently. Performance (BW, ADG, DMI, G:F), and health (BRD1, BRD2 and BRD3 morbidity rate and mortality rate) variables were analyzed for treatment differences using the Mixed procedure of SAS 9.4 (SAS Institute Inc., Cary, NC) in a randomized complete block design. In EXP1, treatment was the fixed effect and block was considered random. In EXP2, treatment, block, and the treatment*block interaction were tested as a fixed effect. The were no significant treatment*block interactions; therefore, only main effects of treatment are reported. Pen was the experimental unit for all dependent variables analyzed. The Mixed procedure was used to retrospectively analyze the effect of WCS on morbidity and mortality. The experimental unit for this model was WCS within block. Treatment effects were considered significant at $P \leq 0.05$, and tendencies were noted for $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Performance

In EXP1, there were no differences ($P \geq 0.63$) in BW, ADG or G:F (Table 4). While not statistically significant ($P = 0.12$), there was a numerical increase in DMI for H2O vs. CON (5.29 vs. 5.09 kg/d, respectively). In EXP2, d 42 and final BW tended ($P \leq$

0.10) to be greater in H2O vs. CON (Table 5). Numerical increases in ADG for H2O from d 28 to 42 and d 42 to 56 contributed to overall ADG tending ($P = 0.08$) to be greater for H2O compared to CON (1.19 vs. 1.07 kg/d). Dry matter intake tended to increase ($P = 0.10$) from d 28 to 42 and was greater ($P < 0.01$) from d 42 to 56 for H2O than CON. There were no differences in interim period G:F ($P \geq 0.34$), but there was a numerical improvement ($P = 0.12$) in overall G:F in EXP2. The numerical increase in DMI in EXP1, coupled with greater DMI and a tendency for greater ADG and BW in EXP2 suggest oral hydration therapy at feedlot arrival may stimulate appetite and improve performance. Using packed cell volume as a proxy for hydration status, it was determined that dehydration is common at parturition in dairy cattle (Klinkon and Zadnik, 1999), and for this reason orally drenching dairy cows with water and various nutritional additives is becoming a common practice during the periparturient period. Decreased NEFA concentrations were reported following drenching with 9.5 L of a combination water and propylene glycol solution at parturition and again 24 h later (Stokes and Goff, 2001) or 1.9 L for 3 d following parturition (Pickett et al., 2003). In both of these studies, propylene glycol was included in the drench, which differs from the present study where water only was administered. The propylene glycol was likely converted to propionate in the rumen prior to absorption, supplying energy to the cows and reducing the need to mobilize lipid stores. Lopez et al. (2018) orally drenched a volume of 2 L to high-risk steers at arrival using water, 200 g/L glycerin solution, or 400 g/L glycerin solution, and reported no differences in performance except a tendency to reduce G:F with the lower glycerin treatment. Investigations in the periparturient dairy cow suggest providing energy via an oral drench improves energy status; however, these

benefits have not been validated in the high-risk beef calf. Providing energy during oral hydration therapy of beef calves at feedlot arrival may have an additive effect on the improved performance responses observed in the present study. Additionally, in studies using transition dairy cows the amount of fluid administered at a single time ranged from 37.85 L (McFadden et al., 2010) to 1.9 L (Pickett et al., 2003). The present study targeted 2.42 L per animal, based on the average arrival BW across all blocks. Body weights were not reported by McFadden et al. (2010), but the cows used by Pickett et al. (2003) weighed 600 kg. Therefore, the rate of water/propylene glycol solution administered in Pickett et al. (2003) was 0.32 L/45.4 kg BW, which is less than the 0.57 L/kg BW used in the current study. However, in the dairy cow study treatment administration was repeated for 3 consecutive d following parturition (Pickett et al. (2003). The response to a water drench treatment is likely affected by the volume offered relative to BW; therefore, further research investigating the appropriate amount of water orally administered to transition dairy cows or newly received beef calves is needed.

The delayed increase in DMI for H2O in EXP2 was unexpected but may be a result of a conservative bunk management protocol or differences in recovery rates from BRD. The conservative bunk management strategy may have limited the desired DMI in the H2O steers to a greater extent than CON. However, cattle were observed daily for bunk aggression, and no differences in feeding behavior were noted. Overall, comparable DMI and ADG have been reported by other authors during the receiving period for light weight beef calves (Moonsie-Shageer and Mowat, 1993; Kegley and Spears, 1995; Lippolis et al., 2016).

Based on equations from Winchester and Morris (1956), the most recent NRC (2016) estimates daily water requirements for a growing 182 kg steer to be 25.4 L/d when the ambient temperature is 26.6° C. Individual animal water intake is known to be highly variable and heavily influenced by ambient temperature and DMI (Winchester and Morris, 1956). The present study offered approximately 2.38 L/animal at arrival, which is less than 10% of the estimated daily water requirement. While hydration status may be improved from the relatively small amount of water administered, it is hypothesized that oral hydration therapy may have additional beneficial mechanisms such as stimulating saliva production, or activation of neural or endocrine signals that modulate DMI. During H2O treatment administration, calves were observed to be chewing on the hydration therapy device as they consumed water. The parotid glands are stimulated to secrete saliva by chewing activity (Church, 1988), and increased salivation provides bicarbonate, electrolytes, and enzymes. In the rumen, these substances would contribute to improved ruminal environment and digestion. Furthermore, the H2O treatment promoted a suckling motion in some calves in response to oral hydration therapy. De Passillé et al. (1993) allowed 2 wk old Holstein dairy calves to suckle an artificial teat following consumption of milk replacer. Those authors reported increased cholecystokinin and insulin in the portal vein in calves allowed to suckle the artificial teat compared to a negative control. While cholecystokinin has satiety signaling mechanisms, it also causes gall bladder emptying and pancreatic enzyme secretion that may positively affect appetite (Crawley and Corwin, 1994). Delivery of bile and pancreatic products to the small intestine would be a source of proteolytic, amylolytic, and lipolytic enzymatic activity (Green and Nasset, 1977; Whitcomb and Lowe, 2007). If high-risk beef calves exhibit a

similar response through the suckling motion initiated by oral hydration therapy, then this may be a mechanism for initiating gastrointestinal activity. While the mechanism is not currently understood, feed intake and performance were increased slightly during the receiving period when oral hydration therapy was provided at initial processing.

Health

In EXP1, the percentage of BRD1 tended ($P = 0.07$) to be greater for H2O than CON, but there were no differences in BRD2, BRD3 or mortality rate ($P \geq 0.39$; Table 6). In EXP2, there was no difference in BRD morbidity rates ($P \geq 0.17$, Table 7), but total mortality tended ($P = 0.06$) to increase and BRD-associated mortality was greater ($P = 0.05$) for H2O than CON. The reason for increased BRD-associated mortality in H2O is not clear. An initial hypothesis was the calf's receptivity to oral hydration therapy being a factor. Increased receptivity to oral hydration therapy was hypothesized to reduce aspiration of water into the respiratory tract; thus, reduced BRD incidence was expected in the more receptive (WCS=3) calves. The retrospective analysis of WCS affecting health outcomes is presented in Table 8 and 9. There was no effect ($P \geq 0.38$) of WCS on BRD morbidity or mortality in either experiment. Another potential explanation we suggest is experimental design may have contributed to statistical differences in mortality. In EXP2, there were 10 steers per pen and in EXP 1 there were 53 heifers per pen. The small pen sample size in EXP2 results in a single death influencing the pen-level mortality rate by 10%. Additionally, sample-level mortality is an infrequent binomial event. These factors increase the likelihood of extreme values derived from the experimental unit (pen) and type I statistical error in the small-pen setting. No differences in death loss in EXP1 with a larger sample size suggests that the difference in mortality

observed in EXP2 could be a result of experimental design. Alternatively, potential biological causes of increased mortality for H2O include increased animal to animal pathogen transmission from the oral hydration apparatus or aspiration of water into the trachea and lungs regardless of receptivity to oral hydration therapy. The hydration apparatus was submerged in an anti-septic chlorohexidine solution between animals; therefore, this precautionary measure should have reduced the likelihood of pathogen transfer from the drenching technique applied. The method for water administration encouraged a suckling motion due to drenching apparatus placement and low water flow rate. The subsequent voluntary swallowing motion reduced the potential for water to enter the trachea and lungs, and no adverse events immediately following the application of oral hydration therapy were observed. However, oral hydration therapy may have caused calves to aspirate water into the respiratory tract, causing increased risk for BRD-associated mortality. Further research is required to determine if the increased BRD-associated mortality in H2O is an anomaly, or an artifact of water aspiration in the respiratory tract.

In both experiments, there were no statistical differences ($P \geq 0.13$) in days to BRD treatment. However, H2O heifers and steers had numerically fewer days to BRD1, BRD2, and BRD3 treatment potentially due to indirect effects of oral hydration therapy and an associated improvement in the immune response to infection resulting in calves displaying clinical signs of illness more rapidly. Additionally, rectal temperature at BRD2 treatment in EXP2 was greater ($P = 0.05$) for H2O, further supporting a more profound inflammatory response in H2O-treated calves that displayed clinical signs of BRD. Ulrich-Lai and Engeland (2002) reported 48-h water-restricted rats had increased

corticosterone concentrations and splanchnic nerve transection reduced the corticosterone response to dehydration. This change suggests neural signaling from the gastrointestinal tract as a modulator of corticosterone release in addition to the traditional stress response associated with hypothalamus-pituitary-adrenal axis stimulation. Increased cortisol from stressors can result in immunosuppression (Richeson et al., 2016). Hydration therapy at feedlot arrival may alter neural signaling from the gastrointestinal tract, reducing cortisol concentration, but this concept is not documented in beef cattle.

IMPLICATIONS

Oral hydration therapy with water at feedlot arrival may be a novel management strategy to rapidly address dehydration and could result in improved performance and DMI during the first 56 d in a feedlot; however, health outcomes in the current study were not improved for H2O. Further investigation into the cause for increased mortality with concurrently improved performance and DMI intake may reveal necessary improvements in apparatus design or application technique. Inclusion of energy, electrolyte, and/or probiotic sources in the water may further enhance receiving calf performance, yet such additives could worsen mortality rate if aspiration of drench solution in the respiratory tract occurs. Oral hydration therapy may be a promising management strategy to improve performance and DMI during the receiving period but further research evaluating improved application of the water drench with various nutritional additives is warranted.

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Figure 2.1. Photograph of the modified oral drenching apparatus used to apply hydration therapy with water.

Table 2.1. Composition of the growing and finishing diets fed to heifers in Exp. 1.

	Diet	
Ingredient, % of DM	Grower	Finisher
Steam-flaked corn	44.4	62.0
Wet corn distillers grain	12.5	21.9
Alfalfa	37.1	9.0
Tallow	-	2.5
Supplement	6.0	4.6
Nutrient composition[1]		
DM, %	65.0	60.3
CP, DM%	14.9	14.5
NEm, Mcal/kg DM	1.80	2.17
NEg, Mcal/kg DM	1.03	1.40

[1]Calculated values from proprietary methods established by the consulting nutritionist of the research site.

Table 2.2. Composition of the growing diet fed to steers in Exp. 2.

Ingredient, % of DM	
Steam-flaked corn	13.9
Sweetbran[1]	56.4
Corn stalks	19.1
Molasses	7.3
Supplement[2]	3.3
Nutrient composition[3]	
DM, %	66.5
CP, DM%[4]	16.6
TDN, DM%[5]	74.0
Nem, Mcal/kg DM[6]	1.76
NEg, Mcal/kg DM[7]	1.14

[1] Wet corn gluten feed

[2]Supplement = 68.94% $CaCo_3$, 19.15% NaCl, 5.25% KCl,2.66% MgO, 2.00% Lecithin, 0.57% $ZnSO_4$, 0.30%Vitamin A, 0.27% Na_2Se0_3, 0.12%, Vitamin E, 0.11% CuSO4, 34 g/909.1 kg Rumensin-90

[3]Proximate analysis conducted at a commercial laboratory (Servi-tech Laboratories, Amarillo, TX).

[4]Determined by combustion (Leco Corporation, Saint Joseph, MI).

[5]$TDN = 4.898 + (89.796 * NE_l)$;
$NE_l = 0.9265 – (0.00793 * ADF\%)$

[6]Mebeef = TDN * 0.01642;
$Nem = (1.37 * Mebeef) – (0.3042 * Mebeef^2) + (0.051 * Mebeef^3) – 0.508$

[7]$NEg = (1.42 * Mebeef) – (0.3836 * Mebeef^2) + (0.0593 * Mebeef^3) – 0.7484$

Table 2.3. Clinical illness score description[1]

Clinical Illness Score	Description	Appearance
0	Healthy	Normal
1	Slightly ill	Inappetence, nasal/ocular discharge
2	Moderately ill	Gaunt, nasal/ocular discharge, lags behind other animals in group, coughing, labored breathing
3	Severely ill	Purulent nasal/ocular discharge, labored breathing, not responsive to human approach
4	Moribund	Near death

[1]Adapted from (Pillen et al., 2016)

Table 2.4. Effect of oral hydration therapy with water on performance of high-risk heifers (Exp. 1).

	Treatment[1]			
Item	CON	H2O	SEM	*P*-value
BW, kg				
d 0	197.4	196.7	2.48	0.63
d 15	212.4	211.8	4.86	0.68
d 56	261.8	262.1	5.87	0.91
ADG, kg/d				
0 to 15	0.99	1.00	0.21	0.90
0 to 56	1.15	1.17	0.08	0.64
DMI, kg/d[2]	5.09	5.29	0.29	0.12
G:F[3]	0.23	0.22	0.01	0.71

[1]H2O = orally administered water at least 1.1 L of water, water administration continued until refusal or 0.76 L/45.4 kg of BW for block 1 or 0.57 L/45.4 kg of BW for blocks 2 through 6 as a maximum, CON = No water administration.
[2]Treatment DMI was calculated by dividing total DM fed to each pe from d 0 to 56 by head days.
[3]Treatment G:F was determined by dividing overall (d 0 to 56) ADG by DMI.

Table 2.5. Effect of oral hydration therapy with water on performance of high-risk steers (Exp. 2).

	Treatment[1]			
Item	CON	H2O	SEM	*P*-value
BW, kg				
d 0	188.7	189.5	0.73	0.42
d 14	195.9	197.2	1.79	0.61
d 28	215.4	218.4	2.13	0.32
d 42	229.1	235.6	2.65	0.10
Final[2]	248.7	256.8	3.09	0.08
ADG, kg/d				
0 to 14	0.51	0.54	0.10	0.80
14 to 28	1.36	1.39	0.07	0.77
28 to 42	0.97	1.14	0.09	0.17
42 to 56	1.39	1.52	0.07	0.23
0 to 56	1.07	1.19	0.05	0.08
DMI, kg/d				
0 to 14	2.62	2.59	0.15	0.90
14 to 28	5.00	5.15	0.15	0.49
28 to 42	5.74	6.10	0.15	0.10
42 to 56	6.85	7.54	0.17	<0.01
0 to 56	5.03	5.27	0.13	0.19
G:F				
0 to 14	0.19	0.20	0.04	0.83
14 to 28	0.27	0.27	0.01	0.81
28 to 42	0.16	0.18	0.01	0.34
42 to 56	0.20	0.20	0.01	0.80
0 to 56	0.21	0.23	0.01	0.12

[1]H2O = offered 0.57 L water / 45.4 kg BW at initial processing. CON= no water at initial processing.
[2]Average of d 55 and 56 BW.

Table 2.6. Effect of oral hydration therapy with water on health of high-risk heifers (Exp. 1).

	Treatment[1]			
Item	CON	H2O	SEM	*P*-value
Morbidity, %				
BRD1[2]	21.5	29.0	-	0.07
BRD2[3]	9.1	10.4	-	0.59
BRD3[4]	2.5	1.2	-	0.40
Mortality, %				
Total	3.4	4.3	-	0.54
Respiratory	2.8	4.0	-	0.39
Days to				
BRD1	16.4	15.8	1.7	0.76
BRD2	31.2	26.1	2.3	0.16
BRD3	-	-	-	-
Rectal temperature, °C				
BRD1	40.3	40.3	0.2	0.60
BRD2	40.3	39.9	0.2	0.22
BRD3	-	-	-	-

[1]H2O = orally administered water at least 1.1 L of water, water administration continued until refusal or 0.76 L/45.4 kg of BW for block 1 or 0.57 L/45.4 kg of BW for blocks 2 through 6 as a maximum, CON = No water administration.
[2]The percentage of cattle treated for BRD at least once.
[3]The percentage of cattle treated for BRD at least twice.
[4]The percentage of cattle treated for BRD three times.

Table 2.7. Effect of oral hydration therapy with water on health of high-risk steers (Exp. 2).

	Treatment[1]			
Item	CON	H2O	SEM	*P*-value
Morbidity, %				
BRD1[2]	33.6	36.4	-	0.64
BRD2[3]	14.8	16.8	-	0.63
BRD3[4]	4.7	8.8	-	0.17
Mortality, %				
Total	3.4	8.8	-	0.06
Respiratory	2.7	8.1	-	0.05
Days to				
BRD1	12.9	10.4	1.14	0.14
BRD2	25.9	20.8	3.77	0.13
BRD3	28.7	27.7	3.68	0.83
Rectal temperature, °C				
BRD1	39.7	39.8	0.18	0.72
BRD2	38.8	39.4	0.20	0.05
BRD3	38.7	39.6	0.36	0.08

[1]H2O = offered 0.57 L water /45.4 kg BW at initial processing. CON= no water at initial processing.
[2]The percentage of cattle treated for BRD at least once.
[3]The percentage of cattle treated for BRD at least twice.
[4]The percentage of cattle treated for BRD three times.

Table 2.8. Population demographics relative to water consumption score (WCS)[1] of high-risk heifers and steers in Exp. 1.

	WCS					
Item	CON	H2O 1	H2O 2	H2O 3	SEM	*P*-value
n	333	109	147	75	-	-
Morbidity						
BRD1[2]	21.5	34.2	26.4	25.5	-	0.38
BRD2[3]	9.1	7.5	11.1	13.3	-	0.72
BRD3[4]	2.4	1.9	0.7	1.3	-	0.78
Mortality						
Respiratory	2.7	5.0	1.9	6.3	-	0.69
Total	3.3	4.9	2.5	6.4	-	0.78

[1]WCS: CON= no water offered at initial processing; H2O 1 = <25% of offered water was consumed; H2O 2 = between 25% and 75% of offered water consumed; H2O 3 = >75% of offered water was consumed. Water was offered at 0.57 L/45.5 kg BW in H2O treatments.
[2]The percentage of cattle treated for BRD at least once.
[3]The percentage of cattle treated for BRD at least twice.
[4]The percentage of cattle treated for BRD three times.

Table 2.9. Population demographics relative to water consumption score (WCS)[1] of high-risk heifers and steers in Exp. 2.

	WCS					
Item	CON	H2O 1	H2O 2	H2O 3	SEM	*P*-value
n	148	42	51	56	-	-
Morbidity						
BRD1[2]	33.7	34.0	38.0	35.8	-	0.99
BRD2[3]	14.8	9.7	18.0	20.7	-	0.73
BRD3[4]	4.7	4.8	10.1	10.1	-	0.73
Mortality						
Respiratory	2.7	4.8	9.9	8.6	-	0.45
Total	3.4	4.8	9.9	10.2	-	0.52

[1]WCS: CON= no water offered at initial processing; H2O 1 = <25% of offered water was consumed; H2O 2 = between 25% and 75% of offered water consumed; H2O 3 = >75% of offered water was consumed. Water was offered at 0.57 L/45.5 kg BW in H2O treatments.
[2]The percentage of cattle treated for BRD at least once.
[3]The percentage of cattle treated for BRD at least twice.
[4]The percentage of cattle treated for BRD three times.

Chapter III: Oral hydration therapy with water and bovine respiratory disease incidence affects rumination behavior, rumen pH, and rumen temperature in high-risk, newly received beef calves

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ABSTRACT

The study objectives were to determine the effect of oral hydration therapy and bovine respiratory disease (BRD) on rumination behavior, rumen pH, and rumen temperature. A random subset of high-risk, auction-sourced bulls from 3 truckload blocks (initial BW = 188.9 ± 19.1 kg) were fitted with a collar containing a 3-axis accelerometer to quantify rumination time and activity (n = 58), and administered a rumen pH and temperature data logging bolus (n = 33). At arrival, subset calves (n = 2/pen) were balanced across treatment pens (n = 15/treatment; n = 10 animals/pen) and randomized to receive 0.57 L water/45.4 kg BW from a modified oral drenching apparatus (**H2O**) or no water administration (**CON**). Standard arrival processing procedures were implemented including surgical castration. Modified-live virus (MLV) respiratory vaccination was delayed until d 28. Technicians assigned a clinical illness score (CIS) daily; calves with CIS ≥ 2 and rectal temperature ≥ 40 °C were considered a BRD case (**RCASE**) and treated with an antimicrobial. The fixed effect of BRD cases vs. non-treated cohorts (**RCON**) was determined retrospectively using data from the accelerometer collar (n = 19 and 29) and rumen bolus (n = 12 and 21, for RCASE and RCON respectively). Daily means and hourly means across days throughout the 56-d observation period were generated. Fixed effects were analyzed using the mixed model procedure with repeated measures. Daily rumen temperature was altered ($P = 0.04$) such that peak rumen temperature occurred earlier for H2O; whereas, CON had increased ($P \leq 0.01$) rumen temperature following delayed vaccination on d 28. Calves diagnosed with BRD had

transiently decreased ($P = 0.04$) active minutes between d 9 and 32, decreased ($P < 0.01$) active minutes between 0800 and 2000 h, decreased ($P < 0.01$) rumination time between 2000 and 0400 h, greater ($P < 0.01$) rumen temperature until delayed vaccination on d 28, greater ($P < 0.01$) hourly rumen temperature between 0900 and 0300, and altered ($P < 0.01$) rumen pH. Earlier peak rumen temperature observed in H2O may indicate physiological modification enabling a more pronounced inflammatory response. Differences in rumination behavior and activity may be useful for early BRD detection.

KEY WORDS: bovine respiratory disease, hydration therapy, rumen pH, rumen temperature, rumination

INTRODUCTION

The cattle marketing process induces stress that may suppress the immune system and predispose cattle to bovine respiratory disease (**BRD**; Taylor et al., 2010). High-risk calves are often abruptly weaned from their dam and transported to an auction market. There an order buyer may purchase individually marketed calves, and relocate them to another facility for sorting into more uniform groups before finally transporting them to a stocker or feedlot facility. These events expose young calves to novel environments, commingling, and feed and water restriction that may result in a negative energy balance and dehydration.

Step et al. (2008) reported greater feed intake by single source calves that were weaned 45 d before transport to the feedlot compared to those derived from auction markets, and greater BRD morbidity rates were reported in the auction market-sourced calves. Feeding and drinking frequency of newly received heifers were decreased in those treated for BRD (Buhman et al., 2000). Furthermore, restricted feed access associated

with the feeder calf marketing system has been modeled by fasting cattle for 32 (Galyean et al., 1981) and 24 h (Cole and Hutcheson, 1985). These authors reported greater rumen pH following fasting with a subsequent decrease at refeeding. However, these experiments used a single pH measurement either 3 d (Galyean et al., 1981) or 4, 14, 24, 48 and 72 h (Cole and Hutcheson, 1985) after refeeding. Limited data exists continuously recording rumination, activity, rumen pH, and rumen temperature in beef calves throughout a 56-d receiving period.

Provision of an oral drench with water in dehydrated or newly received cattle may promote feed intake and improve performance (Stokes and Goff, 2001; Tomczak et al., 2019); however, the underlying mechanisms behind this response have yet to be elucidated. Therefore, the objective of this study was to quantify rumination time, activity, rumen temperature, and rumen pH in high-risk, newly received beef cattle relative to oral hydration therapy with water and clinical BRD incidence. It was hypothesized that oral hydration therapy would alter pH, and increase rumination time. Cattle clinically diagnosed with BRD were hypothesized to have increased rumen temperature and decreased rumination time and activity compared to non-treated cohorts.

MATERIALS AND METHODS

All animal procedures associated with this study were approved by the West Texas A&M University Institutional Animal Care and Use Committee (#02-05-17). There were 3 truckload blocks of high-risk feeder steers and bulls transported 739 km from a central TX order buyer facility to the West Texas A&M University Research Feedlot between June 2017 and September 2017 to evaluate the impact of oral hydration therapy at feedlot arrival on subsequent performance and health (Tomczak et al., 2019).

Before arrival, a subset from each block were randomly selected to be fitted with a rumination collar (Allflex Livestock Intelligence, Madison, WI) and a rumen pH and temperature data logging bolus (Well Cow Limited, Roslin, UK). The rumination collar was fitted around the calf's neck to position the 3-axis accelerometer on the left side of the animal. The collars continuously recorded rumination and active minutes and the data were summarized in 2 h increments. The rumen pH and temperature data logging boluses were administered via intubation. The weighted boluses were designed to settle in the rumen via peristaltic contractions aided by the weight of the bolus. Rumen pH and temperature were logged every 15 min. The subset animals were selected via chute entry order at the order buyer facility, where every fourth bull to enter the chute was fitted with the data recording devices. This randomization method continued until 20 bulls per truckload block were selected and fitted with the devices. Steers and bulls were balanced by sex and stratified to treatment pens by purchase BW (n = 10 bulls or steers/pen). The subset bulls were also balanced across treatment pens (n = 2 subset bulls/pen). For rumination and activity data 1 animal from each treatment was removed from the data set (1 due to a gastrointestinal blockage and 1 due to lameness) resulting in 29 calves per treatment. The data logging boluses were originally designed for mature dairy cows. Due to the large size of the boluses used in lighter BW cattle, some were not able to pass into the rumen. Successful bolus retention and readability allowed for 19 H2O and 14 CON animals in the final rumen pH and temperature data set.

Cattle were housed in 6.1 m by 26.9 m soil surface pens providing at least 0.61 m per animal of linear bunk space. Initial processing, BRD case definition, diet (Table 1) and feed bunk management are described in Tomczak et al. (2019). It is important to note

all bulls were surgically castrated and administered a non-steroidal anti-inflammatory drug (meloxicam, 1 mg/kg BW) at arrival and a pentavalent modified-live virus (MLV) vaccine (Titanium 5, Elanco, Greenfield, IN) was not administered until d 28. Calves were weighed every 14 d throughout the 56-d receiving period.

Experimental treatments consisted of oral hydration therapy (**H2O**) or negative control (**CON**). Oral hydration therapy was administered using a modified drenching apparatus described by Tomczak et al. (2019). The H2O treatment was offered 0.57 L water/ 45.4 kg of BW during initial processing. The drenching apparatus was placed in an anti-septic solution containing chlorohexidine between each H2O treated animal.

Data collection and statistical analysis

Raw rumination and active minutes were logged continuously and then summarized in 2 h time blocks starting at midnight (0000) using the Data Flow II program (Allflex Livestock Intelligence). Daily rumination and active minutes were the sum of the twelve 2 h time blocks from 0000 to 2359 within a day. Hourly rumination and active minutes represent minutes spent ruminating or in motion in each 2 h time block across the 56-d receiving period. Rumen temperature and pH were logged every 15 min throughout the 56-d receiving period. This data was rounded to the nearest 15 min interval and averaged by hour using a computer software program (Microsoft Excel 2010, Microsoft, Redmond, WA).

The MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) was used to analyze the fixed effect of oral hydration therapy on daily and hourly rumination minutes, active minutes, rumen pH, and rumen temperature. Pen was the experimental unit for comparison of the experimental treatments. Daily means model included hydration

therapy treatment, day, and their interaction as fixed effects. Truckload block, pen, and block by pen interaction were considered random. Day was included as a random effect to test for hourly differences across days. The subject for repeated measures was pen within block.

Cattle treated at least once for BRD (**RCASE**) were compared to their non-treated cohorts (**RCON**) to retrospectively evaluate the effect of clinical BRD diagnosis on rumination minutes, active minutes, rumen pH, and rumen temperature. The models used were identical to the oral hydration therapy models except animal was the experimental unit and BRD outcome was a fixed effect. Animal was used as the experimental unit in these models because BRD diagnosis was assessed on an individual animal basis. The BRD diagnosis data were not balanced (19 vs 39; 12 vs 21; RCASE vs RCON; for collar and data logging bolus data, respectively) because calves could not be randomly assigned to BRD diagnosis. If a fixed effect was statistically significant, $\alpha \leq 0.05$, then least squares means were separated using the PDIFF ($P \leq 0.05$) option of SAS. Tendencies were noted when $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Oral hydration therapy

There was no treatment × day interaction for active minutes ($P = 0.84$), but there was a treatment × hour interaction ($P < 0.01$, Fig. 1) where H2O had reduced ($P = 0.09$) active minutes at 0800 h compared to CON. The peak activity hours are representative of the typical eating behavior of ruminants where meals are concentrated around early morning and twilight (Welch and Hooper, 1988). Feed delivery in the current study

began at approximately 0730 h, concomitant with the initial peak in activity at 0800 h. The subsequent evening activity peak occurred at 1800 h.

For time spent ruminating there was no 2-way interaction between day and water treatment ($P = 0.30$); however, there was a day effect ($P < 0.01$, Fig. 2). Daily rumination minutes increased markedly through d 25, then smaller increases continued through the remainder of the receiving period. Additionally, there was a hydration treatment × hour interaction ($P < 0.01$), but no treatment differences within hour ($P \geq 0.12$) for rumination minutes. Greater intake, and more specifically forage intake, has been correlated with increased time spent ruminating (Gentry et al., 2016). As reported in Tomczak et al. (2019), DMI for these calves increased through d 28 of this 56 d study. Increased DMI likely caused increases in daily rumination minutes.

There was no interaction for daily rumen pH ($P \geq 0.23$); however, there was a day effect ($P < 0.01$, Fig. 3). Average daily rumen pH was greatest at arrival, but decreased until d 7 and remained static at a pH of approximately 6.0 through d 24. On d 24 through d 56, pH equilibrated to approximately 6.2. There was also a 2-way interaction ($P < 0.01$) between hour and hydration treatment, where H2O had greater pH at 0700 and 0800 h compared to CON (Fig. 4). Steers were deprived of feed and water for 24 h, re-fed and watered for 24 h, feed and water deprived for another 24 h and finally re-fed by Cole and Hutcheson (1985) in order to alter feed intake levels for 3 d. Total volatile fatty acids (VFA) was least following the second fasting period but increased by 3 d post-fast. The authors suggested fasting decreased rumen fermentation capacity as indicated by decreased VFA concentrations. Decreased VFA concentrations contribute to increasing pH. In the current study, rumen pH was more acidic on d 3 compared to d 0 and rumen

pH continued to decline through d 7, indicating increased rumen fermentation after arrival. The high-risk cattle used in the present study may have required more time to restore rumen fermentative capacity compared to Cole and Hutcheson (1985) as they experienced longer feed and water deprivation and were acclimating to a new environment, feed, and social grouping. Galyean et al. (1981) also reported increased rumen pH and decreased total VFA concentration following a 32 h fast when cattle were transport stressed. At re-feeding, rumen pH decreased and VFA concentration increased. Ruminal VFA concentrations were not measured in the present study, but it is hypothesized decreased VFA concentrations in the rumen caused greater pH at arrival.

There was an oral hydration therapy treatment × day interaction ($P = 0.04$) for rumen temperature where an initial peak occurred on d 6 for H2O, but this did not occur until d 8 for CON (Fig. 5). Additionally, CON had an increase in rumen temperature following MLV vaccination on d 28. There was an oral hydration therapy treatment × hour ($P < 0.01$; Fig. 6) interaction, where CON had greater rumen temperature than H2O from 0400 to 0600 h. The febrile response is initiated by pro-inflammatory cytokines such as tumor necrosis factor (TNF) α and interleukin-1 (Roth and Blatteis, 2011; Tesch et al., 2018). The earlier increase in rumen temperature may indirectly indicate a more rapid inflammatory response following feedlot arrival, which could be beneficial for mitigation of viral or bacterial infection associated with BRD. After initial MLV respiratory vaccination on d 28, CON had a greater ($P \leq 0.01$) rumen temperature 3 d following vaccine administration. The differential febrile response subsequent to MLV vaccination was unexpected, but may be due to differences in immunocompetence

between treatments. Research evaluating the effects of oral hydration therapy on the various components of the immune system is warranted to investigate this hypothesis.

Bovine respiratory disease

There was a BRD × day interaction ($P < 0.01$) for active minutes, where RCASE had decreased active minutes intermittently from d 9 through d 33 (Fig. 7). Buhman et al. (2000) documented feeding and eating behavior in 250 kg heifers for 57 d following feedlot arrival. In this study heifers classified as a BRD case had decreased eating frequency, eating duration, drinking frequency, and drinking duration from d 11 to 27. Sowell et al. (1999) reported fewer eating and drinking bouts by morbid steers than healthy steers during a 32-d receiving period. Reduced activity 4 to 5 d before BRD diagnosis have also been reported (Pillen et al., 2016). In the present study, active minutes is an indicator of general motion and does not differentiate eating or drinking behavior from other activity. However, it is hypothesized the reduced activity values indicate decreased eating and drinking events driven by stress, infection, and the associated inflammatory response. In both the present data and that reported by Buhman et al. (2000) calves treated at any point during the study were classified as BRD cases for the statistical analysis, so some data points for BRD cases may be similar to healthy cattle because they were collected at times when cattle were not experiencing respiratory infection. Before and following convalescence from the BRD event, calves classified as RCASE likely had activity levels comparable to cattle never treated for BRD, so the difference in activity is likely greater during a BRD event than the current data indicate. No difference in activity between RCASE and RCON after d 33 is likely due to the overall resolution of the natural BRD challenge in our study population.

Additionally, there was a BRD × hour interaction ($P < 0.01$; Fig. 8) for active minutes, where RCON was greater than RCASE between 0800 and 2000 h. The decrease in active minutes for RCASE is suggestive of decreased activity around primary meal times. Decreased activity is also likely driven by depression induced by the inflammatory response. Depression in cattle, indicated by lethargy and distended head and ears, is also used as a sign to indicate potential BRD cases (Step et al., 2008; Pillen et al., 2016). Decreased locomotion spares energy to support metabolic processes and the fever response during the inflammatory response (Hart, 1988). An active inflammatory response may be driving decreased activity levels in RCASE. Also noteworthy, the lack of difference in active minutes between 2000 and 0800 h. Cattle are typically inactive during these hours regardless of health status. This may indicate behavior monitoring for disease identification in production settings may only require data capture for specific times of the day; thereby, reducing the amount of data transfer required.

There was no BRD X day interaction ($P = 0.24$) for rumination minutes, but there was a day effect ($P < 0.01$; Fig. 2). All RCASE were identified as BRD cases before d 17, suggesting the majority of the disease challenge occurred before d 25, allowing down regulation of the immune response and a subsequent increase in DMI. The initial rapid increase in rumination minutes (Fig. 2) may also be partially explained by cattle recovering from BRD.

There was an interaction between BRD and hour ($P < 0.01$; Fig. 9). No differences occurred in hourly rumination minutes from 0800 through 1800 h, but RCON had increased ($P < 0.01$) rumination minutes from 0200 to 0600 h and 2000 to 2400 h. Hourly rumination minutes within a day have an inverse pattern compared to hourly

activity values (Fig. 8 vs Fig. 9). Rumination minutes were lowest during times of greatest activity, which occurred early in the morning and just before twilight. Hourly rumination minutes observed from the current study are comparable to both the maximum and minimum reported by Gentry et al. (2016) and Weiss et al. (2017) which quantified rumination time using the same technology in beef cattle. However, the current data set has a more pronounced mid-day peak in rumination than the previous publications. In all three studies feed was delivered once per day. Differences in the pattern of hourly rumination time within day may be influenced by differences in feeding behavior across different feeding environments. In the present study, sub-set calves (n = 2 per pen) were group fed in pens with concrete bunks and 8 other animals. Weiss et al. (2017) used individually-housed cannulated steers, and Gentry et al. (2016) evaluated steers in groups of 9 with individual feed data collected using Calan head gates. Feed delivery systems that individually isolate cattle during meals may alter feeding behavior and subsequent hourly rumination pattern with in a day, and further research is needed to better understand the proposed mechanism for the reported differences.

There was a 2-way interaction ($P < 0.01$) between hour and BRD incidence for rumen pH, where RCASE had numerically reduced rumen pH compared to RCON between 1600 and 2100 h ($P < 0.10$; Fig. 10). Following morning feed delivery, the rumen pH in RCON declined to a greater extent than RCASE likely due to decreased feed intake by RCASE caused by the anorectic behavior induced by inflammation (Plata-Salamán et al., 1988). Decreased feed intake likely limited VFA production resulting in greater rumen pH in RCASE calves. Laarman et al. (2012) used rumen pH boluses in young Holstein bulls and found that hourly pH decreased rapidly following feed delivery,

then increased gradually through the remainder of the day, which agrees with observations in the present data set. A limitation of the BRD effects noted is that calves were classified as RCASE after a single treatment for BRD. Throughout the 56-d trial, RCASE were likely experiencing infectious challenge for only a portion of the time and overall health status improved as the study progressed.

There was also a BRD × day interaction ($P < 0.01$; Fig. 11) for daily rumen temperature, such that RCASE had greater rumen temperatures than RCON except for the 12 d following MLV respiratory vaccination on d 28. There was also a BRD treatment × hour ($P < 0.01$; Fig. 12) interaction for rumen temperature. There was no difference in rumen temperature between RCON and RCASE from 0300 through 0800 h ($P \geq 0.06$), but for all other time intervals RCASE had greater ($P \leq 0.05$) rumen temperature than RCON. Increased rumen temperature in RCASE was probably due to increased inflammation in response to infectious agents involved in BRD. After MLV vaccination (on d 28), RCON rumen temperature increased from the inflammatory response, while RCASE already had increased rumen temperature on d 28 that did not increase further. Timsit et al. (2011) used rumen temperature boluses to diagnose BRD in 24 bull calves for 40 d after feedlot arrival. If a bull had a ruminal hyperthermia episode for greater than 6 h they were visually examined for clinical BRD signs then chute restrained to measure rectal temperature and evaluate lung auscultation. There was confirmed BRD diagnosis in 38 out of 52 suspected cases featuring rumen hypothermia episodes, resulting in a positive predictive value of 73%. These findings support our observation of increased rumen temperature in RCASE.

CONCLUSIONS

There was an initial post-arrival peak in rumen temperature 2 d earlier in calves administered oral hydration therapy, suggesting an earlier and more stimulated immune response. The biological mechanism for this outcome is not yet known, but may be influenced by improved hydration and energy balance in H2O. The incidence of clinical BRD in this subset population resulted in decreased activity, less time spent ruminating, and increased rumen temperature. Changes in these variables could be used to assist with BRD diagnosis in the future. At arrival, high-risk auction-sourced feeder calves had elevated rumen pH, which decreased for 7 d, before equilibrating and increasing gradually through the remaining 56 d. Alternatively, time spent ruminating was minimal initially, but increased with increasing DMI through d 28. These data identify potential variables for BRD diagnosis, and quantify rumination behavior during the receiving period for high-risk feeder calves.

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Table 3.1. Diet composition

Ingredient, % of DM	
Steam flaked corn	13.9
Sweet Bran[1]	56.4
Corn stalks	19.1
Molasses	7.3
Supplement[2]	3.3
Nutrient composition[3]	
DM, %	66.5
CP, DM%	16.6
TDN, DM%	74.0
NEm, Mcal/kg DM	1.76
NEg, Mcal/kg DM	1.14

[1]Wet corn gluten feed

[2]Supplement = 68.94% $CaCo_3$, 19.15% NaCl, 5.25% KCl,2.66% MgO, 2.00% Lecithin, 0.57% $ZnSO_4$, 0.30%Vitamin A, 0.27% Na_2Se0_3, 0.12%, Vitamin E, 0.11% CuSO4, 34 g/909.1 kg Rumensin-90

[3]Proximate analysis at a commercial laboratory (Servi-tech Laboratories, Amarillo, TX)

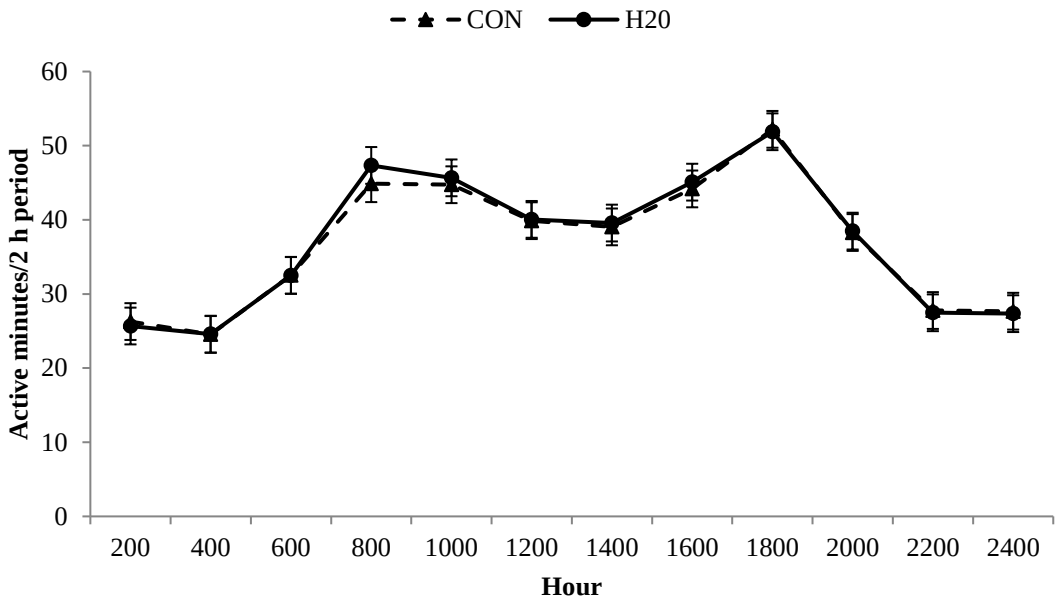

Figure 3.1. Hourly activity for calves administered oral hydration therapy with water (H2O) at feedlot arrival and negative control (CON). Active minutes was generated from an accelerometer collar (Allflex Livestock Intelligence, Madison, WI) with 2 h data logging intervals averaged by experimental treatment across the 56-d following feedlot arrival. Effect of treatment, $P = 0.82$; hour, $P < 0.01$; and treatment x hour, $P < 0.01$. *H2O differs from CON within hour ($P < 0.05$).

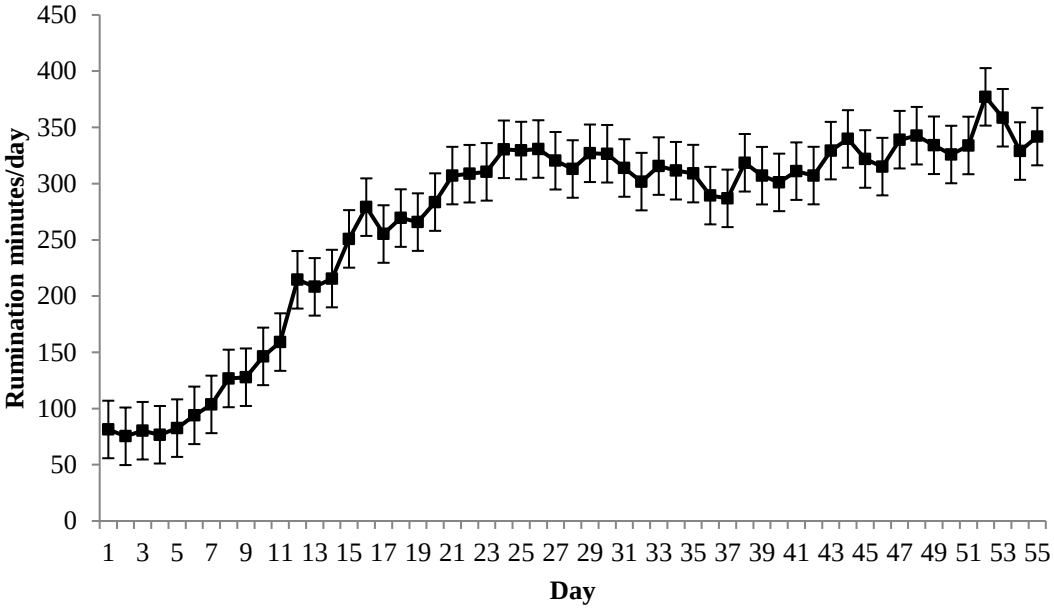

Figure 3.2. Daily rumination minutes in high-risk feeder calves during the 1st 56-d following feedlot arrival. Rumination time was determined using an accelerometer collar (Allflex Livestock Intelligence, Madison, WI) with daily means averaged from 2 h data logging periods. Effect of BRD, $P = 0.81$; day, $P < 0.01$; and BRD x day, $P = 0.30$.

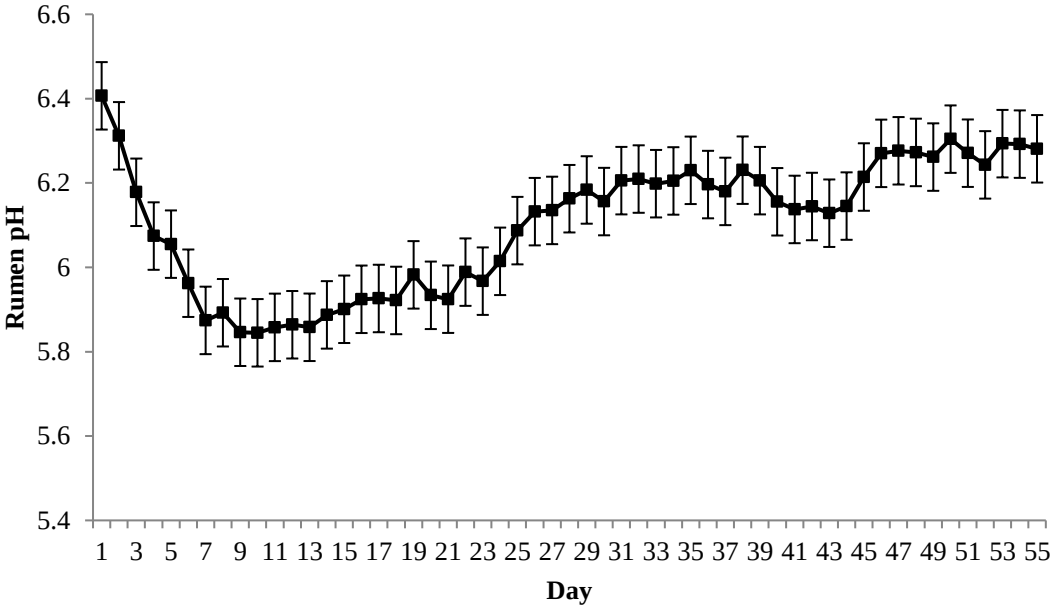

Figure 3.3. Daily rumen pH for high-risk feeder calves during the 56-d feedlot receiving period. Rumen pH was determined from a data logging bolus (Well Cow Limited, Roslin, UK), where daily pH was averaged from data logged every 15 min. Effect of BRD, $P = 0.51$; day, $P < 0.01$; and BRD x day, $P = 0.23$.

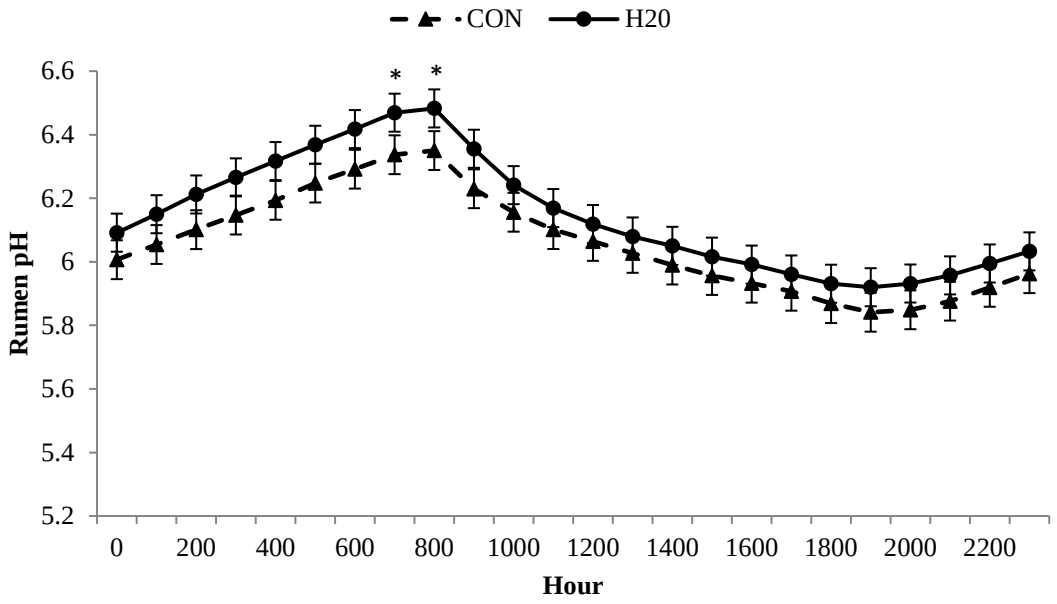

Figure 3.4. Hourly rumen pH differs between calves administered oral hydration therapy (H2O) at feedlot arrival and negative control (CON). Rumen pH was determined from a data logging bolus (Well Cow Limited, Roslin, UK) with hourly means generated by experimental treatment averaged across the 56-d following feedlot arrival from data logged every 15 min. Effect of treatment, $P = 0.18$; hour, $P < 0.01$; and treatment x hour, $P < 0.01$. *H2O differs from CON within hour ($P < 0.05$).

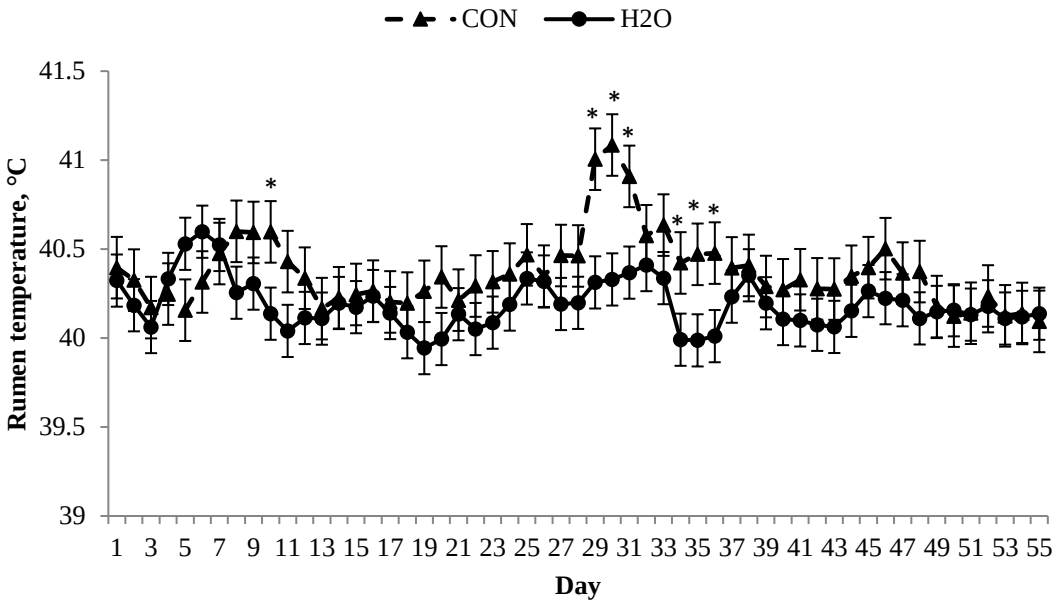

Figure 3.5. Daily rumen temperature differs between calves administered oral hydration therapy (H2O) at feedlot arrival and negative control (CON). Rumen temperature was determined from a data logging bolus (Well Cow Limited, Roslin, UK) with daily means averaged by experimental treatment from data logged every 15 min. Effect of treatment, $P = 0.18$; day, $P < 0.01$; and treatment x day, $P = 0.04$. *H2O differs from CON within day ($P < 0.05$).

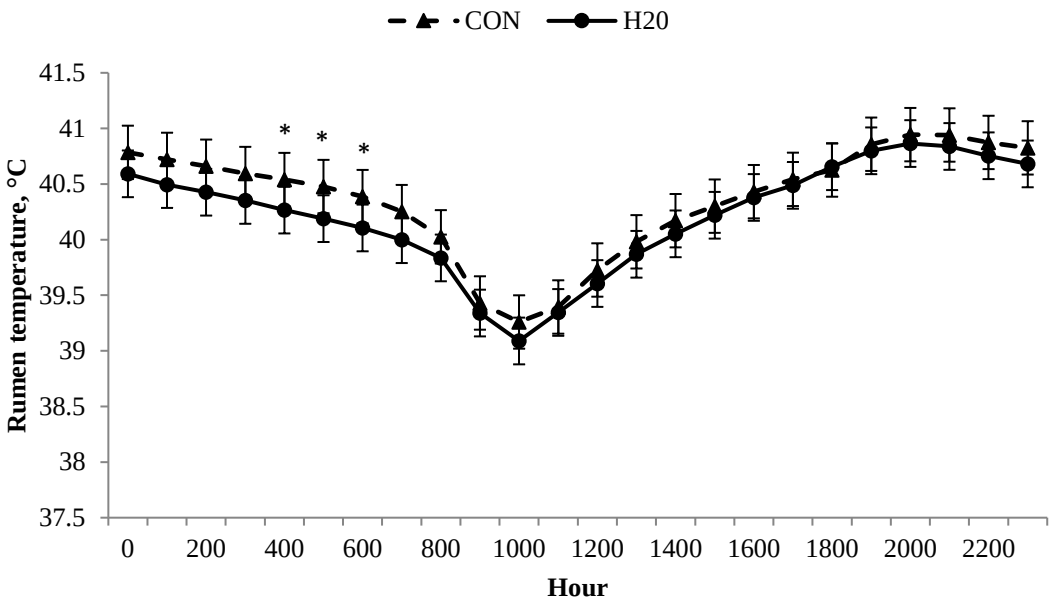

Figure 3.6. Hourly rumen temperature differs between calves administered oral hydration therapy (H2O) at feedlot arrival and negative control (CON). Rumen temperature was determined from a data logging bolus (Well Cow Limited, Roslin, UK) with hourly means generated by experimental treatment across the 56-d following feedlot arrival from data logged every 15 min. Effect of treatment, $P = 0.29$; hour, $P < 0.01$; and treatment x hour, $P < 0.01$. *H2O differs from CON within hour ($P < 0.05$).

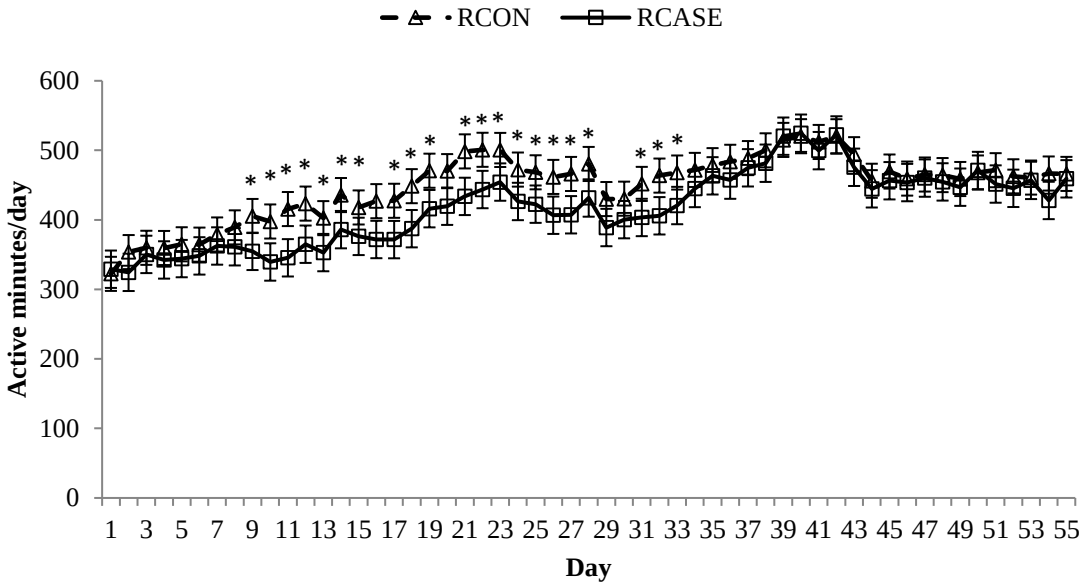

Figure 3.7. Daily activity differs between calves diagnosed and treated at least once for BRD (RCASE) and those never treated (RCON). Active minutes was generated from an accelerometer collar (Allflex Livestock Intelligence, Madison, WI) with daily means averaged by BRD status from 2 h data logging periods. Effect of BRD, $P = 0.02$; day, $P < 0.01$; and BRD x day, $P < 0.01$. *RCASE differs from RCON within day ($P < 0.05$).

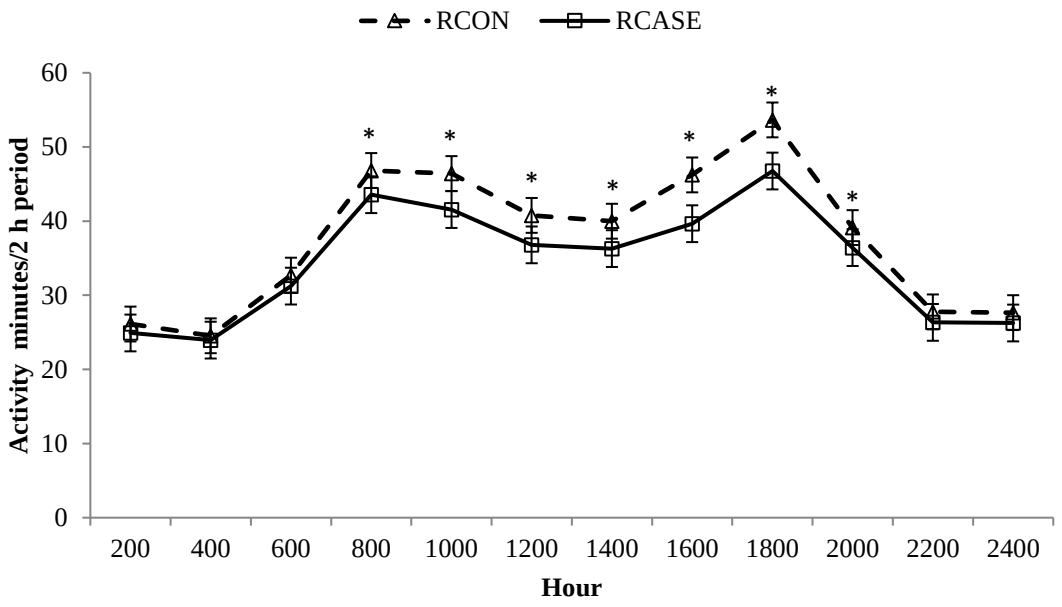

Figure 3.8. Hourly activity differs between calves diagnosed and treated at least once for BRD (RCASE) and those never treated (RCON). Active minutes was generated from an accelerometer collar (Allflex Livestock Intelligence, Madison, WI) with 2 h data logging intervals averaged by BRD status across the 56-d following feedlot arrival. Effect of BRD, $P = 0.71$; hour, $P < 0.01$; and BRD x hour, $P = 0.04$. *RCASE differs from RCON within hour ($P < 0.05$).

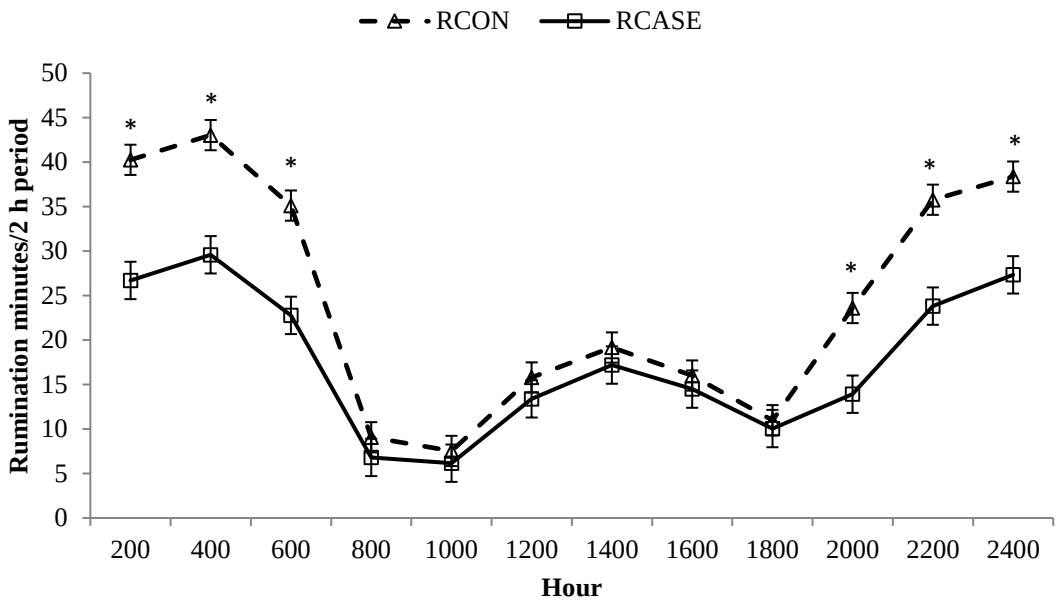

Figure 3.9. Minutes spent ruminating every 2 h differs between calves diagnosed and treated at least once for BRD (RCASE) and those never treated (RCON). Rumination time was determined using an accelerometer collar (Allflex Livestock Intelligence, Madison, WI) with 2 h data logging intervals averaged by BRD status across the 56-d following feedlot arrival. Effect of BRD, $P < 0.01$; hour, $P < 0.01$; and BRD x hour, $P < 0.01$. *RCASE differs from RCON within hour ($P < 0.05$).

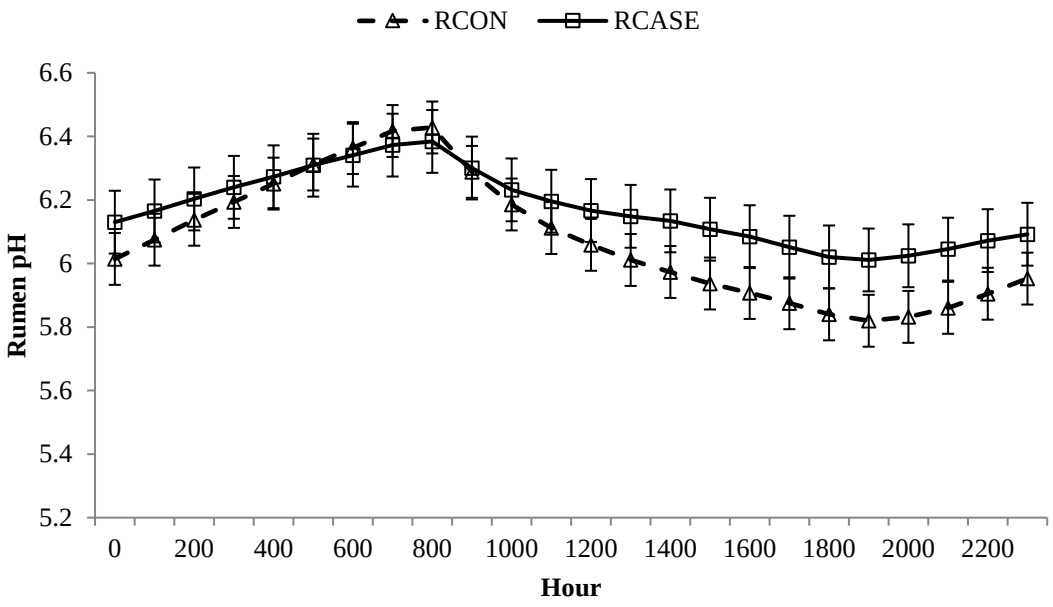

Figure 3.10. Hourly rumen pH for calves diagnosed and treated at least once for BRD (RCASE) and those never treated (RCON). Rumen pH was determined from a data logging bolus (Well Cow Limited, Roslin, UK) with hourly means generated by BRD status averaged across the 56-d following feedlot arrival from data logged every 15 min. Effect of BRD, $P = 0.36$; hour, $P < 0.01$; and BRD x hour, $P < 0.01$. *RCASE differs from RCON within hour ($P < 0.05$).

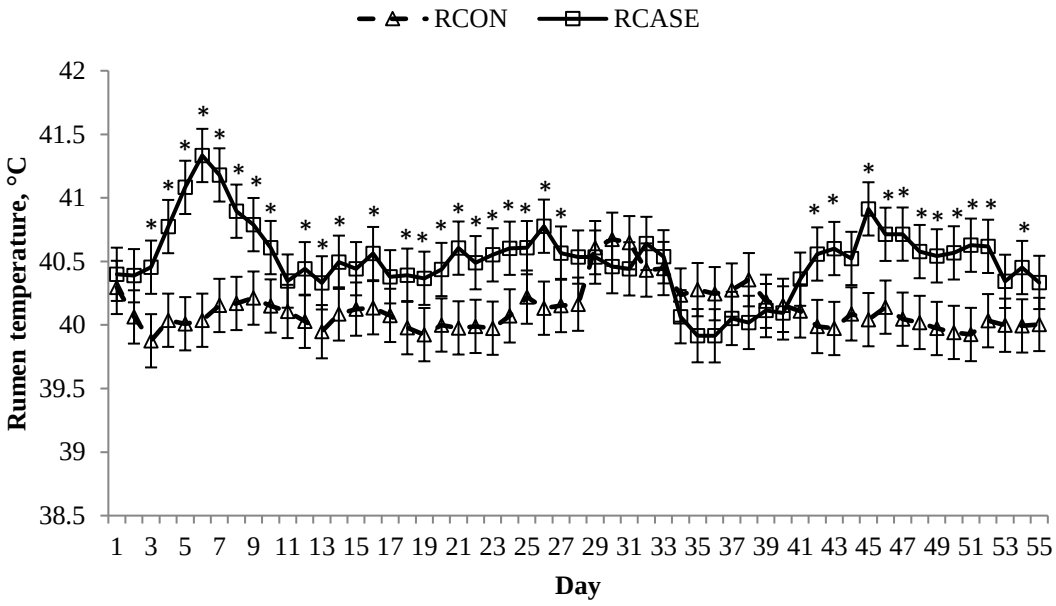

Figure 3.11. Daily rumen temperature differs between calves diagnosed and treated at least once for BRD (RCASE) and those never treated (RCON). Rumen temperature was determined from a data logging bolus (Well Cow Limited, Roslin, UK) with daily means averaged by BRD status from data logged every 15 min. Effect of BRD, $P < 0.01$; day, $P < 0.01$; and BRD x day, $P < 0.01$. *RCASE differs from RCON within day ($P < 0.05$).

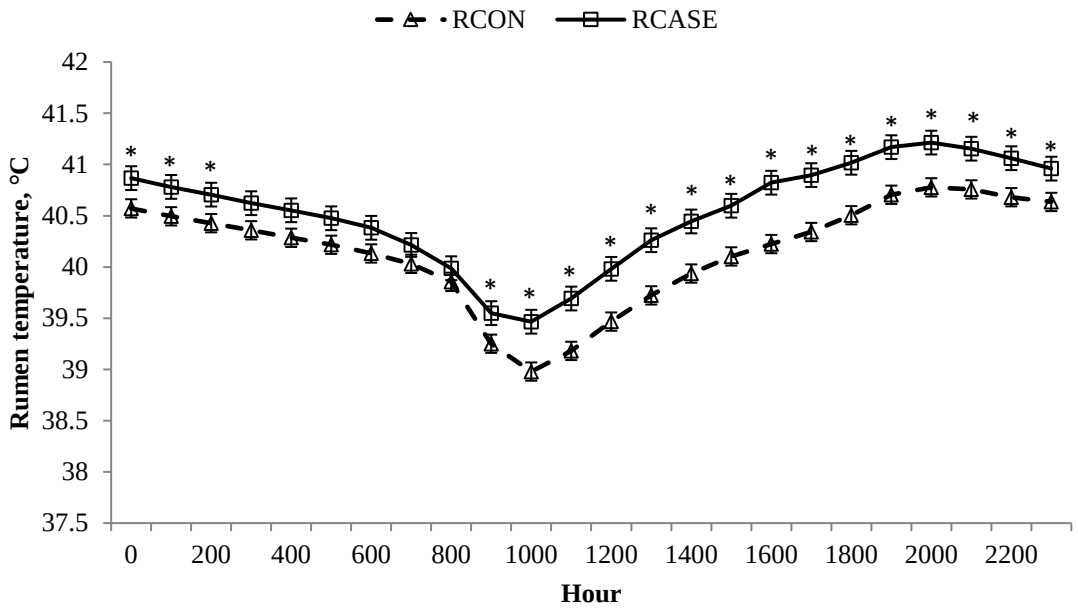

Figure 3.12. Hourly rumen temperature differs between calves diagnosed and treated at least once for BRD (RCASE) and those never treated (RCON). Rumen temperature was determined from a data logging bolus (Well Cow Limited, Roslin, UK) with hourly means generated by BRD status across the 56-d following feedlot arrival from data logged every 15 min. Effect of BRD, $P < 0.01$; hour, $P < 0.01$; and BRD x hour, $P < 0.01$. *RCASE differs from RCON within hour ($P < 0.05$).

Chapter IV: Performance, rumination, and rumen pH responses to different dietary energy density and feed management strategies in auction derived feedlot cattle

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ABSTRACT

Auction derived steers (n = 36; BW 284 ± 11 kg) were received to compare performance, rumination characteristics, and rumen pH differences due to alternative ration energy densities and feed management strategies during a 56 d receiving study. Cattle were weighed on day -1 and randomized to 1 of 3 treatments. Time spent ruminating was quantified with a 3-axis accelerometer ear tag. Rumen pH and temperature was logged in a random subset (n = 6 per treatment) by a ruminal bolus. Cattle were processed identically and were housed in individual pens. The modified-live virus respiratory vaccination was delayed until day 28. The **FIN** cattle were provided their daily feed as a high energy density (1.39 Mcal NEg/kg) diet. The **FIN+H** cattle were provided the same diet, but were also offered 0.5% BW DM as coastal Bermuda hay on days 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28. The **CON** cattle were fed a low energy density (0.93 Mcal NEg/kg) diet from day 0 to 7, then transitioned to the FIN diet by replacing an additional 25% of the daily feed call with FIN every 7 d until 100% of the diet was FIN on day 29. Feed calls for CON were increased more aggressively (0.45 kg DM daily for day 1 to 7, every other day for day 8 to 14) than FIN and FIN+H (0.45 kg DM every other day for day 1 to 7, daily for day 8 to 14). Performance and DMI were analyzed using PROC MIXED in SAS with treatment as a fixed effect. Rumination, pH, and temperature models included repeated measures. There was no treatment difference observed for BW, ADG, or G:F ($P \geq 0.12$). There was a treatment × day interaction ($P = 0.06$) for rumen temperature, where FIN increased more rapidly following vaccination on day 28 compared to CON ($P \leq$

0.04). Daily rumination minutes were greater ($P < 0.01$) for CON than FIN from day 7 to 22. Additionally, CON had the greatest ($P < 0.01$) hourly rumination from 2000 to 0800 h. Lower minimum daily rumen pH occurred in FIN+H ($P \leq 0.06$) on weeks 1, 2 and 6 to 8 compared to CON. There were minimal statistical differences in area under the curve or time below pH thresholds likely due to large animal to animal variation. Hourly rumen pH was reduced ($P \leq 0.05$) for FIN vs FIN+H and CON during the initial 28 d, but greater ($P = 0.05$) for FIN and FIN+H during the final 28 d. When cattle are individually fed, greater energy density rations can be fed initially without compromising performance, but this needs to be evaluated at the pen level where greater DMI variation is probable.

KEY WORDS: energy density, rumen pH, rumen temperature, rumination

INTRODUCTION

Feed intake in auction derived feeder calves is low during the initial 14 days after feedlot arrival. Hutcheson and Cole (1986) reported DMI to be 1.5% of BW during this time and the updated Nutrient Requirements of Beef Cattle (National Academies of Sciences, 2016) publication correspondingly recommends increasing nutrient density of starter diets to meet nutrient requirements after feedlot arrival. Improved receiving period performance has been reported with increased dietary energy density (Lofgreen et al., 1975; Fluharty and Loerch, 1996). Using data from 6 trials, Rivera et al. (2005) evaluated the effect of dietary roughage inclusion level and concluded that decreased roughage inclusion (increased energy) improved ADG but increased bovine respiratory disease (BRD) morbidity rate.

Acidosis is a metabolic disease resulting from the accumulation of total organic acid and lactate in the rumen, which leads to a decrease in rumen pH and overtime compromised ruminal epithelium (Owens et al., 1998; Steele et al., 2011). Typically, greater roughage inclusion in feedlot starter diets is used to mitigate metabolic disorders such as acidosis during transition to a high concentrate, energy dense finishing diet (Richeson et al., 2019). An additional challenge is many of the diagnostic signs for BRD and acidosis are analogous, which increases the probability of misdiagnosis of either disease.

We hypothesize increased BRD morbidity for cattle fed a high concentrate starter diet is confounded by ruminal acidosis. Limit feeding an energy dense ration may support improved performance while reducing morbidity risk. The objective of the present study was to compare nutritional management strategies during the receiving period and quantify their effects on rumination characteristics, rumen pH, DMI, and performance. We hypothesize newly received cattle will self-limit their feed intake of a high energy density diet upon entry to the feedlot due to stress and anorexia. Although the high energy diet may increase acute acidosis risk during the receiving period, the cattle will consume more energy to support basal immune and metabolic functions and growth more rapidly than a traditional high roughage, low energy starter diet. Whereas, increased roughage levels in the starter diet will allow for increased DMI and rumination time and improved buffering capacity of the rumen.

MATERIALS AND METHODS

All animal procedures associated with this study were approved by the West Texas A&M University Institutional Animal Care and Use Committee (#01-09-18). On

October 8, 2018, 36 auction derived crossbred beef steers (BW = 284 ± 11 kg) arrived at the Texas A&M AgriLife Research Feedlot in Bushland, TX. The following morning (day -1), steers were tagged in the ear with a unique visual identification number, administered clostridial vaccine (Ultrachoice 8, Zoetis, Kalamazoo, MI), Mannheimia haemolytica leukotoxoid (Presponse SQ, Boehringer Ingelheim Vetmedica, St. Joseph, MO), anthelmintic (Dectomax, Zoetis) and a growth promoting implant (Revalor-IS, Merck Animal Health, Kenilworth, NJ). Steer BW was also recorded and used to stratify calves into 3 groups. Experimental treatment was randomly assigned to a group. Steers were allowed *ad libitum* access to coastal Bermuda hay and water overnight. The following morning (day 0), cattle were weighed again and affixed with an ear tag containing a 3-axis accelerometer (Allflex Livestock Intelligence, Madison, WI) to continuously record activity and rumination minutes. A sub-set (n = 6 per treatment group) were administered a data logging bolus (Well Cow Limited, Roslin, UK) in the rumen that recorded pH and temperature every 15 min. Following day 0 processing, steers were penned individually (2.1 m × 17.1 m). Neighboring pens shared a fence line water tank (379 L), which was filled every other day. During the 1st 3 d, 9 steers were administered antimicrobial treatment (Draxxin, Zoetis) based on the presence of clinical illness signs (depression, nasal discharge, ocular discharge). An interim BW was recorded on a day 28 concurrent with initial modified-live virus respiratory vaccine (Bovi-Shield Gold 5, Zoetis). Initial (days -1 and 0) and final (55 and 56) BW were the average of BW recorded on 2 consecutive days

The nutritional management strategy differed and was part of the experimental treatments evaluated in this study. All cattle were initially offered 1% of initial BW as

their treatment diet on a DM basis. The **CON** cattle were fed a high roughage, low energy density starter diet (Table 1) for the initial 7 d before being transitioned to a greater energy density, lower roughage finisher diet over 21 d by replacing 25% of the daily feed call every 7 d. The **FIN** cattle were offered the finisher diet starting on day 0 and remained on the same diet until the end of the study, and **FIN+H** were fed identical to FIN, except long-stem hay was offered at 0.5% initial BW DM-basis on days 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28. Starting on day 29, all cattle were delivered their entire feed call as the finisher diet. Bunk management differed, such that feed offered for CON was increased by 0.45 kg DM if no residual feed remained at the morning (0600 h) bunk reading from day 1 to 7. From day 8 to 14, the amount of feed offered to CON was increased 0.45 kg DM after 2 consecutive days of no residual feed. For FIN and FIN+H treatments, feed offered was increased 0.45 kg DM after 2 consecutive days of no residual feed at morning bunk reading from day 1 to 7. Starting on day 8 for FIN and FIN+H, and day 15 for CON, feed offering was increased 0.45 kg DM daily if no residual feed remained at morning bunk reading through day 28. Starting on day 29, feed calls were increased 0.45 kg DM after 2 consecutive days of no residual feed for all treatments. Feed was delivered twice daily (0900 and 1300 h) with the amount of feed being divided evenly between the primary and secondary feeding. During the dietary transition for CON, half of the daily feed amount for each ration was provided during each feeding time. Residual feed was weighed back daily, and sub samples were collected for DM analysis. For FIN+H, hay was only weighed back prior to delivery of next hay offering.

Data Collection and statistical analysis

The 3-axis accelerometer ear tag continuously logged time spent ruminating in 2 h increments starting at midnight (0000 h). Hourly rumination reflects the amount of time spent ruminating in each 2 h time block averaged across the initial 28 d of the 56-d receiving period. Daily rumination was calculated by multiplying the average of the 2 h time blocks within a day by 12. The ruminal pH boluses recorded a single pH and temperature measurement every 15 min throughout the 56-d receiving period. This data was rounded to the nearest 15 min interval and then averaged by hour using a software program (Microsoft Excel 2010, Microsoft, Redmond, WA). Hourly and daily pH were calculated using the same method as rumination except hourly pH was averaged within day. When rumen pH was less than the designated thresholds (pH = 5.2 or 5.6), cattle were assumed to be below the threshold for the entire 15 min period. Time below pH thresholds was calculated by summing the total minutes comprised of 15 min intervals indicated below the threshold within day. Area under the curve (AUC) was calculated by multiplying the absolute difference in pH below 5.6 or 5.2 by 15, then the average hourly AUC within day was multiplied by 24 to get daily means. Weekly values are reported as the average time below, or AUC across days within week for each pH threshold.

Interim period performance outcomes (DMI, ADG, G:F) were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Inst Inc., Cary, NC) with treatment as the fixed effect and animal as the experimental unit. The models for daily DMI, rumination time and rumen pH included fixed effects of treatment, time, and treatment × time interaction with repeated measures using animal as the subject. Each model tested the covariance structures compound symmetry, autoregressive,

autoregressive heterogeneous, and ante-dependence. The covariance structure with the smallest Akaike information criterion value was then used for the corresponding dependent variable. When fixed effects were significant ($P \leq 0.05$), means were separated using the Pdiff option in SAS. Tendencies are noted where $P < 0.10$.

RESULTS AND DISCUSSION

Performance

There was no difference in BW, ADG, or G:F ($P \geq 0.56$; Table 2). There was a treatment × day interaction for daily DMI ($P < 0.01$; Fig. 1). Daily DMI for CON increased more rapidly than FIN and was greater ($P \leq 0.04$) from day 19 to 24 and on days 29 and 30, but did not differ ($P \geq 0.06$) after day 35. The FIN+H cattle consumed less ($P \leq 0.04$) than CON on the days that hay was not fed; however, on days hay was fed the DMI for FIN+H was not different ($P \geq 0.20$) from CON except days 1 and 4 ($P \leq 0.01$). There were no differences in daily DMI between treatments from day 36 through the end of the study ($P \geq 0.06$) except day 53 where CON was greater ($P = 0.01$) than FIN+H. Cattle were weighed on days 55 and 56 which likely contributed to the reduced intake on those days. The more rapid increase in DMI observed for CON was influenced by the difference in feed management protocol; however, the lack of difference in DMI beginning on day 36 suggests cattle may be program fed a diet with greater energy density upon feedlot arrival without compromising subsequent feed intake during the latter part of the receiving period. Fluharty and Loerch (1996) reported a linear increase in ADG and G:F with increasing energy density when cattle had ad libitum access to diets containing 70, 75, 80, or 85% concentrate on a DM basis. Research published by Lofgreen et al. (1975) suggests improved performance with diets containing greater

energy densities up to 1.10 Mcal NEg/kg. The dietary CP content was not included in this manuscript, but may become a limiting factor for growth when energy content increases beyond 1.10 Mcal NEg/kg. A met-analysis conducted by Rivera et al. (2005) determined improved DMI and ADG with greater dietary energy densities during the receiving period. However, in these publications the protocol for increasing feed offered did not differ between dietary ration energy densities. For the present study feed management strategy varied between treatment, such that the DMI for FIN and FIN+H was potentially limited to a greater extent than CON relative to *ad libitum* DMI. The current data suggest greater energy ration densities can be fed to newly received cattle, and when managed appropriately do not compromise DMI during the latter part of a 56-d receiving period compared to more traditional lower energy density diet. Steers were individually fed in the current study, so results should not be extrapolated to group fed cattle where there is potential for greater animal to animal variation in DMI. By individually feeding steers, their intakes were controlled by the amount delivered. In a group housing scenario, sufficient feed is delivered for all animals in the pen so a more aggressive eater may consume significantly more than the average, while a less aggressive animal would be consuming less than the average amount of feed delivered on a per animal basis. Further research on feeding behavior dynamics in a group housed setting is warranted to better understand the incidence of metabolic upsets when high energy density rations are offered at feedlot arrival.

Rumination

There was a treatment × day interaction ($P < 0.01$; Fig. 2) for daily rumination minutes during the initial 28 d period. The CON cattle had greater ($P \leq 0.05$) rumination

minutes than FIN from day 7 to 22. Additionally, CON had greater ($P \leq 0.04$) daily rumination minutes than FIN+H on days 3, 7, 9, 11, 12, 13, 14, 15, 19, 20, and 21. There was also a treatment × hour interaction ($P < 0.01$; Fig. 3), such that CON had greater ($P \leq 0.03$) rumination minutes than FIN and FIN+H from 2000 to 0600 h across the initial 28 d period. Greater rumination time in CON is consistent with the findings of Weiss et al. (2017), who reported increased rumination minutes in diets with greater forage inclusion rates or larger particle size. As hypothesized in the present study, the starter diet had greater forage inclusion, and the increase in hourly and daily rumination minutes observed for CON during the initial 28 d was probably an artifact of the difference in the amount of roughage consumed. When rumination time was expressed as rumination minutes per kg of DMI (Fig. 4), there was a treatment × day interaction ($P < 0.01$), where CON was greater ($P < 0.01$) than FIN+H on days 4, 7, and 12. There was also greater ($P < 0.04$) rumination minutes per kg DMI for CON compared to FIN on days 2, 4, 7, and 10 to 14. In agreement with our results, Gentry et al. (2016) reported greater rumination minutes per kg of DMI in cattle consuming diets with a greater rate of inclusion of chopped corn stalks.

Rumen pH

There was a treatment × hour interaction ($P < 0.01$; Fig. 5) during the initial 28 d for rumen pH, where FIN had a reduction ($P \leq 0.04$) in rumen pH vs. CON and FIN+H from 1500 to 2100 h. From 2200 to 0300 h, FIN had reduced ($P \leq 0.04$) pH compared to FIN+H with CON being intermediate. There was also a treatment × hour interaction ($P < 0.01$; Fig. 6) for rumen pH from day 29 to 56, where CON had a reduction ($P \leq 0.04$) in rumen pH compared to FIN and FIN+H from 0100 to 1000 h. Additionally, FIN+H had a

greater ($P \leq 0.05$) rumen pH than CON at 0000, 1900, 2100, and 2200 h and was greater ($P \leq 0.05$) than FIN at 1400, 1500, and 1600 h. Weiss et al. (2017) reported greater ruminal pH when diets included 10% corn stalks compared to 5%. Increased rumen pH for CON during the initial 28 d was likely driven by greater roughage inclusion in the starter diet. From day 29 to 56, reduced rumen pH in CON was probably driven by day 29 being the first time their entire daily feed delivery was offered as finisher, suggesting there is still a metabolic challenge even when cattle are transitioned more gradually to high energy density diets. The diurnal pattern of rumen pH observed in the current study is comparable to previously reported observations in cattle (Bevans et al., 2005; Laarman et al., 2012), where rumen pH decreases rapidly following feed consumption and then gradually recovers.

Daily average, minimum, and maximum pH by weekly periods are reported in Table 3. There was a lower minimum pH for FIN+H vs. CON during week 1 ($P = 0.05$) and 2 ($P = 0.06$). During week 5 CON had lower average ($P = 0.05$) and maximum ($P = 0.06$) pH than FIN. Additionally, FIN+H had a lower minimum pH compared to FIN during weeks 6 to 8. At the pH threshold 5.6, there was a greater ($P = 0.04$; Table 4) AUC for FIN compared to CON during week 3, and FIN tended ($P \leq 0.10$) to have a greater AUC during week 4 and time below pH 5.6 during week 3. There were no differences in AUC or time below pH 5.2 ($P \geq 0.13$). When subacute acidosis is defined as a pH below 5.6 for more than 12 h (Bevans et al., 2005), acidosis was not induced by any of the nutritional management strategies when treatment means are generated from individual animals. However, as Bevans et al. (2005) noted, there is large animal to animal variation in the ability to tolerate greater starch levels. Despite large animal to

animal variation, the numerical trends across weeks suggest increased AUC and time below pH 5.6 from CON to FIN+H to FIN during the initial 4 wk, but during weeks 6 to 8 this trend is reversed for AUC. During weeks 6 to 8, AUC for pH 5.2 was again numerically greater in CON vs FIN+H and FIN. This change in numerical trend, lower average and maximum pH during week 5, and lower hourly pH in CON through the evening during the last 28 d of the study suggest there is still an acidosis risk when more conservative receiving strategies are implemented, but the acidosis risk occurs later in the receiving period during dietary transition.

Rumen temperature

There was a treatment × day interaction ($P < 0.01$; Fig. 7) for rumen temperature, where FIN and FIN+H had greater rumen temperature than CON intermittently throughout the 56-d study. On days 29 and 30, immediately following modified-live virus respiratory vaccination on day 28, FIN had a greater rumen temperature than CON. This suggests a divergent febrile response influenced by diet following antigenic stimulation. Following a lipopolysaccharide challenge, Reuter et al. (2008) reported greater rectal temperatures in cattle fed 70% concentrate diets compared to 30% concentrate diets. Greater energy density may be associated with a greater febrile response to antigenic stimulation; however, the mechanisms that may influence this hypothesis requires further evaluation. It is possible that increased dietary energy allows a more robust inflammatory response following vaccination (Reuter et al., 2008; Schwertner et al., 2011).

During the initial 28 d there was not a treatment × hour interaction ($P = 0.24$), but there was a treatment effect ($P = 0.02$; Table 5). The FIN and FIN+H treatments had greater rumen temperature than CON during this time. Russell (1986) quantified

fermentation heat following a glucose load in a continuous culture model. When cultures were pulsed with glucose, there was a rapid increase in heat produced. Using an acidosis challenge model Wahrmund et al. (2012) reported an increase in rumen temperature when half the daily feed was replaced with cracked corn compared to a negative control where there was not change in feed delivery. Additionally, the greatest rumen temperatures coincided with ruminal fermentation of the feed. Greater rumen temperature in FIN and FIN+H compared to CON may be a result of the greater amount of starch in the finisher diet being more rapidly digested to glucose and fermented by rumen bacteria increasing heat produced similarly to the response reported by Russell (1986) and Wahrmund et al. (2012).

CONCLUSIONS

Feeding diets with energy concentration similar to finishing diets in commercial cattle production during the receiving period did not have negative consequences on cattle performance when cattle were housed individually, and may result in a greater febrile response to antigen exposure. Large variation in rumen pH relative to the same dietary energy density treatment further illustrates the inconsistency in acidosis risk between cattle fed and managed similarly. Additional research is needed to better understand the mechanisms that influence the inconsistent responses to diet adaptation in cattle. Furthermore, our data suggests there is acidosis potential for both a traditional receiving strategy that uses a high roughage, low energy density diet prior to transition to a diet with greater energy density or a non-traditional approach of starting cattle feeding with a low roughage, high energy density diet without subsequent dietary transition. Because intake is typically reduced for the first 2 wk following arrival to a feedlot, cattle

can be fed a high energy density diet at arrival when individually housed. However, use of high energy density diets at arrival needs to be evaluated in a pen feeding scenario where acidosis risk is greater due to the potential for increased DMI variation within individual animals.

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Table 4.1. Ingredient and nutrient composition of treatment diets.

	Diet		
Ingredient, % of DM	Starter	Finisher	Coastal Bermuda Hay
Corn stalks	14.15	6.40	-
Haygrazer	30.46	-	-
Steam flaked corn	13.90	63.58	-
Sweet Bran[1]	32.44	18.14	-
Corn oil	4.23	3.72	-
Molasses	-	3.10	-
Supplement[2]	3.48	3.37	-
Urea	0.82	1.26	-
Limestone	0.50	0.44	-
Nutrient composition[3]			
DM, %	76.91	79.29	90.00
CP, %	14.5	13.9	3.5
NDF, %	42.78	16.30	68.8
Fat, %	8.09	8.02	1.0
Ca, %	0.78	0.59	0.30
P, %	0.51	0.48	0.10
S, %	0.20	0.17	0.07
Na, %	0.27	0.20	0.01
ME, Mcal/kg[4]	2.47	3.02	1.39
NEm, Mcal/kg	1.54	2.05	0.59
NEg, Mcal/kg	0.93	1.39	0.11

[1]Wet corn gluten feed

[2]Supplement was formulated to meet or exceed vitamin and mineral requirements established by National Academies of Sciences, Engineering, and Medicine (2016). Supplement provided 290 mg/hd/d of monensin and 64 mg/hd/d of tylosin (Elanco Animal Health, Greenfield, IN)

[3]Calculated from individual ingredient analysis

[4]Energy values from BCNRM 2016 software

Table 4.2. Nutritional management strategy affects receiving period performance.

	Treatment[1]				
Item	CON	FIN+H	FIN	SEM	*P*-value
BW, kg					
Initial[2]	286.6	287.0	287.7	3.26	0.97
day 28	324.2	320.2	319.5	4.90	0.76
Final[2]	377.0	370.0	372.1	6.89	0.76
ADG, kg/day					
0 to 28	1.34	1.18	1.14	0.14	0.56
28 to 56	1.88	1.78	1.88	0.14	0.84
0 to 56	1.62	1.48	1.51	0.11	0.67
DMI, kg/day					
0 to 28	4.91	4.37	4.29	0.22	0.12
28 to 56	8.38	7.64	7.83	0.35	0.32
0 to 56	6.65	6.01	6.07	0.27	0.20
G:F					
0 to 28	0.263	0.269	0.258	0.0252	0.95
28 to 56	0.223	0.233	0.241	0.0134	0.65
0 to 56	0.239	0.245	0.247	0.0105	0.86

[1]CON-offered starter diet initially, then transitioned to finisher by replacing 25% of daily feed call with finisher every 7 d. FIN+H-offered finisher ration throughout study and 0.5% of BW as hay on day 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28. FIN-offered finisher ration throughout the study.
[2]Average of 2 d BW

Table 4.3. Nutritional management strategy affects daily average, maximum and minimum pH across week.

	Treatment[1]				
Item	CON	FIN+H	FIN	SEM	*P*-value
Week 1, pH[2]					
Average	5.89	5.35	5.55	0.17	0.11
Minimum	5.78[a]	5.23[b]	5.36[ab]	0.05	0.05
Maximum	6.58	6.82	6.39	0.26	0.51
Week 2, pH					
Average	5.99	5.65	5.61	0.13	0.10
Minimum	5.60[a]	5.16[b]	5.39[ab]	0.11	0.06
Maximum	6.46	6.41	6.42	0.16	0.97
Week 3, pH					
Average	5.99	6.07	5.97	0.23	0.95
Minimum	5.45	5.38	5.47	0.27	0.97
Maximum	6.52	6.74	6.62	0.18	0.69
Week 4, pH					
Average	5.73	5.74	5.64	0.13	0.82
Minimum	5.36	5.36	5.10	0.17	0.45
Maximum	6.32	6.67	6.49	0.15	0.21
Week 5, pH					
Average	5.65[a]	5.81[ab]	6.04[b]	0.10	0.05
Minimum	5.11	5.10	5.21	0.12	0.74
Maximum	6.42[a]	6.53[a]	6.84[b]	0.13	0.02
Week 6 to 8, pH					
Average	6.59	6.56	6.46	0.10	0.57
Minimum	5.51[ab]	5.34[a]	5.64[b]	0.09	0.06
Maximum	6.55	6.58	6.63	0.13	0.89

[1]CON-offered starter diet initially, then transitioned to finisher by replacing 25% of daily feed call with finisher every 7 d. FIN+H-offered finisher diet throughout study and 0.5% of BW as hay on d 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28. FIN-offered finisher diet throughout the study.

[2]represents d 2-7

[ab]Within a row, means without a common letter superscript differ ($P < 0.05$)

Table 4.4. Nutritional management strategy affects area under the curve (AUC) and time below pH 5.6 and 5.2.

	Treatment				
Item	CON	FIN+H	FIN	SEM	*P*-value
pH=5.6					
AUC, ΔpHxmin					
Week 1[2]	22.9	65.1	93.2	26.1	0.20
Week 2	29.3	32.4	75.6	26.4	0.41
Week 3	34.3[a]	106.2[ab]	216.8[b]	44.9	0.04
Week 4	30.2	83.3	144.1	35.2	0.10
Week 5	64.3	83.4	74.4	44.0	0.92
Week 6-8	129.9	47.1	11.3	74.8	0.47
Time below, min/d					
Week 1[2]	63.6	197.3	295.3	73.9	0.13
Week 2	185.8	410.1	511.2	128.4	0.23
Week 3	264.7[a]	415.7[ab]	644.5[b]	100.6	0.06
Week 4	438.4	451.8	623.0	122.9	0.49
Week 5	482.8	365.5	397.1	105.5	0.67
Week 6-8	152.5	145.1	127.8	58.8	0.95
pH=5.2					
AUC, ΔpHxmin					
Week 1[2]	0.5	7.8	8.1	3.6	0.27
Week 2	0.0	1.9	1.6	1.2	0.48
Week 3	0.1	0.0	10.7	6.4	0.30
Week 4	1.5	4.6	0.0	3.7	0.42
Week 5	8.0	9.4	3.0	5.4	0.66
Week 6-8	34.9	6.4	0.0	29.4	0.61
Time below, min/d					
Week 1[2]	4.9	133.9	83.3	42.5	0.14
Week 2	1.6	51.5	91.7	61.7	0.60
Week 3	0.9	67.7	229.7	76.2	0.13
Week 4	40.0	33.2	103.6	42.2	0.43
Week 5	63.3	79.9	33.0	45.5	0.75
Week 6-8	64.2	62.5	75.6	75.6	0.61

[1] CON-offered starter diet initially, then transitioned to finisher by replacing 25% of daily feed call with finisher every 7 d. FIN+H-offered finisher ration throughout study and 0.5% of BW as hay on d 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28. FIN-offered finisher ration throughout the study.

[2]represents d 2-7

[ab]Within a row, means without a common letter superscript differ ($P < 0.05$)

Table 4.5. Nutritional management strategy affects rumen temperature during the initial 28 d following feedlot arrival.

	Treatment[1]				
Item	CON	FIN+H	FIN	SEM	*P*-value
Temperature, ºC	39.4[a]	39.8[b]	39.9[b]	0.13	0.02

[1]CON-offered starter diet initially, then transitioned to finisher by replacing 25% of daily feed call with finisher every 7 d. FIN+H-offered finisher ration throughout study and 0.5% of BW as hay on d 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28. FIN-offered finisher ration throughout the study.

[2]represents d 2-7

[ab]Within a row, means without a common letter superscript differ ($P < 0.05$)

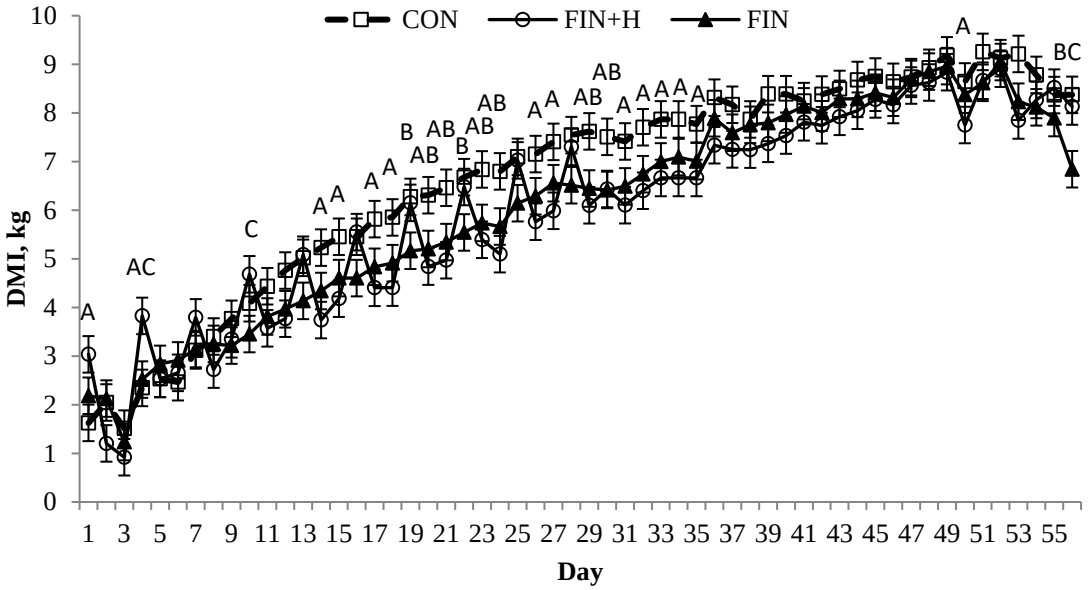

Figure 4.1. Nutritional management strategy affects daily DMI. The CON cattle were offered starter diet initially, then transitioned to finisher by replacing 25% of daily feed call with finisher every 7 d. The FIN+H cattle were offered finisher diet throughout study and 0.5% of BW as hay on day 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28. The FIN cattle were offered finisher diet throughout the study. Effect of treatment, $P < 0.01$; day, $P < 0.01$; and treatment x day, $P < 0.01$. [A]CON differs from FIN+H ($P < 0.05$) within day. [B]CON differs from FIN ($P < 0.05$) within day. [C]FIN+H differs from FIN ($P < 0.05$) within day.

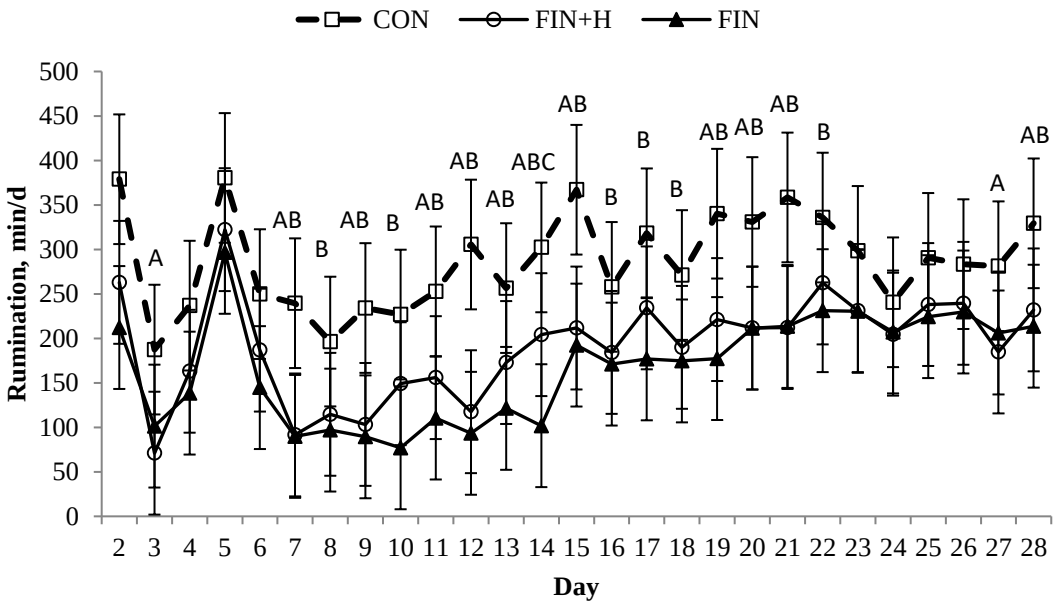

Figure 4.2. Nutritional management strategy affects hourly rumination minutes during the first 28 d after feedlot arrival. The CON cattle were offered starter diet initially, then transitioned to finisher by replacing 25% of daily feed call with finisher every 7 d. The FIN+H cattle were offered finisher diet throughout study and 0.5% of BW as hay on day 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28. The FIN cattle were offered finisher diet throughout the study. Effect of treatment, $P < 0.01$; day, $P < 0.01$; and treatment x day, $P < 0.01$. [A]CON differs from FIN+H ($P < 0.05$) within day. [B]CON differs from FIN ($P < 0.05$) within day. [C]FIN+H differs from FIN ($P < 0.05$) within day.

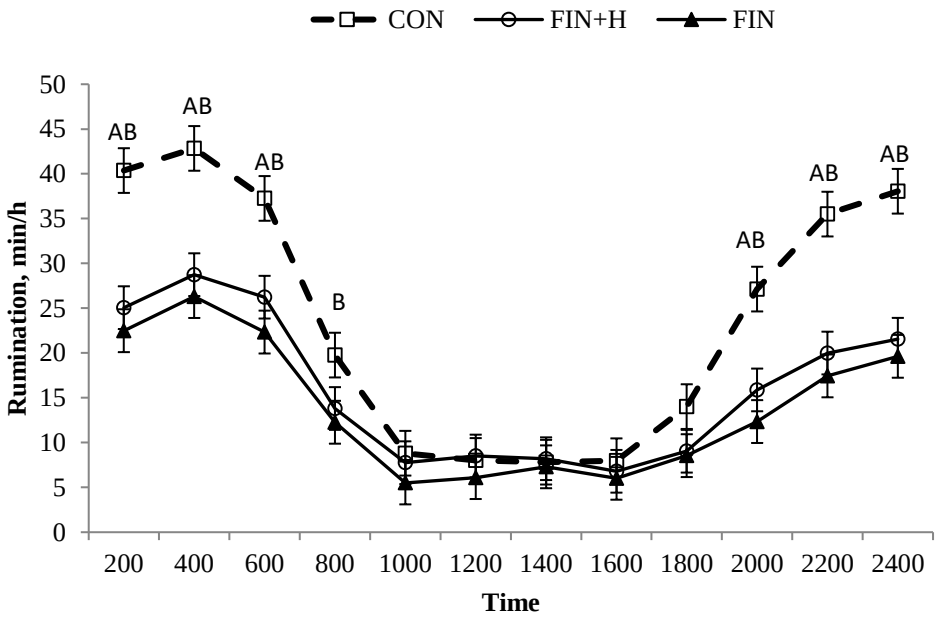

Figure 4.3. Nutritional management strategy affects hourly rumination minutes across the first 28 d after feedlot arrival. The CON cattle were offered starter diet initially, then transitioned to finisher by replacing 25% of daily feed call with finisher every 7 d. The FIN+H cattle were offered finisher diet throughout study and 0.5% of BW as hay on day 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28. The FIN cattle were offered finisher diet throughout the study. Effect of treatment, $P < 0.01$; day, $P < 0.01$; and treatment x day, $P < 0.01$. [A]CON differs from FIN+H ($P < 0.05$) within day. [B]CON differs from FIN ($P < 0.05$) within day. [C]FIN+H differs from FIN ($P < 0.05$) within day.

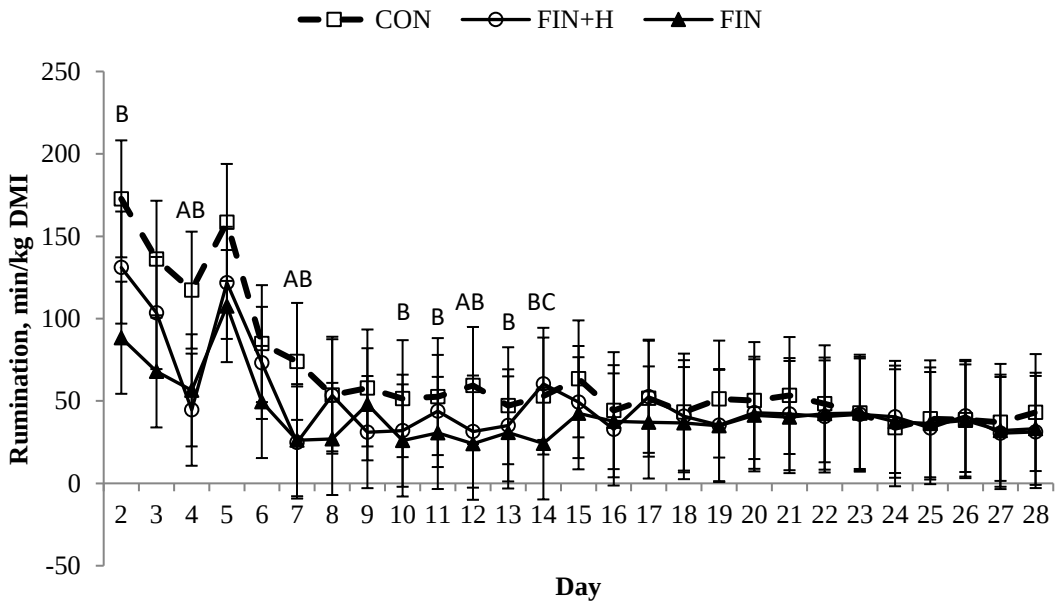

Figure 4.4. Nutritional management strategy affects rumination minutes per kg DMI during the 1st 28 d after feedlot arrival. The CON cattle were offered starter diet initially, then transitioned to finisher by replacing 25% of daily feed call with finisher every 7 d. The FIN+H cattle were offered finisher diet throughout study and 0.5% of BW as hay on day 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28. The FIN cattle were offered finisher diet throughout the study. Effect of treatment, $P < 0.01$; day, $P < 0.01$; and treatment x day, $P < 0.01$. [A]CON differs from FIN+H *(*$P < 0.05$) within day. [B]CON differs from FIN *(*$P < 0.05$) within day. [C]FIN+H differs from FIN *(*$P < 0.05$) within day.

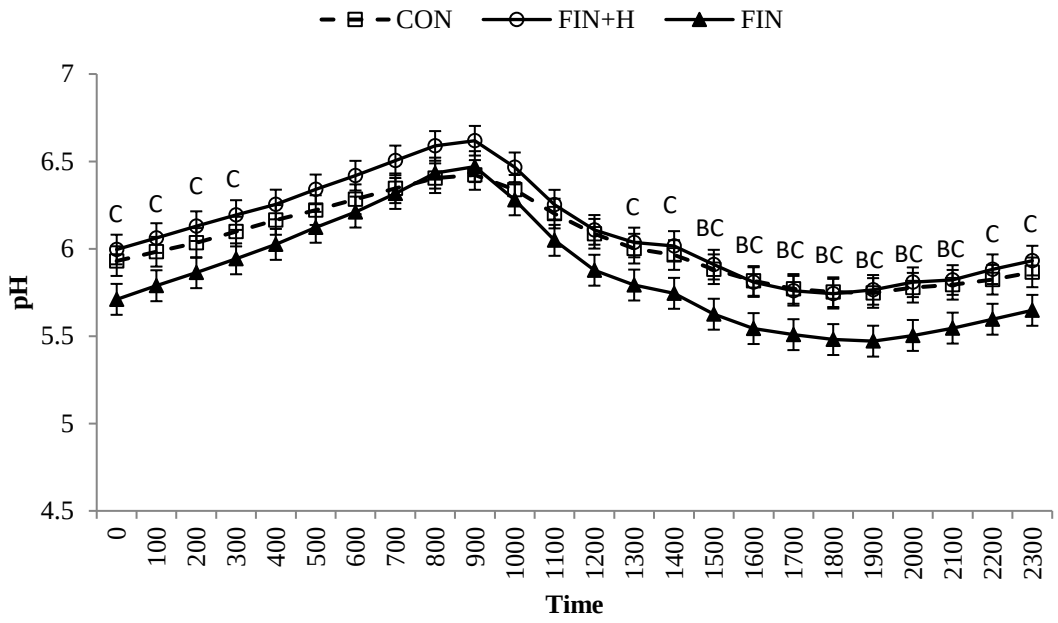

Figure 4.5. Nutritional management strategy affects average hourly pH across the first 28 d after feedlot arrival. The CON cattle were offered starter diet initially, then transitioned to finisher by replacing 25% of daily feed call with finisher every 7 d. The FIN+H cattle were offered finisher diet throughout study and 0.5% of BW as hay on day 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28. The FIN cattle were offered finisher diet throughout the study. Effect of treatment, $P = 0.16$; day, $P < 0.01$; and treatment x day, $P < 0.01$. [A]CON differs from FIN+H ($P < 0.05$) within day. [B]CON differs from FIN ($P < 0.05$) within day. [C]FIN+H differs from FIN ($P < 0.05$) within day.

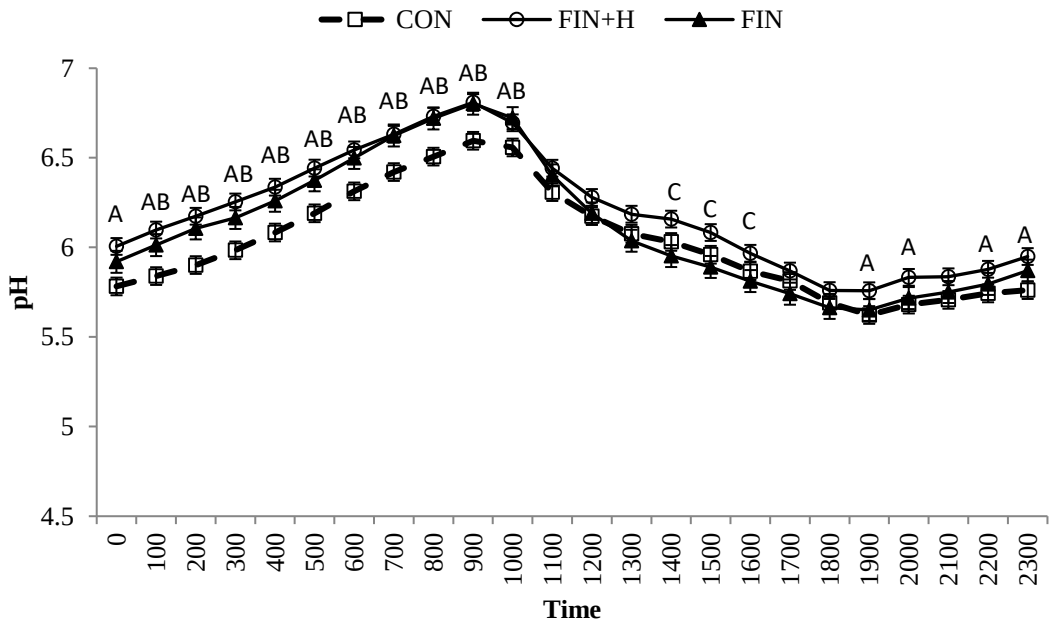

Figure 4.6. Nutritional management strategy affects average hourly pH across days 29 to 56 after feedlot arrival. The CON cattle were offered starter diet initially, then transitioned to finisher by replacing 25% of daily feed call with finisher every 7 d. The FIN+H cattle were offered finisher diet throughout study and 0.5% of BW as hay on day 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28. The FIN cattle were offered finisher diet throughout the study. Effect of treatment, $P = 0.06$; day, $P < 0.01$; and treatment x day, $P < 0.01$. ^{A}CON differs from FIN+H ($P < 0.05$) within day. ^{B}CON differs from FIN ($P < 0.05$) within day. ^{C}FIN+H differs from FIN ($P < 0.05$) within day.

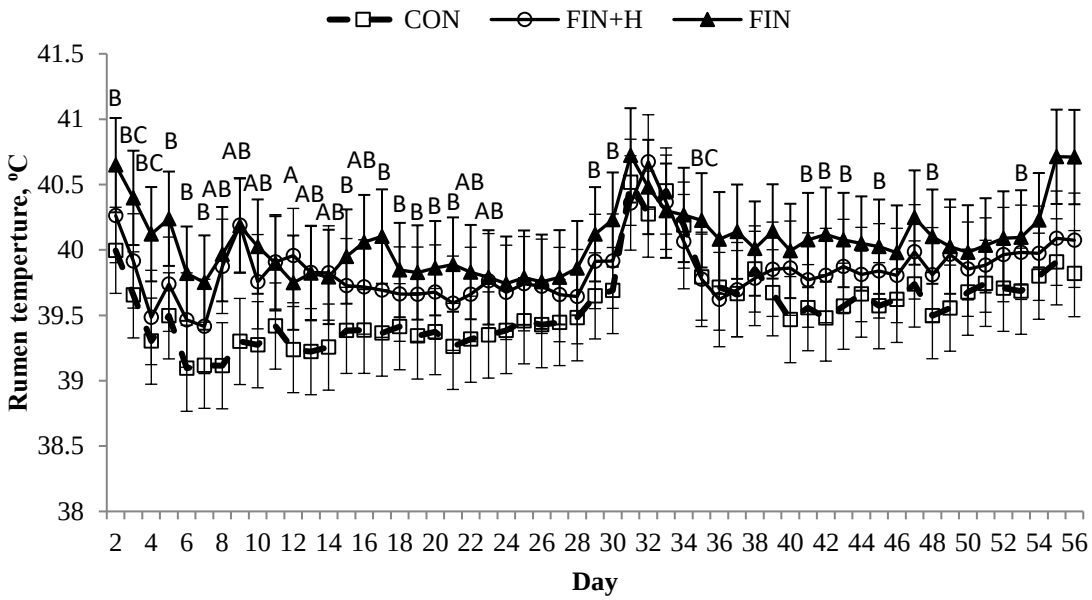

Figure 4.7. Nutritional management strategy affects daily average rumen temperature. The CON cattle were offered starter diet initially, then transitioned to finisher by replacing 25% of daily feed call with finisher every 7 d. The FIN+H cattle were offered finisher diet throughout study and 0.5% of BW as hay on day 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28. The FIN cattle were offered finisher diet throughout the study. Effect of treatment, $P < 0.01$; day, $P < 0.01$; and treatment x day, $P = 0.06$. ^{A}CON differs from FIN+H *(*$P < 0.05$) within day. ^{B}CON differs from FIN *(*$P < 0.05$) within day. ^{C}FIN+H differs from FIN *(*$P < 0.05$) within day.