NUTRITIONAL AND MANAGEMENT STRATEGIES TO IMPROVE PERFORMANCE, NUTRIENT DIGESTIBILITY, AND SUSTAINABILITY OF FEEDLOT CATTLE

by

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ABSTRACT

A series of studies were conducted to evaluate live animal performance, health, carcass characteristics, nutrient digestibility, ruminal characteristics, and environmental emissions of feedlot cattle. The first study explored the impacts of feeding an industry standard finishing diet throughout the receiving and finishing period compared to a high roughage receiving diet during the receiving period with subsequent adaptation to the finishing diet on health, performance, serum chemistry, ruminal pH, and rumination of high-risk feedlot cattle. Treatment diets were offered ad libitum and consisted of: 1) finishing diet for the entire feeding period (FIN) or 2) receiving diet for the first 56 d, followed by transition to the finishing diet (REC). All cattle were consuming the same diet on d 74. A subset of cattle were randomly selected to quantify ruminal pH, temperature, and rumination time. Ultrasound images were captured on d 0, 74, and 146 to determine fat thickness, and carcass characteristics were determined after slaughter. Cattle fed REC had greater ($P < 0.01$) dry matter intake (DMI) from d 0 to 74, but DMI did not differ ($P = 0.80$) from d 74 to the end of the finishing period (final). Metabolizable energy intake was not different from d 0 to 74 ($P = 0.20$), d 74 to final ($P = 0.80$), or overall ($P = 0.78$). At d 74 and final, body weight (BW) of FIN was 10 kg greater ($P \leq 0.10$) than REC. Cattle consuming FIN had greater ($P < 0.01$) average daily gain (ADG) and increased ($P < 0.01$) gain:feed (G:F) from d 0 to 74. Feed cost of gain (FCOG) was less for FIN from d 0 to 74 ($P < 0.01$), but not different from d 74 to final (P

= 0.89). There was no difference ($P \geq 0.31$) in health outcomes between treatments. On d 74, FIN had greater ($P = 0.04$) fat thickness over the rump and rib, but did not differ ($P \geq 0.41$) at d 146 or in the carcass. Carcasses of FIN had greater ($P = 0.04$) hot carcass weight (HCW), but no difference ($P \geq 0.12$) in ribeye area, yield grade, or quality grade. There was no difference ($P = 0.18$) in liver abscess rate between treatments. Ruminal pH was greater (diet × day interaction; $P < 0.01$) for FIN on d 2 and 61, and rumination time was less (diet × day interaction $P < 0.01$) for FIN from d 0 to 28. Because of increased G:F and decreased FCOG with no impact on health, providing a finishing diet to high-risk calves upon arrival may be a viable alternative to a traditional receiving diet.

The second study evaluated effects of feeding grain milling products (GMP) on nutrient digestion, passage rate, ruminal pH, and ruminal volatile fatty acid (VFA) and ammonia concentrations of ruminally fistulated beef cattle. Four Angus × Hereford steers were used in a 4 × 4 Latin square design. Each period consisted of 21 d of dietary adaptation, 5 d of total tract digestibility and passage rate, volatile fatty acid (VFA) and ammonia (NH_3), and ruminal pH collections, 3 d of in situ rumen digestibility, and 1 d for rumen evacuations. Diets were analyzed for physically effective neutral detergent fiber (peNDF) using the Penn State Particle Separator. Treatments were no GMP (CON), 20% wet distillers grains with solubles (WDGS20), 20% Sweet Bran (SB20), or a combination of 10% wet distillers grains with solubles and 20% Sweet Bran (COMBO). The proportion of dietary particles > 4.0 mm was greatest ($P < 0.01$) for CON, intermediate for SB20, and least for WDGS20 and COMBO, but peNDF did not differ ($P = 0.11$) among treatments. Total tract neutral detergent fiber (NDF) digestibility was greater ($P \leq 0.05$) for COMBO than CON, and acid detergent fiber (ADF) digestibility

was greater for WDGS20, SB20, and COMBO than CON. A diet × hour interaction ($P \leq 0.05$) was observed for molar proportions of propionate, butyrate, and valerate. Ruminal pH also had a diet × hour interaction ($P = 0.02$). There was a tendency ($P = 0.07$) for area under the curve (AUC) of 5.6 to be greater for SB20 and COMBO compared to CON. Before rumen evacuations, there was a tendency for DMI to be greater ($P = 0.06$) for GMP diets than cattle consuming CON. Although there was no difference ($P = 0.26$) in the DM quantity of rumen particulate, CON had the greatest ($P = 0.01$) amount of particulate relative to DM intake. Rumen evacuated samples from WDGS20 had a greater ($P \leq 0.05$) quantity of crude protein, NDF, ADF, and ether extract compared to SB20. Overall, inclusion of GMP in the diet improved total tract fiber digestion, altered VFA concentrations and nutrients within the rumen particulate, and tended to increase AUC.

In the final study, a model was developed to depict and compare feedlot diets and growth technologies used in 1990 vs. 2020 and their influence on cattle performance and carbon footprint was determined. Dietary changes from 1990 to 2020 included the adoption of GMP feeds while decreasing inclusion of corn and traditional roughage sources. In 1990, available growth technologies included estradiol implants and the ionophore monensin; whereas, in 2020 combination implants including both trenbolone acetate and estradiol, monensin, and ractopamine hydrochloride (in the final 28 to 42 d) were used. In both 1990 and 2020, use of available technologies increased final BW, ADG, G:F, and HCW compared to no technology. From 1990 to 2020 initial BW, final BW, ADG, G:F, and HCW, and DMI increased. Total days on feed (DOF) increased by 44 in 2020 compared to 1990. Use of growth technologies in both 1990 and 2020 decreased total greenhouse gas emissions per animal (CO_2e). Because cattle had greater

DOF in 2020 than 1990, all sources of greenhouse gas emissions per animal increased. However, because of greater total BW gain in 2020, when expressed as CO_2e/kg BW gain, greenhouse gas emissions decreased by 4.4% from 1990 to 2020. Feedlots in 2020 produced 47.5% more BW gain with 1.4% less cattle, while only increasing total CO_2e by 39.5%, indicating changes in technologies and diet formulations have improved efficiency and reduced the carbon footprint of feedlot cattle production in the past 30 yr.

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CHAPTER I

REVIEW OF LITERATURE

Introduction

The beef industry is an evolving system that continues to innovate and adapt based on market supply and demand. However, unlike other sectors of food animal production, the beef industry does not lend itself to a vertically integrated system. Currently, production of calves relies heavily on small-scale, family-owned operations with less than 100 animals. According to the National Agriculture Statistics Service (NASS, 2017) Census of Agriculture, the average cow herd is 43.5 animals, and herds with less than 100 animals account for 44.0% of the beef cow inventory. In addition, no change in the percentage of herds less than 100 animals has occurred since cow herd size reporting was initiated in 1982.

Because the beef cattle industry is segmented and distributed across the U.S., many calves sold will be transported long distances and comingled before entering the feedlot. The stress of the marketing process can have long-term health and financial implications. Therefore, weaning, preconditioning, and backgrounding programs which keep cattle on pasture or in dry lots before feedlot arrival can help decrease the incidence of disease when cattle enter the feedlot. However, it is not possible to use these programs in all situations, and as a result highly stressed cattle can frequently enter the feedlot directly after weaning and sale.

Once cattle enter the feedlot, the goal is to provide them with high quality diets to produce the most cost-effective weight gain. To do this, feedlots have capitalized on the use of grain-milling products (GMP) such as distillers grains (DGS) and corn gluten feed (CGF). Grain-milling products can supply energy and protein at a reduced cost compared to other feedstuffs such as corn and soybean meal. While a large body of research exists focused on specific GMP feeds and their associated impacts on feedlot performance, less research is available investigating the digestibility and passage rate of GMP feeds, particularly in diets containing combinations of multiple GMP. Additional research is also needed to determine how these feeds influence the rumen environment and microbial populations and understand how this relates to animal performance.

In addition to GMP feeds, feedlots use growth-promoting technologies to increase growth performance and gain:feed (G:F) ratio. New technologies are constantly being researched and introduced. Some of these technologies include the use of hormonal implants, ionophores, and beta-adrenergic agonists. Depending on the size and marketing strategy used by the feedlot, different combinations of hormonal implants may be used to achieve optimal profitability. Currently, the 2 ionophores used in feedlots are monensin, and lasalocid (Samuelson et al., 2016). In addition, there are 3 beta-adrenergic agonists (βAA) approved for use in feedlot cattle (ractopamine hydrochloride, zilpaterol hydrochloride, and lubabegron). However, ractopamine hydrochloride is currently the only βAA commercially available in the U.S. Along with development of growth technologies, beef cattle genetics continue to improve which improves cattle performance and increases the beef produced from one animal.

Concomitant with technology and dietary formulation advances in the beef industry, consumers have become more concerned with livestock stewardship practices in recent yr. One of the largest consumer concerns is the environmental impact and emissions produced from cattle in feedlots. Because this is a relatively new challenge in the agriculture industry, limited historical data is available to calculate how the feedlot industry has altered emissions, carbon footprint, and the sustainability of beef production over time. This literature review will discuss bovine respiratory disease (BRD), acidosis, feedlot arrival management, GMP ingredients, digestion of GMP, and environmental implications of feedlot cattle production.

Bovine Respiratory Disease

Bovine respiratory disease (BRD) is a multifaceted disease complex in cattle. During the marketing process, cattle experience a series of processes which could include all or some of the following: weaning, transport to the auction market (AM), comingling, transport to an aggregator, further commingling, limited availability of feed and water, and transport to the feedlot (Duff and Galyean, 2007). Because of the complexity of the marketing process, it can take multiple days and typically induces stress which can result in immunosuppression (Carroll and Forsberg, 2007). Immunosuppression can lead to increased susceptibility to viral infection of the upper respiratory tract and subsequent damage of the cilia (Griffin et al., 2010). Disruption of cilia function allows commensal bacteria to move into the lungs and become infectious (Songer and Post, 2005).

Immune Response in Cattle

The immune system consists of both innate and adaptive segments. The innate immune system is the first line of defense against pathogens that is non-specific and

consists of physical barriers and antigen-nonspecific cellular components (Carroll and Forsberg, 2007). The antigen-nonspecific cellular components include leukocytes and consist of neutrophils, monocytes, dendritic cells, eosinophils, basophils, and natural killer cells. Leukocytes recognize pathogen-associated molecular patterns (PAMP) commonly found on bacteria and viruses such as lipopolysaccharide in gram-negative bacteria or deoxyribonucleic acid/ribonucleic acid found in viruses (Janeway et al., 2001).

After leukocytes have been activated and begin to respond to an infection, they produce cytokines which regulate inflammation and increase immune cell recruitment (Baumann and Gauldie, 1994). Cytokines of the innate immune system include interleukins (IL), interferons (IFN), chemokines, and tumor necrosis factor-α (TNF- α) that can initiate the acute phase response to further increase immune cell function (Baumann and Gauldie, 1994). After the innate immune system has been activated, antigen presenting cells display antigen to naïve T cells and induce them to produce $CD4^+$, and $CD8^+$ T cells as part of adaptive immunity (Woodland, 2003). Cytotoxic $CD8^+$ T cells directly attack pathogens, while $CD4^+$ T cells can either be T helper 1 (Th1) or T helper 2 (Th2) cells that produce cytokines to either increase $CD8^+$ T cells or B cell production (Fulton, 2009). The role of B cells is to produce specific antibodies that bind to antigens and neutralize them and/or present the antigen to T cells for recognition (Carroll and Forsberg, 2007).

Stress

Categories of stress associated with the cattle marketing process include physical, psychological, and physiological (Cooke, 2017). Physiological stress responses can be

categorized as either acute or chronic stress. Acute stress is a short-term event of less than 24 h that allows a quick and complete recovery (Trevisi and Bertoni, 2009). In contrast, chronic stress is a prolonged stress event that fails to restore homeostasis within 24 h (Mendoza et al., 2000).

Exposure to stress activates the hypothalamus pituitary adrenal (HPA) axis and was reviewed by Minton (1994). Release of adrenocorticotropic hormone (ACTH) from the pituitary gland is stimulated by corticotropin-releasing hormone (CRH) and vasopressin (VP). Production of CRH and VP takes place in the periventricular neurons of the hypothalamus and is stimulated by higher brain functions (Whitnall, 1993). In addition, IL-1β and IL-6 can act as a secretagogue to stimulate the release of ACTH (Matta et al., 1992). After ACTH is produced, it acts on the adrenal glands to stimulate production of glucocorticoids. Cortisol is the most common glucocorticoid produced in response to stress in cattle. Furthermore, the sympathetic nervous system can release epinephrine and norepinephrine from the adrenal medulla via the sympathetic nervous system to increase heart rate and mobilize glycogen stores (Hadley, 2000).

In addition to the HPA axis, the acute phase response (APR) is activated by stress. The APR stimulates production of pro-inflammatory cytokines such as TNF-α, IL-6, and IFN-γ (Petersen et al., 2004). Pro-inflammatory cytokine production helps stimulate the innate immune system and modulates animal behavior by inducing fever, depression, and anorexia (Hughes et al., 2013). Glucocorticoid production such as cortisol helps to regulate these cytokines, and in chronic stress can downregulate the ability of cytokines to induce an adaptive immune response and decrease the likelihood of excessive inflammatory conditions that can be detrimental to the animal (Sapolsky et al., 2000). In

addition, glucocorticoids act as a negative feedback mechanism on the pituitary gland to inhibit ACTH production (Queyras and Carosi, 2004). Therefore, chronic stress can cause immune suppression to avoid negative effects from cytokine production, but could also lead to viral and bacterial infection of the animal.

Using simulated stress from transport and handling, Hudson et al. (2020) evaluated effects on cattle performance and leucocyte production after 3 d and 627 km of transport compared to an unstressed control. Stressed cattle consumed less feed in the first 14 d after feedlot arrival, but did not have differences in average daily gain (ADG) or body weight (BW). This suggests there is an interaction between exposure to stress and cattle appetite. Because the stress was sustained over 3 d, cortisol concentrations for the stressed cattle were less than the control cattle, which suggests negative feedback of cortisol production occurred before blood collection. Total leukocytes were decreased for stressed cattle compared to control for at least 21 d after feedlot arrival. These data indicate that innate immune function of cattle stressed for 3 d during weaning, transport, and handling is reduced and may lead to a greater incidence of morbidity.

Pathogens of Bovine Respiratory Disease

Stress-induced immunosuppression can lead to an initial infection with either a single or multiple viruses. The initial viral infection of the upper respiratory tract is believed to be the first infectious step in development of BRD. The most common viruses associated with BRD include bovine herpes virus-1 (BHV-1), bovine viral diarrhea virus (BVDV), bovine respiratory syncytial virus (BRSV), and parainfluenza-3 (PI-3V; Fulton, 2009). A non-complicated infection with BHV-1 can cause infectious bovine rhinotracheitis (IBR) that can produce lesions within the nose of cattle (Nandi et al.,

2009). In addition, BHV-1 can become latent within nerve cells and recrudesce when the immune system is weakened (Pastoret et al., 1982). Therefore, stress that causes immunosuppression can also cause IBRV recrudescence in cattle (Seiver, 2019).

Bovine viral diarrhea virus results in clinical signs such as depression and fever, but the primary impact of BVDV is the immunosuppression. There are 2 biotypes of BVDV, including cytopathic and noncytopathic, that can be further classified as 1a, 1b, and 2. A unique property of BVDV is that cattle can become persistently infected with the virus and do not have any immune response to it. These cattle appear normal and healthy, but are susceptible to mucosal disease (Roeder and Drew, 1984). McClurkin et al. (1984) designed an experiment to understand how cattle become persistently infected with BVDV and determined if a naive dam is exposed to BVDV between 42 and 125 d of gestation, the calf will likely be persistently infected but will also be less thrifty than non-infected calves. When cattle are persistently infected with BVDV, they continuously shed a large amount of the virus into the environment, and other animals can then become infected with BVDV. Richeson et al. (2012) determined that exposure to a persistently infected animal can decrease BW gain after cattle enter a backgrounding facility. In addition, cattle sourced from an AM have greater susceptibility to chronic illness when exposed to a persistently infected animal than cattle that have been backgrounded (Richeson et al., 2012). The greater susceptibility for chronic illness is likely caused by the combination of suppressed immunity and increased exposure to BVDV.

Bovine respiratory syncytial virus is similar to human RSV and causes depression, fever, and anorexia from the production of IL-6 and IL-8. The innate immune response to a BRSV infection preferentially stimulates the Th2 response and avoids a

large stimulation of CD8+ cytotoxic T cells (Gershwin, 2012). If there are fewer cytotoxic T cells present, the immune response will be less effective at mitigating viral infection. There is still limited research on BRSV, and understanding of the disease relies largely on RSV research within humans. However, unlike RSV, vaccines have been approved for cattle to prevent BRSV infection. Previously, using a modified-live virus vaccine increased the incidence of disease when administered within a short time after natural BRSV infection (Kimman et al., 1989). Therefore a more conservative alternative is using a DNA vaccine that does not contain the entire BRSV genome in either the live or killed form. Taylor et al. (2005) evaluated the use of a DNA vaccine for the f gene of BRSV and observed some immune protection, but at a much lower level than after natural exposure to BRSV.

After initial infection with a virus, commensal bacteria of the upper respiratory tract can migrate to the lungs and grow rapidly. The most common bacteria associated with BRD include *Mannheimia haemolytica, Pasteurella multocida, Histophilus somni,* and *Mycoplasma bovis* (Griffin et al., 2010). Signs of bacterial infection of the respiratory tract include ocular discharge, depression, anorexia, fever, increased respiration, and cough. Clinical illness is most commonly observed within the first 7 to 27 d after arrival to the feedlot or other stressful event (Duff and Galyean, 2007).

Acidosis

Ruminal acidosis is a common metabolic disorder in feedlot cattle that could cost producers approximately $9.40 per animal from losses in performance (Stock, 2000). Ruminal acidosis describes the reduction in ruminal pH that disrupts fermentation of feed

and absorption of nutrients in ruminants such as cattle. The main acidic substrates within the rumen include volatile fatty acids (VFA) such as propionic, acetic, butyric, and lactic acid. Under normal circumstances within feedlot cattle consuming a grain-based diet, the VFA's produced during fermentation are absorbed across the rumen wall and the ruminal pH remains within the range of 5.8 to 6.5 (Nagaraja and Titgemeyer, 2007). If the VFA concentration surpasses the absorption rate of the ruminal epithelium, either from rapid production of VFA or decreased absorptive capacity, it can cause a rapid reduction in ruminal pH. Rapid fermentation of starch is the most common cause of decline in rumen pH (Owens et al., 1998). There are 2 main classifications of ruminal acidosis, subacute and acute. Subacute acidosis occurs when rumen pH is between 5.2 and 5.6, while acute acidosis is classified when the rumen pH is less than 5.2 (Cooper et al., 1998). Acidosis has similar clinical signs as BRD and can include decreased dry matter intake (DMI), anorexia, depression, laminitis, and death (Nocek, 1997). However, in subacute acidosis, decreased DMI and growth performance may be the only clinical signs (Owens et al., 1998). Death from acute acidosis is caused by a rapid increase in D(+) lactic acid production that is absorbed into the blood and results in systemic acidosis (Owens et al., 1998).

There are several aspects of feedlot management that can decrease the potential for acidosis such as accurate feed delivery amount, consistent time of feeding, adequate dietary roughage, and proper dietary adaptation. The effect of feed amount fluctuation was studied by Schwartzkopf-Genswein et al. (2004). The study was designed to evaluate cattle consuming 110% and 90% of ad libitum intake in 3 d intervals for 28 d compared to a treatment fed ad libitum. Animals were housed individually with no competition for

feed. Ruminal pH was measured continuously and averaged every 15 min. Although a difference in average pH throughout the d was not observed, fluctuating the amount fed tended to cause more time throughout the d where ruminal pH was below 5.8. In addition, when analyzing only the times when feed was offered at 110%, ruminal pH did not decline as fast or to the same extent as when cattle were only offered 90% of ad libitum. Because cattle did not have the availability to eat ad libitum when consuming 90%, this suggests that feed restriction is a more significant contributor to acidosis than overfeeding.

In a 4 × 4 Latin square, González et al. (2009) evaluated the effect of delaying feed delivery on feeding behavior. Orts were collected at 0745 and feed was either provided at 0800, 0900, 1000, or 1100. Barley straw and concentrate feed were also supplied in separate compartments to evaluate feed consumption preferences. When feed delivery was delayed, cattle consumed less concentrate and more straw. In addition, the amount of feed consumed each time cattle visited the bunk increased linearly with the amount of time delayed before feeding, and the amount of time spent consuming feed throughout the day decreased by 30 min when feeding was delayed by 3 h. The results from Schwartzkopf-Genswein et al. (2004) and González et al. (2009) indicate that time and amount of feed provided can change the feeding behavior of cattle, which may result in over-consumption of feed which can subsequently cause ruminal acidosis.

In addition to the consistency of feeding time and quantity provided, it is important to provide cattle an adequate amount of roughage in feedlot diets to stimulate rumination and maintain papillae function. Rumination is the act of regurgitation and chewing of a feed bolus to help decrease particle size and incorporation of sodium

bicarbonate, a buffer, from saliva into the feed. Chibisa et al. (2020) observed that as silage inclusion increased in barley-based diets, rumination time increased linearly per kg of DMI. In addition, they observed that the minimum, maximum, and mean pH of cattle fed no silage was less compared to cattle fed 12.0% silage on a dry matter (DM) basis. The time below pH of 5.8, 5.5, and 5.2 decreased quadratically as silage inclusion increased from 0.0% to 12.0%. However, the increased rumen pH when feeding roughage can be associated with both greater rumination and the dilution of starch in the diet.

Feedlot cattle are most at risk for acute acidosis during adaptation to a high concentrate diet from a forage-based diet. During this adaptation period, the rumen transitions away from digesting fibrous feeds in favor of digestion of highly fermentable carbohydrates by altering microbial populations that are present within the rumen environment. If the transition is done improperly, it can result in short- and long-term performance implications from a variety of metabolic disorders such as acidosis, bloat, and liver abscesses (Cheng et al., 1998; Nagaraja and Chengappa, 1998; Owens et al., 1998). Therefore, approximately 14 d is required to allow a controlled adaptation of the rumen microbiome and animal feeding behavior (Brown et al., 2006).

Olumeyan et al. (1986) conducted a study to understand changes in rumen microbial population during transition to a high concentrate diet. The diets consisted of alfalfa hay and grain (sorghum grain and cracked corn). The authors quantified the changes in ruminal pH and microbial populations as cattle were provided diets that contained 80:20, 50:50 and 20:80 alfalfa hay and grain. Each diet was fed for 2 wk before the next more concentrated diet was provided after which the 20:80 diet was fed for 4 wk to ensure microbial populations had stabilized. In this study, the authors observed a

decrease in pH from the 80:20 diet to the 50:50 diet, but pH did not decrease further when cattle were switched to the 20:80 diet. Amylolytic bacteria did not increase until 2 wk after the 20:80 treatment was initially fed, but lactate-utilizing bacteria increased with concentrate level and continued to increase for 2 wk after the 20:80 treatment was fed. These delayed changes in the population of amylolytic and lactate-utilizing bacteria could explain the necessity for at least 14-d of dietary adaptation to high concentrate diets.

Nutritional Management upon Feedlot Arrival

The current paradigm in the feedlot industry is to provide a diet containing greater proportion of roughage compared to the finishing period along with long-stemmed hay immediately after arrival to the feedlot (Richeson et al., 2019). A survey of feedlot consulting nutritionists indicated that most nutritionists recommend using 30.0% to 50.0% grain in the receiving diet and 64.0% of nutritionists recommended providing free choice hay for an average of 4 d after feedlot arrival (Samuelson et al., 2016). However, roughage sources are more expensive per unit of energy provided to the animal compared to processed grains (Brokken et al., 1976; Galyean and Hubbert, 2014). In addition, roughage prices are more unstable because of regional markets that are highly influenced by weather (Bartle et al., 1994).

The purpose of the receiving diet is to allow cattle to acclimate to a new environment by providing a familiar feed and a starting point to transition the rumen microbiome to a high-energy, grain-based diet. The length of time cattle are offered a receiving diet is highly dependent upon preference, but may be extended to slow cattle growth to reach a specific marketing point. Pritchard (1987) evaluated growth

performance and carcass characteristics of cattle fed a low or high energy grower diet for 112 d before transition to a finishing diet. The cattle consuming the low energy grower diet had an additional, moderate energy diet fed from d 113 to 168 as a transition diet. Cattle were slaughtered at an equivalent 12^{th} rib fat measurement. Cattle that consumed the higher energy diets throughout the feeding period had greater ADG, lighter final BW, and required fewer d on feed to achieve a similar 12^{th} rib fat composition, indicating they deposited more fat at a lighter weight than the cattle fed the low energy grower diet. There was no difference in DMI among dietary treatments, which resulted in cattle consuming the high energy diet having greater G:F. In this study, the cattle that consumed the high energy diets tended to have greater quality grade and had greater yield grade than the low energy treatment. Pritchard (1987) concluded that depending on feed cost and market timing, there may be use for both a low energy and high energy diet as a grower diet.

Because there are a variety of reasons why cattle may be provided a receiving diet for more or less time, much of the previous nutritional research has focused on the transition period of acclimating cattle to consume a high grain finishing diet. The dietary transition is important to reduce the risk of acidosis, as described previously. There are 2 main approaches to dietary transition in the feedlot which include either use of multiple step-up diets or blending the receiving and finishing diet. In 2007, approximately 76.0% of nutritionists indicated that they used multiple step-up diets to transition cattle to the finishing diet (Vasconcelos and Galyean, 2007), with a mean number of 3 diets and a maximum of 5. By 2015, the percentage of nutritionists using multiple step-up diets was reduced to 56.3% (Samuelson et al., 2016). The second most common dietary adaptation

method is using 2 diets fed at increasing and decreasing proportions to introduce the cattle to the high grain content gradually. The popularity of a 2 diet blend has increased from 14.0% of nutritionists using this method in 2007 (Vasconcelos and Galyean, 2007) to 41.0% of nutritionists in 2015 (Samuelson et al., 2016). As more nutritionists have switched from a step-up style transition to a 2 diet blend, the average time to the final diet has increased from 21 d in 2007 (Vasconcelos and Galyean, 2007) to 27 d in 2015 (Samuelson et al., 2016). However, this difference should be interpreted with caution because different nutritionists may have responded to each survey and therefore, the results may not reflect true changes in practices.

In lieu of a receiving diet and subsequent transition, limit-feeding a high energy finishing diet has been used to "start" cattle in the feedlot. Limit-feeding the finishing diet reduces the amount of starch consumed without using a high roughage diet. Bierman and Pritchard (1996) evaluated feedlot performance of cattle limit fed the finishing diet (1.39 Mcal NE_g/kg) compared to an ad libitum provision of 5 step-up diets with the first diet containing 0.98 Mcal NE_g/kg. At the beginning of the study, the limit-fed cattle were provided feed at 1.7% of BW on a DM basis, and DMI increased by approximately 0.36 kg/d until they reached ad libitum intake. The cattle receiving the step-up diet treatment were consuming the finishing diet by d 12, and consumed feed ad libitum for the entirety of the study. Overall, DMI was less for limit-fed cattle, but ADG was not different, resulting in improved G:F. Weichenthal et al. (1999) also observed improvements in G:F from decreased DMI and no difference in ADG when limit-feeding cattle for 21 d compared to a 4 diet step-up system over the same time period. The step-up system provided dry-rolled corn at an increasing proportion from 45.0% to 83.0%. Limit-fed

cattle had slightly greater 12th rib fat thickness at harvest, but also numerically greater final BW (538 vs. 546 kg). Additional research by Spore et al. (2019) also indicates that limit feeding a high-energy diet compared to ad libitum intake of a lower energy diet increases DM and OM digestibility and increases G:F. Overall, a limit-feeding management strategy can improve G:F, decrease feed waste, and reduce the complexity in feed batching. However, accidental overfeeding when using a limit-feeding management strategy can cause acidosis because of rapid consumption. In addition, bunk space must be greater so that aggressive animals do not overconsume feed, and more submissive animals are further restricted (Galyean et al., 1999a).

A less used nutritional strategy is providing ad libitum offering of a high-energy finishing diet upon arrival to high-risk cattle. The high-risk category of cattle refers to cattle that have unknown history of vaccination and experienced chronic stress, are comingled, and have been exposed to novel pathogens. Richeson et al. (2019) reviewed the concept of the receiving diet paradox, where high-risk cattle arrive to the feedlot under stress that causes inflammation and anorexia and concomitantly cattle have an increased energy requirement from the immunological challenge. As a result, these types of cattle are unable to consume adequate energy to meet there nutrient requirements by consuming a traditional receiving diet. Hutcheson and Cole (1986) reported that stressed cattle had DMI between 0.5% and 1.5% of BW while Richeson et al. (2019) more recently reported a range between 1.24% and 1.79% of BW during the first 14 d. Lofgreen et al. (1975) observed that when self-limiting DMI, high-risk cattle consuming a diet with greater energy concentrations had greater ADG, BW and G:F. However, Lofgreen et al. (1975) also reported that cattle fed a high energy diet had greater

morbidity than cattle consuming a high roughage diet. However, Richeson et al. (2019) indicated the increased morbidity observed by Lofgreen et al. (1975) may be a type 1 error because of a small sample size or potential misdiagnosis of BRD in acidotic cattle.

Subsequently, Lofgreen et al. (1980) used 540 AM calves in a 3 × 2 factorial design with 3 levels of concentrate (25.0, 50.9, and 75.0% of DM) with or without free choice alfalfa hay. Lofgreen et al. (1980) observed that cattle consuming 50.0 or 75.0% concentrate diets had greater ADG with numerically more animals requiring BRD treatment. The cattle offered free choice alfalfa hay had less BRD morbidity, less animals requiring a second treatment, and reduced death loss compared to cattle not offered free choice alfalfa hay. In a regression analysis of data collected at the New Mexico State University Clayton Livestock Research Center, Rivera et al. (2005) reported that morbidity decreased as the proportion of roughage increased in diets of newly received cattle. In addition, ADG increased and DMI decreased as roughage inclusion increased. An economic analysis was conducted from these regressions to determine differences in profitability of providing 40.0% and 100.0% roughage diets. Because of improvements in growth performance, almost 5 times greater profitability was realized in the cattle fed 40.0% roughage diet despite slightly greater morbidity and mortality. Therefore, even if using a high energy receiving diet increased morbidity, the performance benefits can improve profitability (Duff and Galyean, 2007).

Fluharty and Loerch (1996) conducted a trial on 60 individually housed steers to determine if 4 levels of concentrate (70.0, 75.0, 80.0 or 85.0%) affected growth performance or morbidity in the first 4 wk after feedlot arrival. Each level of concentrate was fed to 15 animals for the entire 4 wk period. Average daily gain increased linearly

with increasing concentrate level in wk 2 and decreased linearly in wk 4. The linear increase in ADG during wk 2 is likely attributed to similar DMI of a greater energy diet. Dry matter intake increased linearly in wk 3 and 4 as the concentrate level increased. It is unclear why a decrease in ADG was observed in wk 4 because both DMI and energy of the 85.0% diet was greater. Morbidity of cattle in this trial was 27.0, 40.0, 33.0, and 20.0% for 70.0, 75.0, 80.0 or 85.0% concentrate inclusion diets but was not statistically different.

To better understand the interplay between nutrition and BRD, Berry et al. (2004) evaluated growth performance and the presence of *P. multocida* and *H. somnus* in newly received feedlot cattle fed different dietary starch (34.0% or 48.0% of ME) and energy (2.4 or 2.6 Mcal/kg ME) concentrations in a 2 × 2 factorial. There was no difference in ADG or morbidity related to starch content or energy level of the diet. It was also reported that cattle treated for BRD consuming the high-energy diet had less prevalence of *P. multocida* and *H. somnus* compared to cattle treated for BRD that were consuming the low energy diet. Because cattle consuming the high energy diet had less prevelance of *P. multocida* and *H. somnus*, this could indicate there was misdiagnosis of BRD in those animals. Morbidity is a subjective measurement based on an observer's perception of clinical symptoms of illness (Galyean et al., 1999b) and because of its subjective nature, a large number of morbid cattle may not be treated. Wittum et al. (1996) quantified this discrepancy when they observed that 68.0% of untreated cattle contained pulmonary lesions. Therefore, improvement in the detection of morbid animals is necessary.

Changes in the ruminal environment and growth performance from feeding a finishing diet upon arrival to high-risk cattle were evaluated by Tomczak et al. (2019).

Thirty-six auction-derived steers in individual pens were monitored for changes in rumen pH and rumination time. Treatments were a finishing diet, a finishing diet with 0.5% BW coastal Bermuda grass hay provided every 3 d, and a high roughage receiving diet followed by transition to the finishing diet over 29 d. The receiving and finishing diets contained 13.9 and 63.6% steam-flaked corn respectively and provided 0.93 and 1.39 Mcal/kg NEg. Both diets also contained wet corn gluten feed (WCGF) as a source of low-starch energy. From d 18 to 24, cattle fed the receiving diet consumed more feed than the finishing diet, and the finishing plus hay treatment had large fluctuations in DMI based on when the hay was provided. However, there was no difference in DMI before d 18 or after d 24. Cattle consuming the receiving diet ruminated more from d 7 to 23 compared to the finishing diet and, cattle provided hay every 3 d only ruminated more on d 14 compared to the finishing treatment. In the first 28 d, the cattle fed a finishing diet had the lowest rumen pH from 1300 to 0300 h. However, after the cattle provided the receiving diet transitioned to the finishing diet (d 29 to 56), they had the lowest ruminal pH from 0000h to 1000 h. These results indicate that cattle experienced similar reductions in pH after consuming the high energy finishing diet independent of the length of time they had been in the feedlot before the finishing diet was provided. In addition, it was concluded that WCGF may help reduce the incidence of acidosis by reducing the overall starch content of the finishing diet.

Grain-Milling Products

Use of GMP has become widespread in the U.S. cattle feeding industry. Examples of GMP include wet distillers grain (WDGS) from the dry milling process and WCGF from the wet milling process. Both of these products can be dried into dry distillers grains

(DDGS) and dry corn gluten feed (DCGF) to make transport and storage less expensive. In the dry milling process used for ethanol production, the corn grain is first ground as a dry ingredient, then moisture is added, and the mixture is cooked, liquefied, and fermented to produce ethanol (Bothast and Schlicher, 2005). The wet milling process is used for the extraction of starch and oil from grains. The grain is soaked before grinding, and then the germ and oil can be extracted (Ramirez et al., 2008).

Because starch is the primary substrate of interest in both the dry and wet milling processes, the resulting end products are lower in starch concentration and higher in digestible fiber and protein. For this reason, non-ruminant species have limited ability to use GMP for energy. In ruminant species, GMP feeds can be used as a protein source, an energy source, or both. However, the feeding value of GMP feeds is controversial because research has shown improvements (Larson et al., 1993; Walter et al., 2010), equivocal effects (Hussein and Berger, 1995; Ranathunga et al., 2010), and detrimental effects (Kampman and Loerch, 1989; Luebbe et al., 2012) on performance when replacing processed corn in the diet. These discrepancies may be from differences in diet formulations including grain processing method (Corrigan et al., 2009), roughage source and quality (Morris et al., 2005), and protein concentration and degradability (Ceconi et al., 2015).

Unlike fiber from roughage sources, the fiber in GMP feeds is highly degradable. Varga and Hoover (1983) indicated that the neutral detergent fiber (NDF) in DGS and CGF were 76.6 and 42.1% degraded after 24 h, respectively. The degradation rate reported for DGS and CGF were 7.2 and 6.5%/h, respectively. In comparison, Varga and Hoover (1983) reported that the NDF in whole corn was 42.3% degraded after 24 h and

had a degradation rate of 5.1%/h. Varga and Hoover (1983) reported the NDF concentration of DGS, CGF, and corn as 38.5, 39.0 and 16.7% respectively. In contrast, DGS, CGF, and corn contain 6.06, 15.2, and 60.68% starch, respectively (NASEM, 2016). Therefore, DGS and CGF provide a greater proportion of degradable fiber that can be used as an energy alternative to starch. Scott et al. (2003) observed that WCGF had a calculated net energy of gain (NEg) between 1.65 and 1.33 Mcal/kg and was between 8.0 and 26.0% less than the NEg of steam flaked corn (SFC). The values for NEg of WCGF, WDGS, and SFC reported by NASEM (2016) were 1.52, 1.74, and 1.67 Mcal/kg, respectively.

Rumination and Ruminal Environment

Because GMP contain less starch and greater proportions of fiber, microbial fermentation produces less total VFA and subsequently reduces the risk of acidosis (Krehbiel et al., 1995). Krehbiel et al. (1995) conducted an acidosis challenge using dry-rolled corn, a combination of dry-rolled corn and WCGF, and 100% WCGF. The results of that study indicated that WCGF reduces but does not eliminate the risk of ruminal acidosis. Previous research suggests that acidosis reduces both DMI and ADG (Owens et al., 1998), and could explain some of the performance improvements associated with feeding of GMP. Because WCGF and DGS can be classified as non-forage fiber sources, the improvements in the ruminal environment may be from starch dilution or a small capacity for physical stimulation to increase rumination (Firkins, 1997).

Maintenance of ruminal health is a balance between dietary composition, eating behavior, feed fermentation and nutrient absorption, and rumination time. Rumination is

the act of regurgitating a feed bolus and re-mastication to incorporate saliva and mechanically digest feed. The physical characteristics of different feed ingredients can influence the rumen environment by providing different buffering capacities and altered rumination behavior within the animal. For example, CGF and DGS have greater buffering capacities than processed corn and alfalfa but had a lower initial pH (Giger-Reverdin et al., 2002). Because VFA and free hydrogens are produced during the fermentation process, bicarbonate from saliva production is an important hydrogen sink to help buffer pH in the rumen (Bailey and Balch, 1961). Saliva production is regulated by the nervous system and increases with DMI and rumination time, thus increasing the amount of bicarbonate available for buffering (Allen, 1997).

The term physically effective NDF (peNDF) has been coined to quantitatively estimate the effect of both NDF concentration and particle size of a feed ingredient or diet on rumination (Mertens, 1997). Particle sizes larger than 3.35 mm were predicted to stimulate rumination by Cardoza (1985), because only a limited number of particles greater than 3.35 mm were present in manure samples. Later, the Penn State Particle Separator (PSPS) was developed to evaluate the distribution of particle size on 5 tiers with descending sieve sizes (19.0, 8.0, 4.0, 1.18 mm sieve and a solid pan). Using the PSPS, peNDF can be quantified "on-farm" by multiplying the NDF concentration of the diet by the percent of feed captured above the 4 mm sieve. Limited data evaluating the PSPS system for peNDF determination in feedlot diets has been completed by Gentry et al. (2016), Weiss et al. (2017), and Jennings et al. (2020). Jennings et al. (2020) evaluated the impact of feedlot diets containing 5.0, 10.0, or 15.0% corn stalks on a DM basis on rumination and ruminal pH. As the proportion of corn stalks increased, WCGF was

removed from the diet so that NDF concentrations in the 3 diets were 20.6, 22.0, and 23.4%. Ruminal pH was lower for cattle consuming the 5.0 and 10.0% corn stalk diets compared to the 15.0% diet and rumination time increased with corn stalk inclusion. In addition, the rumination/kg of DM and NDF intake was greater for the 10.0 and 15.0% corn stalk diets compared to the 5.0% corn stalks diet. However, the rumination/kg of peNDF was similar between the 5.0 and 15.0% corn stalk diets and greatest for the 10% corn stalk diet. This indicates that the NDF within corn stalks and WDGS effected rumination differently and peNDF may not accurately predict rumination time when WDGS is included in the diet.

To understand the effect of dietary inclusion of WCGF and WDGS on rumination in feedlot cattle, Spowart (2020) compared a steam-flaked corn control diet to diets with 20.0% WDGS, 20.0% WCGF, or 20.0% WCGF and 10.0% WDGS. The peNDF of each diet was 9.22, 9.93, 10.95, and 11.19% respectively. Rumination per kg of DMI was only different on 3 d. However, when rumination was measured per kg of peNDF, the cattle consuming the WCGF diet and the diet with combination of WCGF and WDGS spent the least time ruminating and the control group spent the most. In addition, the ruminal pH of cattle consuming diets containing GMP was greater than the control. Therefore, in feedlot diets containing GMP, the current calculation of peNDF may not accurately predict rumination or ruminal pH.

Digestibility of Corn Gluten Feed and Distillers Grains

Because WCGF and DDGS may alter the rumen environment and rumination behavior of cattle, understanding their digestive characteristics is important to be able to

use these feeds effectively. Although WCGF and WDGS are produced from grains, their nutrient composition is vastly different and alters microbial digestion and host metabolism of the resulting fermentation products. Abe and Horii (1978) reported that the cell wall degradability of WCGF was more than 80.0% in an in vitro system, indicating that the fiber is readily digestible by rumen microbes. Subsequently, Firkins et al. (1985) conducted a series of 8 trials that evaluated the digestibility, metabolism, passage rate, and feedlot performance of cattle consuming CGF and DGS. Overall, there were limited differences between the wet and dry forms of DGS and CGF. When compared to a control diet with no GMP, DGS and CGF had similar or greater DMI in all 8 of the trials. Nitrogen intake and digestibility were greater in DDGS diets compared to WDGS. In addition, WCGF had greater NDF digestibility than DCGF and a no GMP control, but passage rate did not differ. There were no detrimental effects from feeding GMP. This indicates that GMP improve digestibility in some circumstances without changing passage rate.

To evaluate differences in digestibility and passage rate of WCGF compared to corn-based diets, Montgomery et al. (2004) used 12 cannulated jersey steers in a 2 × 2 factorial Latin square design. Diets contained steam-flaked corn, 20.0% alfalfa hay, and either 0.0 or 40.0% WCGF fed ad libitum or at 1.6% of BW. Dry matter intake was greater for cattle fed WCGF compared to corn-based diets. Total tract OM and NDF digestibility were greater for diets containing WCGF. Wet corn gluten feed also increased passage rate by 0.15%/h compared to corn-based diets, likely because of the small particle size. This disagrees with Abe and Horii (1978), but the difference in passage rate between the 2 studies could be caused by differences in roughage inclusion rate, source,

or particle size. In addition to digestibility and passage rate differences, Montgomery et al. (2004) observed that cattle fed WCGF had greater ruminal pH, with less total VFA, propionate, and acetate than cattle fed corn diets. The increase in ruminal pH indicates that feeding WCGF may improve the rumen environment.

Staples et al. (1984) evaluated 4 levels of WCGF (0.0%, 20.0%, 30.0%, and 40.0%) in dairy cattle diets. All diets contained 50.0% corn silage and decreasing concentrations of ground corn and soybean meal as WCGF was used to replace these feedstuffs. Dry matter intake decreased with greater proportions of WCGF, which contradicts observations in beef cattle. In addition, there was a linear decrease in DM, OM, and NDF digestibility as WCGF increased in dairy cattle diets. Although there was no difference in total VFA between dietary treatments, there was a linear increase in acetate and decrease in the proportions of propionate as WCGF replaced corn and soybean meal. As a result, total milk production decreased as WCGF increased in the diet. This indicates that inclusion of WCGF in diets containing higher proportions of roughage than typical beef cattle diets may affect digestion differently than when fed as a component of grain-based diets.

In a Nebraska beef report, Vander Pol et al. (2007) evaluated the digestibility and rumen impacts of including 40.0% WDGS in a dry-rolled, corn-based diet compared to a diet with no WDGS. There was no difference in rumen pH between treatment diets. Acetate was less, and propionate was greater when WDGS was fed, resulting in an acetate to propionate ratio of 1.05 for the WDGS diet and 1.31 for the control diet. Propionate can be directly used for gluconeogenesis by cattle while acetate cannot, therefore WDGS may be a more efficient source of energy compared to dry-rolled corn.

Total tract digestibility of DM, OM, NDF, and starch was not affected by WDGS inclusion in the diet. However, total tract fat digestion was greater for cattle fed 40.0% WDGS compared to no WDGS. The greater total tract fat digestibility may be because the fat in WDGS is less hydrogenated in the rumen and easier to digest by intestinal enzymes (Vander Pol et al., 2007).

Environmental Impact of Cattle

Overview of Greenhouse Gasses

Recently, cattle production has come under scrutiny as a major contributor to the global greenhouse gas (GHG) production that can cause increased global temperature. Greenhouse gases from cattle production include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Greenhouse gasses can absorb infrared radiation from the sun and can be classified as primary or secondary based on the wavelength of absorbed radiation. The primary form of CO_2 absorbs in the range of 12 to 17 µm of wavelength, and the secondary form absorbs radiation that is either above or below these wavelengths (Tuckett, 2019). Although the primary greenhouse effect has been in existence for millions of years, allowing life on earth, the secondary greenhouse effect is of concern because it can increase average global temperature by approximately 1 °C (Tuckett, 2019).

In the past 270 yr, CO_2 concentrations in the atmosphere have increased by 43.0%, and the average temperature has increased by 0.8 to 1.1 K (Tuckett, 2019). Although these values may be correlated over the past 270 yr, historical data collected in 1480 and between 1750 and 1920 indicate global temperature changes do not match CO_2

concentrations in the atmosphere. This suggests there may be other factors influencing global temperature independent of CO_2 concentration. An explanation is that the primary and secondary greenhouses gasses may have previously been working against each other by absorbing similar wavelengths of infrared radiation, but now may be working in synchrony by absorbing a wider range in wavelengths from a difference in atmospheric composition (Tuckett, 2019).

In addition to the amount of energy that a GHG can absorb, the lifetime each GHG is present in the atmosphere is important to understand its potency. In the Intergovernmental Panel on Climate Change (IPCC, 2013) report, the lifetime of CO_2, CH_4, and N_2O were 50 to 200 yr, 12 yr, and 114 yr, respectively (Stocker, 2014). As GHG's absorb more energy and spend more time in the atmosphere, they retain more heat within the atmosphere and contribute a greater amount to global warming. Because GHG have different global warming potentials, a CO_2 equivalent (CO_2e) can be calculated to equalize the effects of each. According to IPCC (2019), the CO_2e for CO_2, CH_4, and N_2O is 1, 25, and 298 respectively.

Nitrous oxide is produced as an intermediate of incomplete nitrification ($NH_4^+ \rightarrow NO_3^-$) or denitrification ($NO_3^- \rightarrow N_2$) from the pen floor and the composting process of manure (Waldrip et al., 2016). Nitrous oxide is an extremely potent GHG with 298 times more global warming potential than CO_2 and has an atmospheric lifespan of about 114 yr (IPCC, 2006, 2019). In 2014, the tropospheric concentration of N_2O was about 326 ppb and was lower than that of both CO_2 and CH_4 (Waldrip et al., 2016). However, because it is more potent, a relatively small concentration of N_2O can cause major effects on radiation absorption and emittance in the atmosphere. Although CH_4 has a much shorter

lifespan in the atmosphere, it can trap infrared radiation to a greater extent than CO_2, making its impact on global warming about 25 times greater (Stocker, 2014). Methane production can come from a variety of industries, including agriculture, energy production from natural gas and petroleum, as well as waste from households (EPA, 2021). Agriculture comprises 10.2% of U.S. GHG emission while transportation, electric power, and industrial production comprise 28.6, 25.1 and 22.9% of U.S. GHG production, respectively (EPA, 2021).

Factors Effecting Methane Production in Cattle

Methane that is eructated by cattle represents an inefficiency in microbial fermentation of nutrients and a loss of energy that could otherwise be used by the animal for biological functions. Therefore, research on reducing CH_4 production of ruminants began with the objective of improving efficiency and performance rather than to decrease GHG production. In 1985, Czerkawski (1985) estimated that the value of gross energy losses from CH_4 production in ruminants was about 24 billion dollars. Therefore, reducing CH_4 production has been a main area of focus for cattle production for over 65 yr, with research in only the past few decades conducted because of concerns for the environmental sustainability of agricultural production systems.

Initial production of CH_4 from eructation begins when solid feeds are retained in the rumen about 4 wk after birth (Anderson et al., 1987). As reticulo-rumen development occurs, CH_4 production rates rapidly increase (Johnson and Johnson, 1995). The total enteric CH_4 loss from fermentation can be variable. Factors affecting CH_4 production include the quantity of dietary carbohydrates fermented in the rumen, the type of

carbohydrate, and the total free hydrogen available in the rumen. Free hydrogen availability is dependent on the ratio of acetate to propionate. In theory, if the ratio of acetate to propionate was 50:50, then no energy would be lost as CH_4, and if only acetate was produced, the energy lost as CH_4 would be 33.0% of GE intake (Wolin and Miller, 1988).

Increased DMI has also been shown to increase total CH_4 production (Johnson et al., 1993). Herd et al. (2014) observed a correlation between DMI and CH_4 production rate ($r^2 = 0.65$). However, as a proportion of gross energy intake, CH_4 production decreases as DMI increases (Johnson et al., 1993; Herd et al., 2014). Maximizing BW gain relies in part upon maximization of DMI in each beef cattle production segment, and limiting DMI may not be an effective option for reducing CH_4 emissions per kg of beef produced. Therefore, altering dietary composition may be a more effective way to decrease CH_4 production from beef cattle. Replacing structural carbohydrates in cattle diets with soluble carbohydrates can decrease the CH_4 produced during rumen fermentation. Moe and Tyrrell (1979) evaluated differences in CH_4 production per gram of cellulose, hemicellulose, and soluble residue. The results indicated that cellulose produced 3 times more CH_4 than hemicellulose and 5 times more CH_4 than soluble residue. In addition to individual feed ingredients, forage and grain processing can influence CH_4 production by increasing digestibility. Chopping, grinding, and pelleting of low-quality forages decreases CH_4 production/kg of DMI (Blaxter and Graham, 1956; Wieser and Wenk, 1970). In addition, steam-flaked corn was less methanogenic than dry-rolled corn in a study by Johnson (1966). The reduction in CH_4 is typically attributed to greater digestibility and reductions in rumen retention time.

As the proportion of concentrate feeds increases in the diet, the acetate to propionate ratio decreases (Siciliano-Jones and Murphy, 1989). This is important because as the relative proportion of propionate increases in the rumen, it acts as a competitive hydrogen sink and decreases methanogenesis (Johnson et al., 1993). In addition to propionate, polyunsaturated fats can also serve as a hydrogen sink to reduce the hydrogen available for methanogenesis (Czerkawski et al., 1966). However, hydrogen used for biohydrogenation of fatty acids only accounts for about 1.0 to 2.0% of the free hydrogen within the rumen (Czerkawski, 1972). Supplemental fat may also negatively affect digestion and DMI when fed at greater than 6.0% of the dietary DM (Hess et al., 2008).

Ionophore feed additives have been shown to improve G:F and reduce DMI (Duffield et al., 2012). Changes in DMI and G:F are caused from manipulation of the rumen environment that increases propionate production and decreases CH_4 production (Chen and Wolin, 1979). Monensin is the most commonly used ionophore in beef cattle production and decreases CH_4 production by inhibiting hydrogen-producing bacteria such as *Streptococcus bovis* (Russell and Strobel, 1989). Therefore, monensin is effective at improving G:F in feedlot cattle while decreasing CH_4 production.

To evaluate different roughage concentrations and use of monensin on CH_4 and VFA production in cattle, Thornton and Owens (1981) fed 3 concentrations of roughage (14.0, 46.2, or 65.7%) with or without 200 mg/d monensin. As roughage concentration increased, CH_4 production also increased. In addition, when monensin was fed to cattle consuming 14.0% and 46.2% roughage, monensin decreased CH_4 production by 16.0%. in contrast, when monensin was fed to cattle receiving 65.7% roughage, it decreased CH_4 by 24.0%. There was a greater decrease in CH_4 production at the high roughage inclusion

because of a greater change in propionate production. The low roughage inclusion (14.0%) had 38.6% greater propionate while the high roughage inclusion (65.7%) increased propionate concentration by 65.6% when monensin was added to each diet. This indicates that adding monensin can improve energy utilization and decrease CH_4 production in all diets.

Greenhouse Gas Production by the Beef Cattle System

Beauchemin et al. (2010) conducted a case study on life cycle GHG emissions from beef production in western Canada. The model included the cow-calf ranch of origin, feedlot, and farmland to represent all segments of beef cattle production. An 8 yr period was modeled to fully account for the lifetime GHG emissions of 120 cows, 4 bulls, and their progeny. The results of the analyses indicated that approximately 80.0% of total GHG production is from the cow-calf system, and only 20.0% was from the stocker cattle and feedlot systems. Over the entire system, 21.73 kg of CO_2e were produced per kg of carcass weight.

In a similar analysis, Stackhouse-Lawson et al. (2012) modeled the beef production system in California that included cow-calf, stocker, calf ranch, and feedlot sectors. The model included the production of feeds and other resources used in cattle production and manure handling. This model was simulated for 25 yr. Overall, an Angus cattle system that included cow-calf, stocker, and feedlot phases resulted in 9,416 kg CO_2e/animal. The cow-calf, stocker, and feedlot sectors accounted for 65.8, 13.9, and 16.9% of emissions, respectively. The total system produced 22.6 kg of CO_2e/kg HCW. When the stocker phase was eliminated from the beef cattle production system total kg of

CO_2e was reduced by 6.5%. The production of Holstein cattle for beef resulted in a much lower GHG production (10.7 kg CO_2e/kg HCW) than traditional cattle systems. Holstein cattle are fed a grain based diet throughout the entire production system that improves G:F and reduces CH_4 production compared to a traditional grazing system.

In addition to dietary changes, growth promoting technologies have the potential to change emissions for cattle by increasing feed efficiency. Beta-adrenergic agonists have been developed to increase protein deposition and decrease fat deposition when fed for the last 4 to 6 wk at the feedlot while improving G:F (Abney et al., 2007; Quinn et al., 2008). Another growth-promoting technology used in the feedlot is hormonal implants that increase DMI, protein deposition, and G:F (Duckett and Andrae, 2001). Because of the improved G:F from beta-adrenergic agonists and hormonal implants, there may be decreased GHG emissions. A model evaluating the use of beta-adrenergic agonists and hormonal implants on GHG production was developed by Stackhouse et al. (2012). Use of implants and beta-adrenergic agonists decreased total GHG emissions. In addition, implants and beta-adrenergic agonists reduced kg of CO_2e/kg HCW by 7.1% and 10.0%, respectively. This suggests that improving G:F of cattle will reduce GHG production.

Implications

Beef producers must continue to find ways to improve animal health and performance while being transparent with consumers about emissions from animal production. Therefore, it is important to understand how the different concepts in this literature review relate systematically. Bovine respiratory disease will continue to be concern in cattle production because of the complexity of the disease and marketing

process of cattle with limited abilities to detect and treat morbid animals. Furthermore, nutritional and management changes that can be applied during and shortly after arrival to the feedlot can help improve performance and profitability and may be more readily acceptable than implementing changes across the entire feedlot system. The use of GMP provides a source of energy in receiving and finishing diets of cattle while decreasing the risk of ruminal acidosis and growth promoting technologies have improved feed efficiency and growth of feedlot cattle.

In addition to greater demand for beef, concerns for environmental sustainability have increased. Although direct mitigation of GHG production has not always been the goal of feedlot production, GHG emissions have decreased because of improvements in management practices and technologies that improve growth efficiency. The use of GMP feeds decreases waste from other industries while providing energy and protein for cattle production. In addition, use of high-energy feedlot diets has helped decrease the amount of GHG emissions produced by beef cattle. Overall, as beef production becomes more efficient the environmental impact will likely continue to decrease.

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CHAPTER II

REPLACING A HIGH-ROUGHAGE RECEIVING DIET WITH A HIGH-ENERGY FINISHING DIET IMPROVED GROWTH PERFORMANCE AND FEED EFFICIENCY WITH NO IMPACT ON HEALTH OF HIGH-RISK NEWLY-RECEIVED CALVES

Abstract

This study evaluated the impacts of feeding a high-energy finishing diet during the receiving and finishing period compared to a lower-energy receiving diet with adaptation to the finishing diet on health, performance, serum chemistry, ruminal pH, and rumination of high-risk feedlot cattle. Five truck-load blocks of steers (n = 101) and bulls (n = 299) were used in a generalized complete block design and assigned to receive: 1) finishing diet for the entire feeding period (FIN) or 2) receiving diet for the first 56 d, followed by transition to the finishing diet (REC). All cattle were fed ad libitum and consuming the same diet by d 74. A subset of cattle (n = 48) was randomly selected to quantify ruminal pH, temperature, and rumination time. Ultrasound images were collected on d 0, 74, and 146 to determine fat thickness over the 12th rib and rump. Carcass characteristics were determined after slaughter. Cattle fed REC had greater ($P <$ 0.01) dry matter intake (DMI) from d 0 to 74, but DMI did not differ (P = 0.80) from d 74 to final. From d 0 to final, DMI was 0.26 kg less for FIN compared to REC (P = 0.01). Calculated metabolizable energy intake was not different from d 0 to 74 (P = 0.20), d 74 to final (P = 0.80), or overall (P = 0.78). At d 74 and final, body weight (BW) of FIN was

10 kg greater ($P \leq 0.10$) than REC. Cattle consuming FIN had greater ($P < 0.01$) average daily gain (ADG) and increased ($P < 0.01$) gain:feed (G:F) from d 0 to 74. Feed cost of gain was less for FIN from d 0 to 74 ($P < 0.01$), but not different from d 74 to final ($P = 0.89$). There was no difference ($P \geq 0.31$) in health outcomes. On d 74, FIN had greater ($P = 0.04$) fat thickness over the rump and rib, but did not differ ($P \geq 0.41$) at d 146. Carcasses of FIN had greater ($P = 0.04$) hot carcass weight with no difference ($P \geq 0.12$) in ribeye area, 12th rib fat thickness, yield grade, or quality grade. There was no difference ($P = 0.18$) in liver abscess rate. There was a treatment × day interaction for blood urea nitrogen ($P < 0.01$) where concentration decreased from d 0 to d 28 in both treatments but was less on d 28 for FIN compared to REC. Ruminal pH was greater (diet × day interaction; $P < 0.01$) for FIN on d 2 and 61, and rumination time was less (diet × day interaction $P < 0.01$) for FIN from d 0 to 28. Overall, these results suggest that providing a finishing diet fed ad libitum to high-risk calves upon arrival may be a viable alternative to a traditional receiving diet.

Introduction

During the marketing process, cattle are weaned and transported to auction barns where they are comingled and have limited access to feed and water. During this period, cattle also experience stress which alters dry matter intake (DMI; Hutcheson and Cole, 1986) and the animal's immune response, resulting in greater incidence of bovine respiratory disease (BRD; Taylor et al., 2010). The term “high-risk” is used to describe cattle that experience stressors and exposure to novel pathogens before arriving to the feedlot. High-risk cattle are typically offered hay and diets containing a greater proportion of roughage than diets fed during the finishing period, despite the increased

energy demand required to support inflammatory processes and decreased DMI. This phenomenon results in a concept described as the "receiving diet paradox" (Richeson et al., 2019).

Most producers manage high-risk cattle by providing a receiving diet with ≥ 30.0% roughage upon arrival (Samuelson et al., 2016) to stimulate DMI and mitigate the risk for ruminal acidosis. Ruminal acidosis is a metabolic disorder that can decrease performance and DMI, and in severe cases, cause death, and is associated with the rapid fermentation of starch in feedlot diets (Owens et al., 1998). In addition to reducing the fermentation rate compared to starch, roughage increases mastication and saliva production, which enhances buffering capacity and may reduce the prevalence of ruminal acidosis (Owens et al., 1998). Because of increased availability of grain milling products (GMP) such as wet corn gluten feed and wet distillers grains, starch concentrations have decreased in feedlot diets without greatly reducing energy concentration in the past several yr. Therefore, an opportunity exists to provide a high energy finishing diet to high-risk, newly received cattle with less risk for ruminal acidosis.

Before GMP became prevalent in the cattle feeding industry, adding cereal grains, high in starch, was the most common way to increase dietary energy concentrations. Previously, Lofgreen et al. (1975) observed that providing a diet with a greater energy concentration during the receiving period increased performance; however, morbidity increased in cattle fed greater energy concentrations. Berry et al. (2004) noted no difference in performance and numerically greater morbidity when cattle were fed diets with increasing starch concentrations. However, cattle fed the high starch diet tended to have a decreased percentage of *Pasturella multocida* and *Histophilus somni* in nasal

swabs compared to cattle consuming diets containing less starch. Taken together, these data indicate cattle consuming high-energy diets may have been misdiagnosed for BRD because of the similarity in clinical signs of ruminal acidosis and BRD.

Including GMP in the diet in place of processed grains can mitigate ruminal acidosis (Krehbiel et al., 1995) and likely reduces the opportunity for misdiagnosis of BRD. In addition to altering dietary ingredients to reduce the risk of acidosis, limiting feed intake can also reduce the starch available to the animal. Although high-risk cattle have a greater energy requirement from exposure to stress and inflammation, DMI is consistently reduced in the first 1 to 3 wk because of inexperience in eating from a bunk and decreased appetite (Richeson et al., 2019). Consequently, increased fermentable fiber and reduced starch concentration afforded by GMP accompanied by the self-limited DMI of high-risk cattle may warrant feeding a finishing diet upon arrival.

We hypothesized that providing a high energy finishing diet upon arrival to high-risk calves would result in greater growth performance compared to a lower energy receiving diet with no effect on BRD morbidity rate. In addition, our hypothesis was that ruminal pH, rumination time, and activity time would be less for FIN compared to REC in the first 2 wk, but not different thereafter. The objective of this study was to determine the effects of providing high-risk cattle ad libitum access to a high energy finishing diet upon arrival, compared to a lower energy receiving diet on growth performance, animal health, ruminal pH, rumination and activity time, serum chemistry, and carcass characteristics.

Materials and Methods

All procedures involving live animals were approved by the West Texas A&M University Institutional Animal Care and Use Committee (2020.04.003)

Cattle Processing

A total of 400 high-risk bulls (n = 299) and steers (n = 101) that weighed 252 ± 5.5 kg were purchased from auction markets in South Texas and shipped to the West Texas A&M University Research Feedlot on 5 different arrival dates (May 6, 2020, May 14, 2020, May 21, 2020, July 28, 2020, and August 19, 2020). Cattle were considered to be high-risk because they originated from sale barns and were comingled with no previous vaccination records. Immediately after arrival on d -1, cattle were individually weighed, given a unique identification ear tag, ear notched to determine persistent infection with bovine viral diarrhea virus, administered a clostridial vaccine with tetanus toxoid (Cavalry 9, Merck Animal Health, Kenilworth, NJ), *Mannheimia haemolytica* bacterin (Once PMH, Merck Animal Health), and given an anabolic implant containing 36 mg zeranol (Ralgro, Merck Animal Health). One animal was removed from the study because it tested positive for persistent infection with bovine viral diarrhea virus. Additionally, cattle received metaphylactic treatment with tildipirosin (Zuprevo, Merck Animal Health, Kenilworth, NJ), and were treated for parasites with ivermectin and clorsulon (Ivermax, Aspen Veterinary Resources, Greely, CO) and albendazole (Valbazen, Zoetis, Kalamazoo, MI). All cattle were provided ad libitum access to long-stemmed hay and water overnight until initiation of the experiment on d 0.

On d 0, cattle were weighed a second time to account for differences in gut fill and determine initial body weight (BW). Initial BW was considered the average of the d -

1 and d 0 BW. Additionally on d 0, bulls were castrated using a castration band (Callicrate Smart Bander, Callicrate Banders, St. Francis, KS) and orally administered 1 mg/kg BW of meloxicam (Unichem Pharmaceuticals, Hasbrouck Heights, NJ). The 3 median BW animals in each pen from the final 2 arrival dates (n = 48) were selected for blood collection and to receive a 3-axis accelerometer ear tag (eSense flex tag, Allflex Livestock Intelligence, Madison, WI) and ruminal pH and temperature bolus (smaXtec pH Plus Bolus, SmaXtec, Graz, Austria). Accelerometer data measured total rumination and activity within a 2 h period, while rumen boluses measured pH and temperature every 10 min. A pentavalent modified-live virus vaccine (Titanium 5, Elanco, Greenfield IN) was administered on d 28. Cattle were re-implanted on d 90 with an anabolic implant containing 200 mg trenbolone acetate and 40 mg estradiol (Revalor XS, Merck Animal Health).

Study Design and Treatments

Each block consisted of 4 pens per treatment with 10 animals per pen, resulting in a total of 20 pen replicates per treatment. Pen was considered the experimental unit. Cattle were stratified according to d -1 BW within each truckload, and randomly assigned to pens such that the average BW and the number of bulls and steers were equalized between pens. Experimental treatments were randomly assigned to pen on d 0 and consisted of: 1) a lower energy receiving diet fed for the first 56 d of the study with a transition to a high energy finishing diet over 18 d (REC; Table 2.1), or 2) a high energy finishing diet fed for the entire feeding period starting on d 0 (FIN). From d 74 to the end of the study (final), cattle were fed the same finishing diet. Diets were formulated to meet or exceed the nutrient requirements of growing and finishing beef cattle (NASEM, 2016).

Ractopamine hydrochloride (Optaflexx, Elanco, Greenfield, IN) was provided in the diet to supply 250 mg/animal/d for the final 34 d on feed (DOF).

Feeding and Health Management

Feed bunks were visually assessed for residual feed at 0630 and 2100 h to determine the amount of feed to provide each d. Feed was provided once daily at approximately 0730, and bunks were managed to allow less than 1 kg of feed remaining at the morning bunk reading. Bunk management between treatments was identical for the entirety of the study. On d 56, dietary transition was initiated for the REC steers using a two-ration blending system where 10.0% of the daily feed allotment was replaced with 10.0% of the finishing diet every 2 d. Therefore, both REC and FIN cattle were consuming the same diet beginning on d 74. Each diet was sampled twice weekly immediately after feed was delivered. Feed samples were then divided into 2 portions. The first portion was analyzed for dry matter (DM; 100˚ C for 24 h) on the d of collection in duplicate and used to calculate DMI, and the remaining sample was stored frozen (-20˚C) and composited twice monthly. Composited samples were analyzed by a commercial laboratory (Servi-tech Laboratories, Amarillo, TX) for DM, organic matter (OM), acid detergent fiber (ADF), crude protein (CP), ether extract (EE), and total starch.

Cattle were monitored daily by trained personnel for signs of BRD and assigned a BRD clinical illness score (CIS, Table 2.2) from 0 to 4. Cattle were removed from the pen and examined further if they had a CIS ≥ 2. Cattle were classified as morbid and treated if rectal temperature was ≥ 40°C and/or they had a CIS ≥ 3. Antimicrobial treatment consisted of: florfenicol (Nuflor, Merck Animal Health, Kenilworth, NJ) for the first treatment, enrofloxacin (Baytril, Bayer Animal Health, Shawnee Mission, KS) for

the second treatment, and ceftiofur crystalline free acid (Excede, Zoetis, Parsippany, NJ) as a third treatment. If cattle remained morbid after the third treatment and prognosis of a full recovery was unlikely, cattle were removed from the study.

Cattle were weighed before feeding on d -1, 0, 14, 28, 56, 74, 174, and 2 consecutive d before harvest. Consecutive weights at the beginning and end of the feeding period were averaged to mitigate differences in gut fill. Concomitant with BW measurements on d 0, 14, and 28, blood was collected via jugular venipuncture from the subset of animals determined on d 0. After blood was collected, it was centrifuged at 1,250 × *g* for 20 min, and the serum was decanted and stored at -20°C for later analysis. Serum chemistry values such as alanine aminotransferase (ALT), blood glucose, blood urea nitrogen (BUN), creatinine, Na^+, K^+, Cl^-, and total CO_2 were analyzed using an automated analyzer (Abaxis VS2, Abaxis, Union City, CA). Back fat, rump fat, ribeye area, and marbling were assessed via ultrasound imaging on d 0, 28, 74, and 174 by an Ultrasound Guidelines Council certified technician using a New ALOKA 500 with a 3.5MHz, 17.2 cm carcass probe (Wallingford, CT). Gain measurements on the ALOKA were set at: Mag = 1.5, overall gain = 90, near gain = -25, and far gain = 2.1. Before images were captured, the area to be ultrasounded was shaved using hair clippers and cleaned using compressed air. Images were analyzed by the International Livestock Image Analysis laboratory (Harrison, AR).

Cattle were transported to a commercial abattoir (Tyson Fresh Meats, Amarillo, TX) when each block was determined to have sufficient fat deposition to grade USDA choice or greater and reached a targeted shrunk BW (635 kg). The average DOF of the 5 blocks was 269 d. After slaughter, hot carcass weight (HCW) and liver score was

recorded by a trained technician (West Texas A&M Beef Carcass Research Center, Canyon, TX). After a 36-h chill, carcasses were assessed for fat thickness over the 12th rib, ribeye area, kidney-pelvic-and-heart fat (KPH), marbling score, and USDA quality grade. Yield grade and dressing percentage were subsequently calculated.

Calculations

Dressing percentage was calculated by dividing HCW by the final shrunk BW (BW × 0.96). To calculate the cost of each diet, the average price per kg of each ingredient purchased over the entire study was determined, multiplied by its dietary inclusion rate and summed. The feed cost was then multiplied by DMI to calculate the daily cost of feed. The average cost of feed was then divided by ADG to calculate feed cost of gain (FCOG). Calculated empty body fat (EBF) was determined using: EBF = 17.76207 + (4.6812 × fat thickness) + (0.01945 × HCW) + (0.81855 × Quality grade) – (0.06754 × ribeye area) as described by Guiroy et al. (2001). Similarly, empty BW (EBW) was also calculated from Guiroy et al. (2001) where EBW = (1.316 × HCW) + 32.29. Adjusted final BW (AFBW) was determined using the equation AFBW = [EBW + (28 – EBF) × 19]/0.891 as described by Tylutki et al. (1994). Performance-calculated net energy (NE) for maintenance (NEm) was calculated using the quadratic equation as described by Zinn and Shen (1998) where NEm = $-b \pm \sqrt{(b^2-4ac)}/2a$. In that equation, a = 0.877 × DMI; b = 0.877 × -EM + (-0.41 × DMI) - EG; and c = -0.41 × -EM where EM = energy for maintenance and EG = energy for gain. Energy for maintenance (EM; Mcal/d) was estimated using EM = 0.077 × BW$^{0.75}$ where BW = average BW × 0.96 (Lofgreen and Garrett, 1968) and energy gain (EG; Mcal/d) was estimated using the equation 0.0557 × EQSBW$^{0.75}$ × ADG$^{1.097}$ where EQSBW = BW × 478/AFBW (Zinn and Shen,

1998; NASEM, 2016). Performance-calculated net energy of gain (NEg) was subsequently calculated from NEm (NEg = 0.877 × NEm - 0.41) as previously described by Zinn and Shen (1998).

Rumination and activity data were collected using 3-axis accelerometer ear tags that provided data as the amount of time spent active or ruminating within a 2 h interval. Time spent ruminating or active was average daily and multiplied by 12 to calculate the total min ruminating or active per d. Rumen boluses produced a single pH reading every 10 min. Daily ruminal pH was calculated by averaging the pH recordings within a d. A pH of 5.6 was considered the threshold for ruminal acidosis (Cooper et al., 1998). It was assumed that if the pH reading was below the threshold of 5.6, the subsequent 10 min were also below 5.6. Daily time below a pH of 5.6 was calculated by summing the time below a pH of 5.6 within a d. To calculate the area under the curve (AUC) of 5.6, the pH reading was subtracted from 5.6 and multiplied by 10 min each time it was below 5.6. The AUC was then summed within d. Rumination and rumen pH data was only observed through d 146 because of limitations in battery life of the technology.

Statistical Analysis

Continuous data (performance and non-categorical carcass data) were analyzed as a generalized complete block design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Dietary treatment was analyzed in the model as a fixed effect with block as a random effect. Ruminal pH, rumination behavior, total activity, and serum chemistry were analyzed as repeated measures using the MIXED procedure with the main effects of treatment, d, and their interaction determined for each repeated variable. Covariance structure was determined by using the lowest Akaike information criterion. Categorical

data, such as morbidity, mortality, quality grade, and liver score were analyzed using the GLMMIX procedure of SAS as binomial proportions. Treatment means are presented as least square means ± standard error of the mean (SEM). Statistical significance was declared at $P \leq 0.05$, and a tendency was declared when $0.05 < P \leq 0.10$.

Results and Discussion

Live Animal Performance

Over the first 74 d of the study, DMI was less ($P < 0.01$; Table 2.3) for cattle consuming FIN compared to REC for every time interval analyzed. Interestingly, this translated to 0.20 kg/d less ($P = 0.01$) DMI for FIN than REC from d 0 to final, despite similar intakes after d 74 ($P = 0.80$), when all cattle were receiving the same finishing diet. Because the diets had different energy densities in the first 56 d, metabolizable energy (ME) intake was evaluated to compare differences in dietary energy consumption. Metabolizable energy intake was less for FIN cattle from d 0 to 14 ($P < 0.01$) and d 14 to 28 ($P = 0.02$), but not different ($P \geq 0.78$) for any of the time periods evaluated after d 28.

A series of similar experiments were conducted at the Clayton Livestock Research Center (Clayton, NM) from 1975 to 1981 to evaluate the implications of dietary energy density and/or concentrate inclusion on growth performance and health of newly received calves. Lofgreen et al. (1975) evaluated diets containing 20.0, 55.0, 72.0, or 90.0% concentrate in 3 experiments. Overall, DMI tended to decrease as percentage concentrate increased in the diet. In a subsequent study, Lofgreen et al. (1980) observed less DMI in cattle consuming a 75.0% concentrate diet compared to a 50.0% and 25.0% concentrate diet. In contrast, Reuter et al. (2008) observed greater DMI of a 70.0% concentrate diet compared to a 30.0% concentrate diet. Close out data from Iowa feedlots

between 1988 and 1997 indicated cattle consuming a diet with > 75.0% concentrate consumed 9.61 kg/d and cattle consuming < 75.0% concentrate diets had 0.31 kg greater DMI (9.92 kg/d) over the entire feedlot period (Koknaroglu et al., 2005). Overall, the majority of previous data agrees with the findings of the current study where REC had greater DMI compared to FIN cattle. This is likely caused by cattle eating to a constant energy and consume less feed when energy concentration increases.

Greater DMI of a lower concentrate diet may be from cattle eating to meet a dietary requirement for energy and consuming more of a less energy dense diet. It was previously observed that when energy in a feedlot diet is diluted by roughage concentration, cattle will increase DMI in an attempt to match the energy intake of the undiluted diet (Price et al., 1980; Krehbiel et al., 2006). When ruminants consume high-forage diets, satiety signaling is likely dictated by gut fill as opposed to the chemical feedback that occurs with high-concentrate diets (Forbes, 2003). Therefore, when DMI is not limited by gut fill, cattle will consume more of a low concentrate diet in an effort to meet energy requirements for maintenance and growth and less of a high-concentrate diet if they are eating to a constant energy intake. Krehbiel et al. (2006) observed a linear decrease in DMI as ME concentration increased in feedlot diets. In addition, providing familiar feed ingredients may increase DMI upon arrival to the feedlot. Cattle arriving to the feedlot have likely been grazing or fed roughage sources such as hay and would therefore be more familiar with roughage-based ingredients compared to concentrates such as grain. Miller-Cushon and DeVries (2011) conducted an experiment using 8 Holstein calves that had either been exposed to hay or grain for 7 wk after birth, then transitioned to a complete diet and observed for 9 wk. The calves previously fed grain

sorted the diet in an attempt to consume a greater proportion of ingredients with smaller particle size, such as concentrates, whereas calves exposed to hay preferred large particle feeds. This resulted in calves exposed to grains having greater ADG in both the first 7 wk and subsequent 9 wk because of increased selection of the more energy dense feeds.

In addition to energy concentration of the diets, the FIN diet contained greater concentrations of monensin compared to REC (34.5 vs. 24.0 g/ton) in an effort to match industry standards for finishing and receiving diets (Samuelson et al., 2016). Monensin has been observed to reduce DMI (Duffield et al., 2012) and therefore could have influenced the DMI in this study. In addition to monensin, dietary composition may have influenced DMI. The FIN diet contained les CP compared to the REC diet (13.2 vs. 13.9). Previously, Galyean and Goetsch (1993) indicated that CP deficiency in diets can cause a decrease in DMI of forages. However, these diets were grain based and neither diet was considered deficient in CP according to NASEM (2016). In addition to differences in CP, corn oil was added to the FIN diet and not to the REC diet. Fat can limit DMI, but the inclusion level used in this study has not previously been observed to negatively impact DMI (Zin, 1989). Further research may be necessary to confirm that CP and fat concentrations did not contribute to the differences in DMI and performance during the receiving period.

Because FIN had less DMI over the first 14 d, un-shrunk BW of cattle consuming REC was 8 kg heavier than FIN (Table 2.4; $P < 0.01$). In addition, dietary protein was greater in the REC diet compared to the FIN diet and may have contributed to the lack of BW gain in the first 14 d for FIN cattle. Because CP is required for immune function a decrease in dietary CP may have reduced the availability of CP available for growth in

the FIN cattle compared to REC. On d 28, FIN had similar un-shrunk BW compared to REC (277 kg; $P = 0.87$) and by d 56 FIN was 8 kg heavier than REC ($P < 0.01$). On d 74, when REC cattle were completely transitioned to the finishing diet, FIN weighed 364 kg compared to 354 kg for REC cattle ($P < 0.01$). Final un-shrunk BW for FIN (665 kg) tended to be greater ($P = 0.10$) than REC (655 kg). Therefore, FIN cattle were able to gain 10 kg more BW in the first 74 d and maintain greater BW through the entire finishing period. In the first 14 d, REC cattle gained 0.63 kg/d while FIN cattle had 0.0 kg ADG ($P < 0.01$). When predicting ADG from DMI and dietary energy concentrations (NASEM, 2016; data not shown), REC cattle were expected to gain 0.28 kg/d while FIN cattle were predicted to gain 0.43 kg/d. Because REC cattle outperformed expected ADG and FIN cattle underperformed expected ADG, this suggests the differences in ADG and BW from d 0 to 14 could be influenced by differences in gut fill during realimentation from the marketing process.

From d 14 to 28, FIN had greater ($P < 0.01$) ADG than REC despite consuming less ME. In addition, from d 28 to 56 FIN had greater ($P < 0.01$) ADG compared to REC with no difference ($P = 0.24$) in ADG from d 56 to 74. No difference in ADG among treatments from d 56 to 74 likely occurred because dietary composition became more similar over that time period as cattle on REC were eating at least a portion of their diet as FIN. Over the first 74 d, FIN had 9.35% greater ($P < 0.01$) ADG than REC with no difference ($P = 0.99$) in ADG from d 74 to final when all animals were consuming the same diet. These results are similar to Lofgreen et al. (1975), where cattle consuming a 90.0% concentrate diet had numerically less ADG during the first wk compared to a

72.0% concentrate diet, numerically greater ADG in the second wk, and statistically greater ADG from d 0 to 28.

Although there was less ME intake in the first 28 d and similar ME intake after d 28, the efficiency of ME utilization may have been different between dietary treatments and influenced ADG. Jennings et al. (2020) observed finishing cattle fed a 15.0% corn stalk diet consumed similar ME to cattle fed a 5.0% or 10.0% corn stalk diet but had reduced ADG. Greater heat production from the fermentation of roughage may have reduced the efficiency of ME utilization by the animals consuming the REC diet (Lofgreen and Garrett, 1968; Reynolds et al., 1991) and allowed cattle fed the FIN diet to have greater ADG after d 14. Another explanation for the differences in performance despite no difference in ME intake is that the ME values reported for concentrate ingredients such as grains in the NASEM (2016) publication are underestimated. Updated equations have been proposed by Galyean et al. (2016) and Hales (2019) to account for differences in the conversion of DE to ME between roughage and concentrate ingredients.

Because of no gain in the first 14 d for FIN, G:F was not calculated for this period. However, from d 14 to 28, 28 to 56, 56 to 74, and 0 to 74 G:F was greater ($P \leq 0.01$) for FIN cattle because they consumed less feed and gained similarly to REC. The increased G:F is from a combination of increased ME concentration and decreased DMI in FIN compared to REC cattle that allowed for similar ME intake and suggests greater ME utilization. After d 74, when all cattle were consuming the finishing diet and had similar DMI, there was no difference ($P = 0.80$) in G:F. However, the overall (d 0 to

final) G:F for FIN was greater ($P < 0.01$) than REC, indicating that differences in G:F for even a portion of the feeding period can impact overall efficiency.

Feed Cost of Gain

Feed cost of gain of cattle consuming both the REC and FIN diets is depicted in Table 2.5. The cost of the FIN diet was \$0.05/kg greater than the REC. However, cost per Mcal net energy for gain (NE_g) is less for grains than forages (Brokken et al., 1976). Therefore, when cost was corrected for the Mcal of NE_g in each diet, the FIN diet was \$0.19/Mcal NE_g and the REC was \$0.22/Mcal NE_g (data not shown). Therefore, the cost of the REC diet was more expensive per Mcal provided to the animal compared to the FIN diet, despite the FIN diet having greater total cost per kg of DM. Greater DMI and less ADG for REC than FIN from d 14 to 28 resulted in REC cattle having \$0.99/kg BW gain greater FCOG ($P = 0.08$). From d 28 to 56, the FCOG for REC cattle was \$0.15 greater ($P < 0.01$) than FIN. As the cattle transitioned to the FIN diet from d 56 to 74, there was no statistical difference ($P = 0.19$) in FCOG for REC (\$1.46/kg) compared to FIN (\$1.37/kg); however, the cumulative FCOG from d 0 to 74 was less ($P < 0.01$) for FIN compared to REC. From d 74 to final, there was no difference ($P = 0.89$) in FCOG because cattle had similar DMI, ADG, and were consuming the same diet. The overall FCOG was \$0.04 greater for REC compared to FIN (\$1.57/kg vs. \$1.53/kg), but was not statistically significant ($P = 0.13$). Nevertheless, when extrapolated to a feedlot capacity of 50,000 animals per year, reducing FCOG by \$0.04 could potentially decrease costs by \$590,000 annually based on an average BW gain of 295 kg (Crawford et al., 2021).

It is important to note FCOG only incorporates feed costs and does not account for differences in labor and depreciation of equipment from feed manufacturing and

delivery. In addition to FCOG, feeding logistics are important to help reduce variable costs. For example, greater bulk density of the diet reduces the weight capacity of a feed truck and requires more travel to and from the mill compared to a lower bulk density diet, resulting in more fuel and equipment use. The bulk density of the REC diet (288 kg/m^3) was approximately 2-fold greater than the FIN diet (144 kg/m^3) because of the greater roughage inclusion. Therefore, the total cost of feeding the REC diet compared to the FIN diet was likely greater than that predicted by the diet costs alone.

Health

Health outcomes are presented in Table 2.6. The proportion of cattle treated once or twice for BRD was 48.5% and 20.0% for both treatments (P = 1.00). The percentage of cattle treated 3 times for BRD was 10.0% and 10.5% for REC and FIN, respectively (P = 0.87). The proportion of cattle treated for illness not associated with BRD such as lameness, abscesses, and bloat did not differ (P = 0.31) among treatments. The mortality rate for REC and FIN was 1.5% and 3.0% and was also not different (P = 0.31). Therefore, the results of the present study suggest that feeding a high energy finishing diet in lieu of a traditional receiving diet containing higher concentrations of roughage increases growth performance and feed efficiency but does not alter health of high-risk cattle. Previously, Lofgreen et al. (1975) concluded that feeding a 90.0% concentrate diet compared to a 72.0 or 55.0% concentrate diet increased morbidity in 107 auction-derived steers (50.0, 40.0, and 36.0% morbidity, respectively). Rivera et al. (2005) later conducted a meta-analysis of data from the Clayton Livestock Research Center (Clayton, NM) and similarly reported a correlation between increased concentrate level and morbidity of feedlot cattle.

The discrepancy between the current research and that of Lofgreen et al. (1975) and Rivera et al. (2005) could be due, in part, to differences in diet formulations among studies. For example, steam-rolled barley was used by Lofgreen et al. (1975) and has greater ruminal starch digestibility compared to steam-flaked corn (Zinn, 1993). In addition, the diets used in the current study contained GMP, which may have reduced the rate of starch fermentation and mitigated the incidence of acidosis. Because BRD and acidosis have similar clinical signs, decreased ruminal acidosis may have reduced misdiagnosis of BRD and minimized differences in morbidity. It is also possible that inflammation from ruminal acidosis may impact susceptibility to BRD. In addition, the study conducted by Lofgreen et al. (1975) only used 107 steers with 2 pens per treatment, and therefore may not have had enough replications to robustly quantify morbidity.

The number of d before cattle were treated once, twice, or thrice for BRD were not different ($P \geq 0.57$) and the average number of d before mortality were not different ($P = 0.38$) between REC and FIN. Snowder et al. (2006) observed that the peak time of BRD morbidity was at 14 DOF, which is similar to the average d to first treatment (17 d) in the current study. Mortality rates in small pen research should be interpreted with caution because mortality rates are typically low and as a result, a single mortality has the potential to greatly influence pen means.

Ultrasound Characteristics

Ultrasound measurements were collected throughout the study to improve the understanding of compositional changes in 12th rib and rump fat thickness, ribeye area, and intermuscular fat over the feeding period. As expected, there was no difference (Table 2.7; $P \geq 0.65$) in any of the ultrasound measurements collected on the d of study

initiation (d 0). By d 74, FIN had greater fat thickness over the 12th rib ($P = 0.04$) and rump ($P = 0.04$) and tended to have greater ribeye area ($P = 0.10$) with no difference in intramuscular fat ($P = 0.93$). However, on d 146 there was no difference ($P \geq 0.37$) among treatments for any of the ultrasound measurements recorded. In addition, rump fat was not different ($P = 0.43$) immediately before slaughter. This indicates that greater dietary energy at the beginning of the feeding period may only have transient effects on carcass composition. Klinger et al. (2007) observed similar ultrasound results when limit-feeding a high energy diet (1.22 Mcal/kg NE_g) compared to a high roughage diet (0.94 Mcal/kg NE_g) during a 77-d backgrounding trial. Cattle fed the high energy diet had greater 12th rib fat on d 77 compared to ad libitum feeding of the low energy diet.

Growth composition at different energy intakes has been previously studied using comparative slaughter (Wright and Russel, 1991). Wright and Russel (1991) enrolled cattle at 250 kg and either provided grass pellets at a high level of energy (0.05 Mcal/kg BW) throughout the trial, or at a low level of energy (0.04 Mcal/kg BW) until they reached 350 kg, when both treatments were offered the same diet. During treatment application, cattle with less energy intake also had less body fat. However, similar to the current study, once dietary energy concentrations of the 2 groups did not differ, cattle consuming the lower energy diet were able to compensate for differences in tissue deposition and carcass characteristics were similar by the time each group reached 450 kg of live weight. These results suggest carcass composition of cattle shifts throughout the feeding period and could offset less fat deposition during backgrounding and/or receiving because of changes in maintenance requirements. Therefore, the current study suggests

that providing a finishing diet earlier in the feeding period does not cause excessive fat deposition in relation to lean tissue and bone growth.

Post-Mortem Carcass Characteristics

As a result of greater final BW, HCW (Table 2.8) of FIN cattle was 9 kg heavier ($P = 0.04$) than REC (414 vs. 405 kg, respectively). Dressing percentage was not different ($P = 0.11$) between FIN (64.8 %) and REC (64.5 %) cattle. There was no difference in carcass 12th rib fat thickness ($P = 0.44$) or carcass ribeye area ($P = 0.11$) among cattle consuming FIN or REC. Furthermore, there was no difference in marbling score ($P = 0.17$) or quality grade ($P \geq 0.31$). Calculated yield grade was also not different between treatments ($P = 0.77$). With the exception of greater HCW for FIN, similar carcass characteristics supports the ultrasound observations on d 146 and illustrates that feeding a high energy diet at arrival does not negatively impact carcass composition. Furthermore, the greater fat deposition measured via ultrasound at the beginning of the feeding period, did not result in over fattening cattle before slaughter. Limited data exists evaluating the effects of dietary energy density during the receiving period on carcass characteristics of finishing cattle. Much of the previous research focusing on this topic (Lofgreen et al., 1975; Lofgreen et al., 1980; Tomczak et al., 2019) has only been evaluated during the receiving period, from 28 to 56 d after arrival and did not report differences in cattle performance and body composition over the entire feeding period or post-mortem carcass characteristics. However, when cattle were followed to slaughter by Lofgreen et al. (1975), there were no differences in carcass composition despite performance differences observed early in the feeding period.

Cattle fed the REC diet had 20.77% liver abscesses and were not different (P = 0.18) from the FIN treatment (14.71%). Liver abscesses are a concern in feedlot cattle because of reduced performance and carcass value associated with their formation (Nagaraja and Chengappa, 1998). Liver abscesses are caused by bacteria that escape from the digestive tract and travel through the portal blood stream to the liver, resulting in the infection that leads to an abscess. Ruminal acidosis predisposes cattle to liver abscesses and can be caused by increased starch concentrations in feedlot diets and/or erratic consumption of starch (Nagaraja and Chengappa, 1998).

In previous research by Klinger et al. (2007), cattle were limit-fed a high energy diet compared to a high roughage diet fed ad libitum during the backgrounding phase in 2 different trials. The backgrounding phase was 77 d and cattle fed the high energy diet were limited to 2.2% of BW and 1.9% of BW in trial 1 and 2 respectively. After the backgrounding phase, cattle were comingled and shipped to a commercial feedlot where they were fed in the same pen until slaughter. There was no difference in the proportion of liver abscesses among treatments in the first trial, but a greater proportion of liver abscesses were observed in the limit-fed cattle in the second trial. When cattle are provided ad libitum feed following DMI restriction, they may over consume and subsequently induce ruminal acidosis that could lead to liver abscesses. Therefore, Klinger et al. (2007) proposed the difference in liver abscess proportion between trials may have been from the more restricted DMI in trial 2 compared to trial 1. In the current study, feed offered was managed similarly for both FIN and REC and could explain the lack of difference in liver abscesses observed in contrast to Klinger et al. (2007).

Body Composition and Performance Calculated Energy

There was no difference in EBF between treatments ($P = 0.15$; Table 2.9). When empty BW was calculated from HCW, there was no difference ($P = 0.46$) between treatments, but FIN was 4 kg heavier than REC. Because there was a numerical trend for EBF to be greater for FIN, the adjusted final BW to a similar EBF was not different ($P = 0.25$) between REC and FIN. Performance-calculated net energy tended ($P = 0.08$) to be greater for FIN than REC. This was expected because of the improvement in G:F for the FIN cattle compared to REC and further supports the hypothesis that cattle consuming FIN used ME more efficiently compared to the REC diet.

Blood Chemistry

There were no differences observed by dietary treatment for serum creatinine, K^+, or total CO_2 ($P \geq 0.18$; Table 2.10). However, there was a diet × day interaction ($P = 0.02$) for BUN where FIN had reduced BUN compared to REC on d 28. Blood urea nitrogen concentrations for both FIN and REC decreased ($P < 0.01$; day effect) from d 0 (10.75 mg/dL and 10.54 mg/dL for FIN and REC, respectively) to d 14 (7.67 and 8.67 mg/dL for FIN and REC respectively). Elevated BUN concentration of newly received cattle on d 0 may be caused by mobilization of protein stores to compensate for inadequate DMI (Richeson et al., 2015), or from immune requirements for amino acids (Petersen et al., 2004). Lower BUN for FIN compared to REC on d 28 is likely from the combination of less DMI, lower dietary CP, and potential differences in microbial utilization of rumen degradable protein because of greater availability of energy from starch digestion. Ellenberger et al. (1989) observed that cattle had decreased BUN after

refeeding from 50.0% of ad libitum DMI despite high protein intake, indicating the efficiency of protein use increases with energy consumption.

Diet × day interactions ($P = 0.03$) were also observed for blood concentrations of Cl^-. On d 14 serum Cl^- for FIN was greater than REC but was snot different on d 0 or 28. Greater DMI for REC in the first 14 d may have caused increased water intake and retention, thereby diluting Cl^- in the blood (Khelil-Arfa et al., 2012). Although there was a diet × day interaction ($P < 0.01$) for Na^+, there were no treatment differences within d. Previously, Apple et al. (1993) observed no difference in blood Na^+ or Cl^- concentrations after sheep were exposed to 18 h of restraint and isolation stress. Cole et al. (1988) observed no difference in serum Na^+ concentrations after 24 h of transport stress in newly received calves. Therefore, differences in DMI and dietary composition likely impacted Cl^- and Na^+ concentrations in this study either directly or indirectly. Khelil-Arfa et al. (2012) noted that feeding greater concentrate levels in dairy cattle diets increased water intake. Therefore, although not measured in the present study, FIN cattle may have consumed more water than REC cattle in proportion to DMI, influencing the rumen osmolality and subsequently Na^+ and Cl^- concentrations. Because Na^+ and Cl^- are transported across the rumen wall through passive diffusion, dilution in the rumen from increased water intake may decrease absorption.

There was a day effect ($P < 0.01$) for ALT concentration, which decreased from d 0 to 14. Alanine transaminase is a marker of liver function, and an increased concentration can indicate liver damage (Pagana and Pagana, 2013). In high-risk cattle, Smock et al. (2020) observed a decline in ALT in the first 14 d after feedlot arrival. If liver function is reduced when high-risk cattle arrive at the feedlot, it is not surprising that

blood glucose concentrations were also less on d 0 compared to d 14 ($P < 0.01$). Because cattle have little ability to absorb glucose directly from feed, gluconeogenesis is an important function of the liver to maintain blood glucose concentrations (Young, 1977). In addition, no DMI during transport could have resulted in the lower blood glucose concentrations observed on d 0 compared to d 14 and 28 (Young, 1977). This suggests that as cattle began consuming feed, they were able to overcome the negative energy balance the resulted from stress and inadequate nutrition before feedlot arrival. There were no treatment differences observed for ALT or glucose concentrations ($P \geq 0.18$).

Rumen pH and Animal Behavior

A diet × day interaction ($P < 0.01$; Fig 2.1) was observed for average daily ruminal pH where FIN had a greater rumen pH than REC on d 2 and 131, but no other time points differed. Greater rumen pH on d 2 was likely influenced by less DMI of the FIN cattle, which could have resulted in lower concentrations of volatile fatty acids (VFA) and caused greater ruminal pH. Greater pH is supported by research conducted by Galyean et al. (1981), where ruminally cannulated steers were fasted for 32 h and compared to a control that had access to feed during the entire experiment. Fasted cattle had greater ruminal pH and less total VFA during fasting and experienced a rapid decline in pH after realimentation. However, total VFA were similar between the fasted and control treatments 24 h after feed was provided and ruminal pH did not stabilize until 72 h. By d 3, ruminal pH of FIN cattle had declined to a similar level as REC. The difference observed on d 131 is likely from random variation and does not appear to have biological significance. Overall ruminal pH of REC and FIN were 6.52 and 6.57 respectively ($P = 0.62$). There was also a diet × day interaction ($P < 0.01$) for time below

a pH of 5.6 (Fig 2.2) and area under a pH of 5.6 (Fig 2.3). Daily time below 5.6 was greater for FIN on d 4 to 8. Similarly, AUC for FIN was greater on d 4, 5, 6, and 19. A pH of 5.6 is considered the threshold for subacute ruminal acidosis in feedlot cattle (Owens et al., 1998). The peak time spent below pH of 5.6 was on d 6, where FIN spent approximately 341 min, and REC spent 154 min in a state of subacute acidosis. After d 8, the daily time below a pH of 5.6 did not exceed 85 min for either treatment. Because ruminal pH was similar between treatment diets before calculated ME intake converged, this may indicate that factors other than acidosis could have influenced differences in DMI.

In a similar study conducted with individually fed newly received calves, ruminal pH tended to be lower for cattle consuming a finishing diet than a receiving diet in the second wk after arrival to the feedlot, but was not different at any other time (Tomczak et al., 2019). The greatest time below a pH of 5.6 and AUC did not occur until wk 3 of the trial, where the time below reached 645 min per d for the finishing diet compared to 265 min for the receiving diet. Although a similar cattle source was used by Tomczak et al. (2019), the delayed reduction in ruminal pH compared to the current study may have been from differences in social dynamics that affect eating behavior of cattle housed individually vs. in a group (González et al., 2008). In addition, Tomczak et al. (2019) reported that bunk management of the FIN diet was designed to allow a slower increase in DMI over the first 14 d that may have resulted in restriction of DMI. After d 14, feed management changed, which allowed DMI to increase more rapidly compared to the first 14 d and may explain the increase in time below and AUC of 5.6 during wk 3.

There was a treatment × day interaction for daily rumination min, where cattle assigned to REC spent more time ruminating on d 1 to 14, 17 to 23, 26, and 28 of the study ($P < 0.01$; Fig 2.4). Cattle in the REC group likely had greater rumination time because of greater dietary roughage inclusion increases DMI and rumination (Galyean and Defoor, 2003). However, after d 28, there was no difference in rumination time except on d 143. Interestingly, the difference in rumination min was not present from d 28 to 56 despite the REC cattle consuming more feed and a greater proportion of roughage than the FIN cattle. When rumination time was expressed per kg of DMI, there was a diet × day interaction ($P \leq 0.05$; Fig 2.5) where the FIN cattle had greater rumination per kg DMI on d 1, 2, and 60 but less on d 4 to 8, 10 to 14, and 18. Greater rumination time per kg of DMI may have contributed to a greater pH for FIN on d 2 compared to REC. The decreased time spent ruminating per kg of DMI on d 4 to 8, 10 to 14, and 18 is likely from the lower inclusion of roughage in the FIN diet. Tomczak et al. (2019) also observed that cattle consuming a receiving diet had greater rumination per kg DMI at the beginning of the feeding period compared to a finishing diet. However, similar to overall rumination min, no difference was observed in rumination per kg of DMI after d 18 except on d 60, despite the greater proportion of roughage in the diet of cattle consuming REC. When roughage particle size and inclusion rate were measured by Gentry et al. (2016), there was no difference in rumination time for the first 111 d in the feedlot. On d 112, although no dietary change had been made, the cattle receiving the diet containing 5.0% roughage began ruminating less than the diets with 10.0% roughage. These results indicate factors independent of diet may influence rumination time. Another explanation for the convergence is that there is a threshold roughage intake required to

stimulate maximum rumination. This concept is supported by rumination/kg of DMI becoming similar for FIN and REC by d 18, and from d 18 to 56 rumination/kg DMI continued to decrease for both FIN and REC with greater DMI. Although there were differences in rumination, there was no dietary effect on animal activity (P = 0.48; Fig 2.6).

Implications

High-risk cattle that enter the feedlot with unknown pre-arrival management have low DMI and increased risk for disease in the first 28 d. For this reason, there is potential to use alternative cattle feeding and management strategies to help facilitate improved performance. Providing a high energy finishing diet upon arrival may be one option to increase growth performance and feed efficiency without negatively impacting health. Results of this study also indicate there may be a greater risk for acidosis in the first wk after feedlot arrival, despite low DMI within both treatments. In addition to growth performance improvements, feed cost of gain is reduced when feeding a high energy diet upon arrival. Additional research is needed to investigate this concept in large pens to understand how a high energy finishing diet would affect cattle performance in a commercial setting where differences in stocking density and feeding behavior may further influence cattle performance, health, and the rumen environment.

Table 2.1: Dietary composition of treatment diets

Item	REC[1]	FIN[2]
Ingredient, % of DM		
Steam-flaked corn	24.2	62.0
Sorghum sudan hay	32.0	-
Corn stalks	-	8.0
Molasses blend[3]	5.0	2.5
Corn oil	-	3.0
WCGF[4]	35.0	20.0
Supplement[5]	3.8	4.5
Nutrient analysis,[6] DM basis		
Dry matter, %	75.5	78.0
Crude protein, %	13.9	13.2
Acid detergent fiber, %	22.1	9.6
Total starch, %	25.9	52.5
ME,[7] Mcal/kg	2.76	3.20
NEm,[7] Mcal/kg	1.66	2.19
NEg,[7] Mcal/kg	1.05	1.51

[1]REC = cattle fed a receiving diet for the first 56 d then transitioned to a finishing diet over 18 d

[2]FIN = cattle fed a finishing diet for the entire feeding period

[3]72 Brix Molasses Blend (Westway Feed Products LLC, Hereford, TX)

[4]Sweet Bran (Cargill, Blair, NE)

[5]REC supplement was formulated to provide 49.24% calcium carbonate, 22.40% rice mill byproduct, 15.80% urea, 7.90% salt, 2.00% lecithin, 1.71% micro mineral premix, 0.31% vitamin E, 0.19% vitamin A, and provided 24.0 g/ton monensin and 8.2g/ton tylosin to the total diet (Hi-Pro Feeds, Friona, TX); FIN supplement contained 38.22% calcium carbonate, 23.06% rice mill byproduct, 18.44% urea, 9.37% potassium chloride, 6.67% salt, 2.00% lecithin, 1.44% micro mineral premix, 0.18% vitamin E, 0.12% vitamin A, and provided 34.5 g/ton monensin and 8.0 g/ton tylosin to the total diet (Hi-Pro Feeds, Friona, TX)

[6]Analyzed by Servi-tech Laboratories, Amarillo, TX

[7]ME, NEm, and NEg were calculated from tabular values (NASEM, 2016)

Table 2.2: Clinical illness score definitions

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

Table 2.3: Dry matter intake of cattle fed a receiving or finishing diet upon arrival to the feedlot

Item	REC[1]	FIN[2]	SEM[3]	*P*-value
Dry matter intake, kg				
D 0 to 14	3.90	2.78	0.13	<0.01
D 14 to 28	6.43	5.19	0.16	<0.01
D 28 to 56	8.18	7.14	0.14	<0.01
D 56 to 74	8.68	8.07	0.17	<0.01
D 0 to 74	7.16	6.17	0.11	<0.01
D 74 to final	8.99	9.02	0.11	0.80
D 0 to final	8.48	8.22	0.10	0.01
Calculated ME intake,[4] Mcal				
D 0 to 14	10.79	8.92	0.36	<0.01
D 14 to 28	17.77	16.62	0.48	0.02
D 28 to 56	22.60	22.86	0.40	0.51
D 56 to 74	25.96	25.85	0.52	0.84
D 0 to 74	20.19	19.77	0.31	0.19
D 74 to final	28.79	28.88	0.36	0.80
D 0 to final	26.41	26.32	0.30	0.78

[1]REC = cattle fed a receiving diet for the first 56 d then transitioned to a finishing diet over 18 d

[2]FIN = cattle fed a finishing diet for the entire feeding period

[3]SEM = standard error of the mean

[4]ME intake = metabolizable energy intake calculated by multiplying daily DMI by dietary ME

Table 2.4: Performance of cattle fed a receiving or finishing diet upon arrival to the feedlot

Item	REC[1]	FIN[2]	SEM[3]	*P*-value
Un-shrunk BW,[4] kg				
D 0	252	252	0.3	0.26
D 14	260	252	1.9	<0.01
D 28	277	277	2.2	0.87
D 56	326	334	2.7	<0.01
D 74	354	364	2.7	<0.01
Final	655	665	5.9	0.10
Shrunk BW,[5] kg				
D 0	242	242	0.3	0.26
D 14	250	242	1.9	<0.01
D 28	266	266	2.1	0.87
D 56	313	321	2.6	0.01
D 74	340	350	2.6	<0.01
Final	629	638	5.7	0.01
Un-shrunk ADG,[6] kg				
D 0 to 14	0.63	0.00	0.14	<0.01
D 14 to 28	1.20	1.81	0.10	<0.01
D 28 to 56	1.74	2.04	0.09	<0.01
D 56 to 74	1.58	1.67	0.08	0.24
D 0 to 74	1.39	1.52	0.04	<0.01
D 74 to final	1.56	1.56	0.03	0.99
D 0 to final	1.47	1.51	0.03	0.18
Un-shrunk G:F[7]				
D 14 to 28	0.188	0.352	0.019	<0.01
D 28 to 56	0.213	0.286	0.010	<0.01
D 56 to 74	0.182	0.207	0.009	0.01
D 0 to 74	0.194	0.245	0.004	<0.01
D 74 to final	0.174	0.173	0.002	0.80
D 0 to final	0.173	0.184	0.003	<0.01

[1]REC = cattle fed a receiving diet for the first 56 d then transitioned to a finishing diet over 18 d
[2]FIN = cattle fed a finishing diet for the entire feeding period
[3]SEM = standard error of the mean
[4]BW = body weight
[5]Shrunk body weight = un-shrunk BW × 0.96
[6]ADG = average daily gain
[7]G:F = gain:feed

Table 2.5: Feed cost of gain of cattle fed a receiving or finishing diet upon arrival to the feedlot

Item	REC[1]	FIN[2]	SEM[3]	*P*-value
Diet cost, $/kg	0.23	0.28	-	-
Feed cost of gain, $/kg				
D 14 to 28	1.80	0.81	0.54	0.08
D 28 to 56	1.13	0.98	0.05	<0.01
D 56 to 74	1.46	1.37	0.07	0.19
D 0 to 74	1.23	1.14	0.03	<0.01
D 74 to final	1.62	1.62	0.02	0.89
D 0 to final	1.57	1.53	0.03	0.13

[1]REC = cattle fed a receiving diet for the first 56 d then transitioned to a finishing diet over 18 d
[2]FIN = cattle fed a finishing diet for the entire feeding period
[3]SEM = standard error of the mean

Table 2.6: Morbidity and mortality measurements for cattle fed a receiving or finishing diet upon arrival to the feedlot

Item	REC[1]	FIN[2]	SEM[3]	*P*-value
1st BRD treatment,[4] %	48.5	48.5	-	1.00
2nd BRD treatment, %	20.0	20.0	-	1.00
3rd BRD treatment, %	10.0	10.5	-	0.87
Other treatment,[5] %	5.0	3.0	-	0.31
Mortality, %	1.5	3.0	-	0.31
Days to 1st treatment	16.2	17.8	2.95	0.58
Days to 2nd treatment	25.8	22.9	5.01	0.57
Days to 3rd treatment	32.5	31.7	5.67	0.88
Days to mortality	58.8	49.5	9.02	0.38

[1]REC = cattle fed a receiving diet for the first 56 d then transitioned to a finishing diet over 18 d
[2]FIN = cattle fed a finishing diet for the entire feeding period
[3]SEM = standard error of the mean
[4]BRD = bovine respiratory disease
[5]Other treatments included bloat, lameness, or injury

Table 2.7: Ultrasound variables of cattle fed a receiving or finishing diet upon arrival to the feedlot

Item	REC[1]	FIN[2]	SEM[3]	*P*-value
12th rib fat thickness, cm				
D 0	0.23	0.23	0.01	0.99
D 74	0.45	0.49	0.02	0.04
D 146	0.86	0.88	0.03	0.68
Rump fat thickness, cm				
D 0	0.24	0.23	0.01	0.87
D 74	0.59	0.64	0.02	0.04
D 146	1.10	1.12	0.03	0.52
Final	1.52	1.49	0.05	0.43
Ribeye area, cm^2				
D 0	44.45	44.15	0.66	0.65
D 74	61.20	63.07	1.11	0.10
D 146	81.76	82.67	1.01	0.37
Intramuscular fat, %				
D 0	2.93	2.93	0.04	0.98
D 74	3.14	3.14	0.04	0.93
D 146	3.61	3.63	0.07	0.84

[1]REC = cattle fed a receiving diet for the first 56 d then transitioned to a finishing diet over 18 d
[2]FIN = cattle fed a finishing diet for the entire feeding period
[3]SEM = standard error of the mean

Table 2.8: Carcass traits of cattle fed a receiving or finishing diet upon arrival to the feedlot

Item	REC[1]	FIN[2]	SEM[3]	*P*-value
HCW,[4] kg	405	414	3.78	0.04
Dressing, %	64.5	64.8	0.20	0.11
12th rib fat thickness, cm	1.47	1.52	0.06	0.46
Ribeye area, cm^2	94.7	96.4	1.03	0.11
Marbling score	44.68	45.95	0.91	0.17
Quality grade, %				
Prime	1.54	1.56	-	0.98
Choice	66.68	70.54	-	0.43
Select	31.25	26.33	-	0.31
Standard	0.53	1.57	-	0.61
Calculated yield grade[5]	3.08	3.10	0.09	0.77
Liver abscesses, %	20.77	14.72	-	0.18

[1]REC = cattle fed a receiving diet for the first 56 d then transitioned to a finishing diet over 18 d
[2]FIN = cattle fed a finishing diet for the entire feeding period
[3]SEM = standard error of the mean
[4]HCW = hot carcass weight
[5]Calculated using the USDA (2017) regression equation

Table 2.9: Empty body fat, empty body weight, adjusted body weight, and performance calculated energy of cattle fed a receiving or finishing diet upon arrival to the feedlot

Item	REC[1]	FIN[2]	SEM[3]	*P*-value
Empty body fat,[4] %	30.54	31.06	0.35	0.15
Empty body weight,[5] %	569	573	5.23	0.46
AFBW,[6] %	585	578	5.72	0.25
Performance-Calculated NE[7]				
NEm Mcal/kg	2.03	2.06	0.02	0.08
NEg Mcal/kg	1.37	1.40	0.02	0.08

[1]REC = cattle fed a receiving diet for the first 56 d then transitioned to a finishing diet over 18 d

[2]FIN = cattle fed a finishing diet for the entire feeding period

[3]SEM = standard error of the mean

[4]EBF = 17.76207 + (4.68142 × fat thickness) + (0.01945 × HCW) + (0.81855 × Quality grade) – (0.06754 × ribeye area) from Guiroy et al. (2001).

[5]EBW = (1.316 × HCW) + 32.29 from Guiroy et al. (2001).

[6]AFBW = adjusted final BW, AFBW = [EBW + (28 – EBF) × 19]/0.891 (Tylutki et al., 1994; Guiroy et al., 2001).

[7]Performance-calculated dietary NEm = $-b \pm \sqrt{(b^2-4ac)}/2a$ and performance-calculated dietary NEg = 0.877 × NEm-0.41, where a = 0.877 × DMI; b = 0.877 × -EM + (-0.41 × DMI) - EG; and c = -0.41 × -EM (Zinn and Shen, 1998). Energy maintenance (EM; Mcal/d) was estimated using EM = $0.077 \times BW^{0.75}$ where BW = average BW × 0.96 (Lofgreen and Garrett, 1968) and energy gain (EG; Mcal/d) was estimated using the equation $0.0557 \times (BW * 478/FSBW)^{0.75} \times ADG^{1.097}$ where FSBW = final shrunk BW.

Table 2.10: Effects of diet on serum chemistry in newly received feedlot cattle

	Treatment			*P*-value		
Item	REC[1]	FIN[2]	SEM[3]	Diet	Day	Diet × Day
Alanine transaminase, U/L						
D 0	22.08	20.17	1.39	0.18	<0.01	0.49
D 14	16.92	14.50				
D 28	18.63	17.92				
Blood urea nitrogen, mg/dL						
D 0	10.54	10.75	0.54	0.11	<0.01	0.02
D 14	8.67	7.67				
D 28*	8.21	6.33				
Cl-, mmol/L						
D 0	99.63	98.54	0.69	0.37	0.03	0.03
D 14*	96.88	98.50				
D 28	97.38	98.54				
Creatinine, mg/dL						
D 0	1.73	1.58	0.07	0.33	<0.01	0.22
D 14	1.20	1.27				
D 28	1.15	1.09				
Glucose, mg/dL						
D 0	82.33	85.04	3.38	0.64	<0.01	0.73
D 14	90.17	92.67				
D 28	98.96	98.25				
K+, mmol/L						
D 0	5.38	5.36	0.13	0.48	0.02	0.65
D 14	5.70	5.52				
D 28	5.66	5.58				
Na+, mmol/L						
D 0	142.71	141.12	0.72	0.53	<0.01	< 0.01
D 14	140.75	139.79				
D 28	140.71	142.00				
Total CO_2, mmol/L						
D 0	25.67	24.42	0.47	0.27	<0.01	0.64
D 14	27.33	26.96				
D 28	27.29	27.13				

[1]REC = cattle fed a receiving diet for the first 56 d then transitioned to a finishing diet over 18 d

[2]FIN = cattle fed a finishing diet for the entire feeding period

[3]SEM = standard error of the mean

[4]HCW = hot carcass weight

*treatments differed within day $P \leq 0.05$

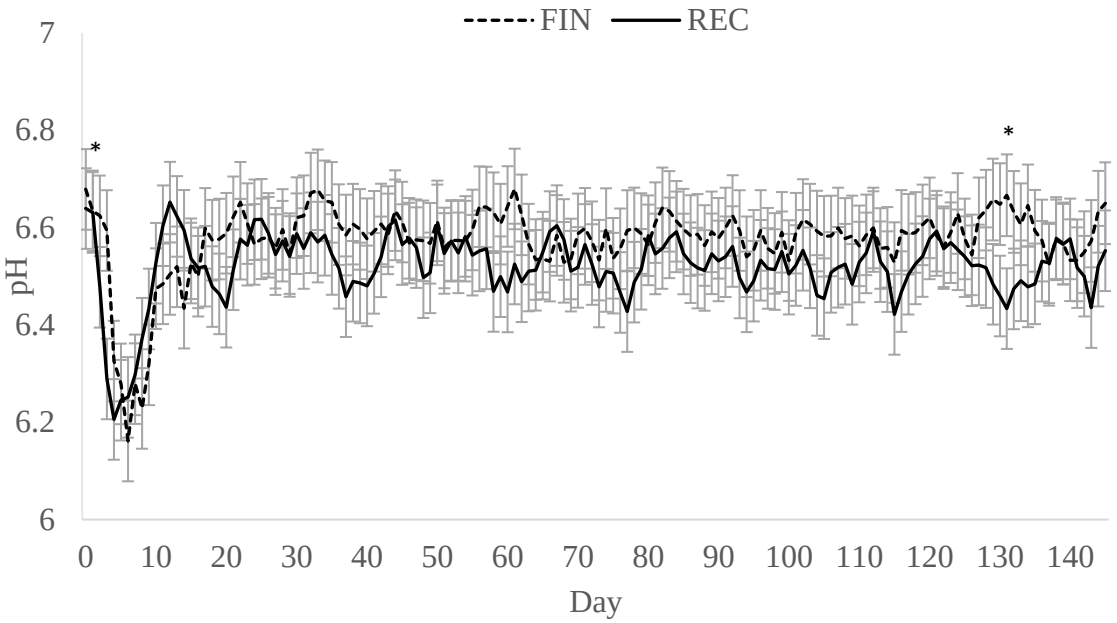

Figure 2.1: Average daily ruminal pH of cattle fed a receiving or finishing diet upon arrival to the feedlot. Effect of treatment $P = 0.62$, day < 0.01, treatment × day $P < 0.01$. *Treatments differ within day, $P \leq 0.05$

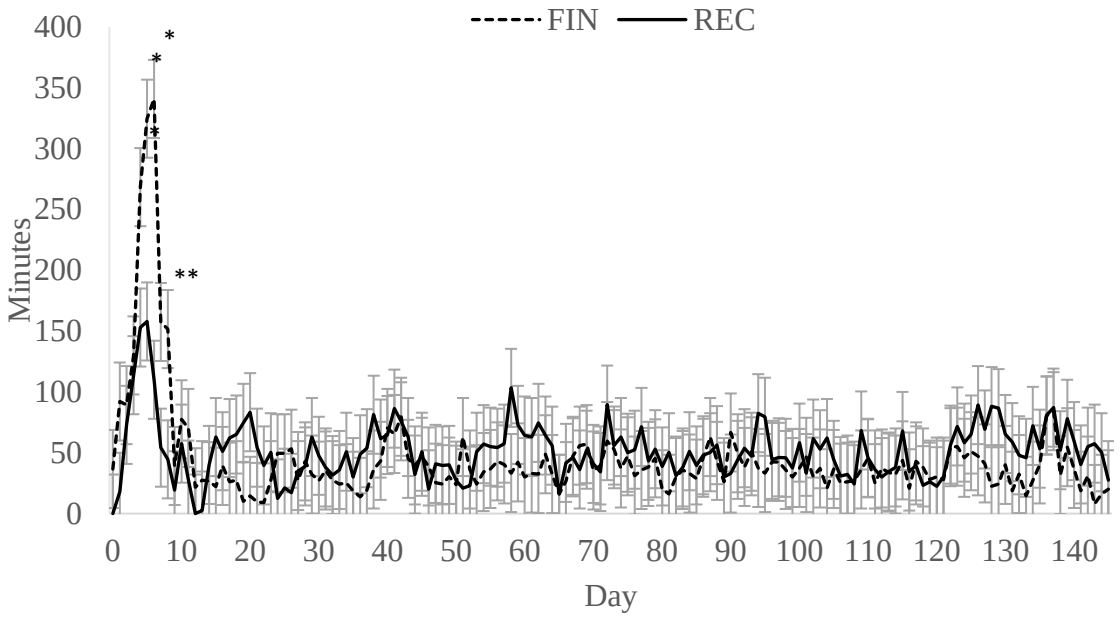

Figure 2.2: Daily time that ruminal pH was below 5.6 for cattle fed a receiving or finishing diet upon arrival to the feedlot. Effect of treatment $P = 0.86$, day < 0.01, treatment × day $P < 0.01$.
*Treatments differ within day, $P \leq 0.05$

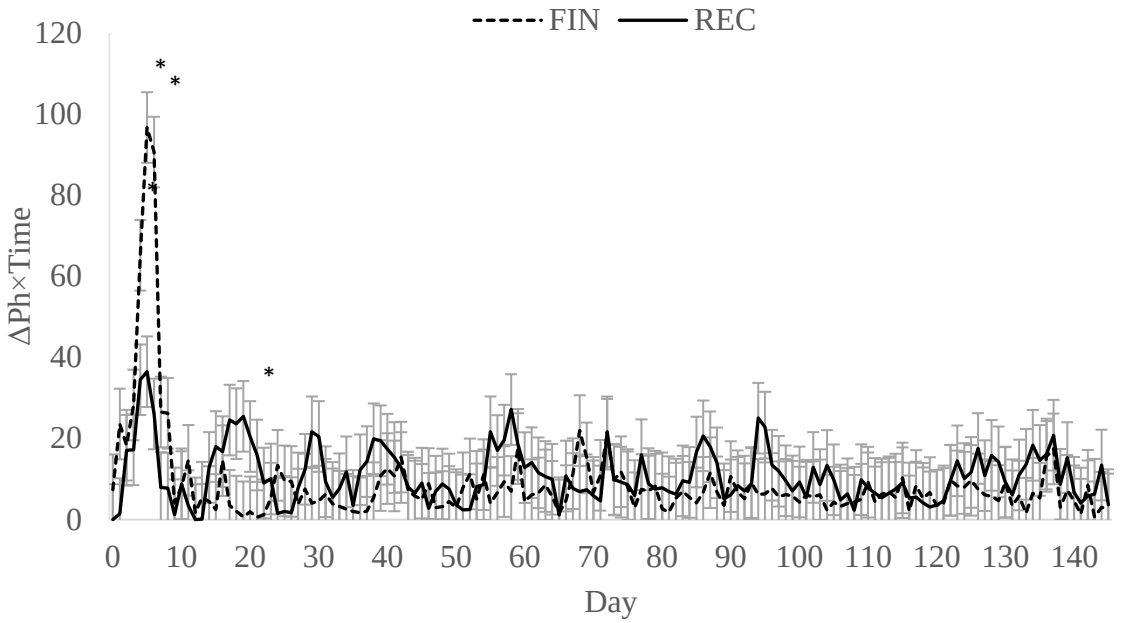

Figure 2.3: Ruminal pH daily area under 5.6 for cattle fed a receiving or finishing diet upon arrival to the feedlot. Effect of treatment $P = 0.82$, day < 0.01, treatment × day $P \leq 0.03$.
*Treatments differ within day, $P \leq 0.05$

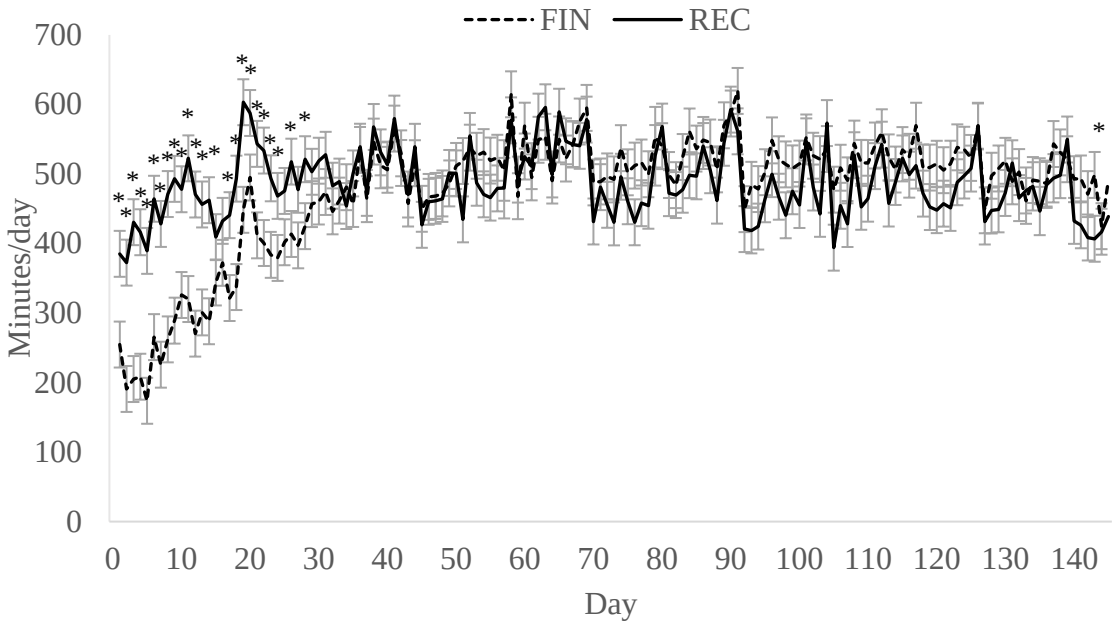

Figure 2.4: Minutes per d of rumination time for cattle fed a receiving or finishing diet upon arrival to the feedlot. Effect of treatment $P = 0.67$, day < 0.01, treatment × day $P <$ 0.01.
*Treatments differ within day, $P \leq 0.05$

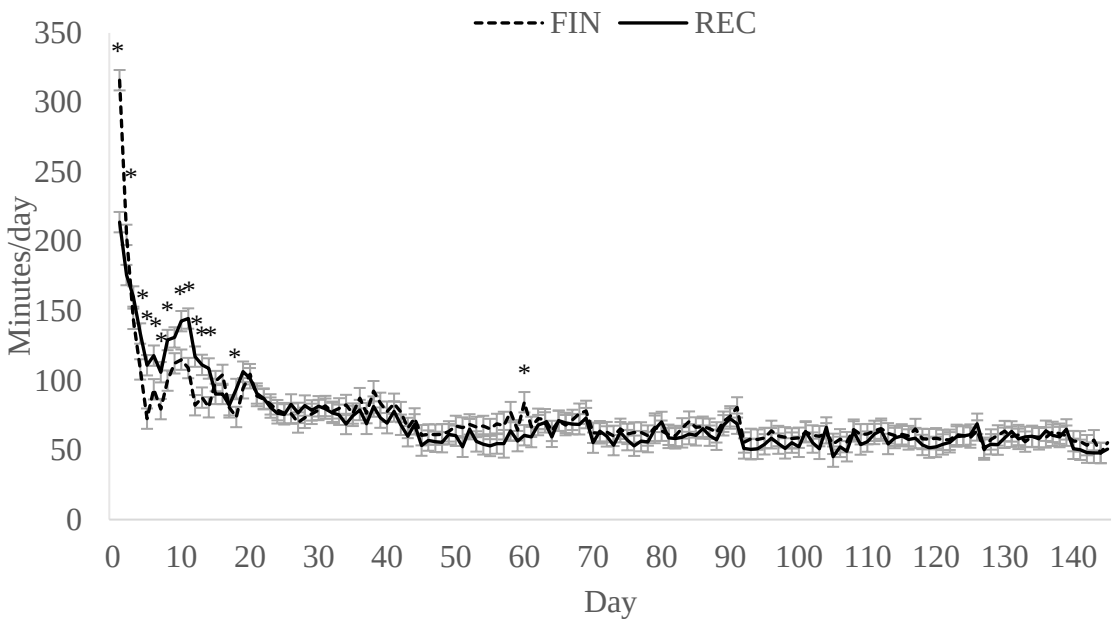

Figure 2.5: Minutes per d spent ruminating per kg of DMI cattle fed a receiving or finishing diet upon arrival to the feedlot. Effect of treatment $P = 0.61$, day < 0.01, treatment × day $P < 0.01$.
*Treatments differ within day, $P \leq 0.05$

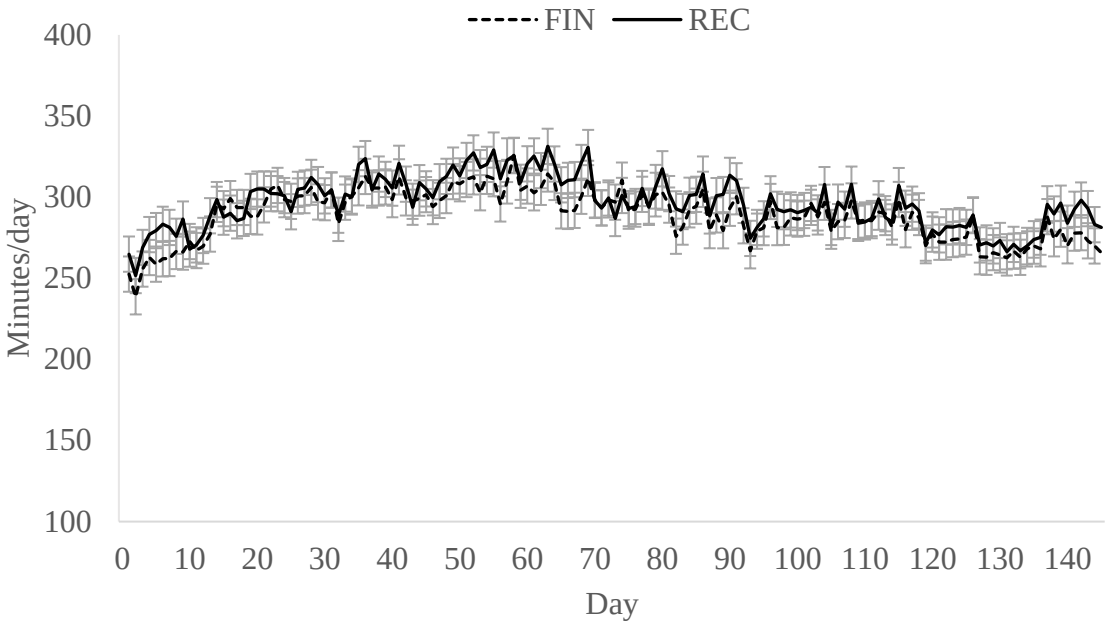

Figure 2.6: Minutes of activity per d for cattle fed a receiving or finishing diet upon arrival to the feedlot. Effect of treatment $P = 0.48$, day < 0.01, treatment × day $P = 1.00$.

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CHAPTER III

IMPACT OF DIFFERING INCLUSION OF GRAIN-MILLING PRODUCT FEEDS ON DIGESTION CHARACTERISTICS OF BEEF CATTLE

Abstract

The objective of this study was to determine the effects of feeding grain-milling products (GMP) on digestion, passage rate, ruminal pH, and ruminal volatile fatty acid (VFA) and ammonia (NH_3) concentrations of beef cattle. Four Angus × Hereford steers were used in a 4 × 4 Latin square design with 4 periods and 4 treatments. Four dietary treatments included diets with no GMP (CON), 20% wet distillers grains with solubles (WDGS20), 20% Sweet Bran (SB20), or a combination of 10% wet distillers grains with solubles and 20% Sweet Bran (COMBO). Diets were analyzed for physically effective neutral detergent fiber (peNDF) using the Penn State Particle Separator. Each experimental period consisted of 21 d of adaptation, 5 d of total fecal collections, 3 d of in situ digestibility determination, and 1 d for rumen evacuations. Rumen fluid was collected via a fistula for VFA and NH_3 analyses and ruminal pH was measured with an indwelling pH bolus. The proportion of particles > 4.0 mm was greatest ($P < 0.01$) for CON, intermediate for SB20, and least for WDGS20 and COMBO, but peNDF did not differ ($P = 0.11$) among treatments. Total tract neutral detergent fiber (NDF) digestibility was greater ($P \leq 0.05$) for COMBO than CON, and acid detergent fiber (ADF) digestibility was greater for WDGS20, SB20, and COMBO than CON. A diet × hour interaction ($P \leq 0.05$) was observed for molar proportions of propionate, butyrate, and

valerate. Ruminal pH also had a diet × hour interaction ($P = 0.02$). There was a tendency ($P = 0.07$) for SB20 and CON to have the largest area under the curve (AUC) under a pH of 5.6. There was a tendency for dry matter (DM) intake before rumen evacuation to be greater ($P = 0.06$) for GMP diets than cattle consuming CON. Although there was no difference ($P = 0.26$) in the DM quantity of rumen particulate, CON had the greatest ($P = 0.01$) amount of particulate relative to DM intake. Rumen evacuated samples from WDGS20 had a greater ($P \leq 0.05$) quantity of crude protein, NDF, ADF, and ether extract compared to SB20. Overall, inclusion of GMP in the diet improved total tract fiber digestion, altered VFA concentrations and nutrients within the rumen particulate.

Introduction

Economic instability, population growth, consumer perceptions, and environmental awareness have shifted livestock production towards more sustainable animal husbandry practices. As a result, these changes have compelled livestock producers to investigate alternative management strategies to efficiently produce beef while combatting increasing feedstuffs costs. As production of ethanol and corn sweeteners continues, affordable products from the grain-milling industry have become common components of beef cattle finishing diets. The 2 most widely used grain milling products (GMP) from these industries are wet distillers grains with solubles (WDGS) from the dry milling process used to produce ethanol and wet corn gluten feed (WCGF) from the wet milling process used to produce corn oil and high fructose corn syrup (Samuelson et al., 2016). Additionally, Sweet Bran (SB; Cargill Corn Milling, Blair, NE) is a proprietary WCGF product that is marketed for use in cattle diets.

Wet distillers grains with solubles, WCGF, and SB contain high concentrations of protein and digestible fiber (Larson et al., 1993), and can be used as a substitute for the high starch processed grains that would otherwise supply dietary energy in feedlot cattle diets (Klopfenstein et al., 2008). When used as a substitute for corn, cattle consuming WCGF or SB exhibited either similar or greater dry matter intake (DMI), average daily gain, and feed efficiency when 40.0% of dry matter (DM) or less was included in dry-rolled corn-based diets (Ham et al., 1995) and 35.0% of DM or less was included in steam-flaked corn-based diets (Macken et al., 2004). Greater performance in cattle fed WCGF and SB is likely because of improvements in total tract digestibility of organic matter (OM), neutral detergent fiber (NDF), and starch as well as a more stable rumen pH (Montgomery et al., 2004; Ponce et al., 2012) that stimulates DMI. In contrast, feeding WDGS has resulted in variable responses in cattle performance, as cattle consuming dry-rolled corn-based diets frequently have greater performance when WDGS is substituted for a portion of the diet, whereas cattle consuming steam-flaked corn-based diets often have lower performance with WDGS (Larson et al., 1993; Corrigan et al., 2009). Furthermore, cattle consuming WDGS had lower total tract DM and OM digestibility than those consuming a diet with no GMP (Corrigan et al., 2009). These results suggest that feeding WCGF or SB to feedlot cattle consuming steam-flaked corn-based diets in moderate amounts positively affects performance and digestion, whereas WDGS included at similar concentrations may negatively impact these parameters. Previous research also suggests diets with WCGF and WDGS have greater liquid and particulate passage rate compared to a diet with no GMP (Firkins et al., 1984; Montgomery et al., 2004). Therefore, understanding the link between particle size, digestibility, and passage

rate can help to illustrate how these feeds influence ruminal fermentation dynamics and total tract digestion.

Rapid fermentation of grains with inadequate volatile fatty acids (VFA) absorption has the potential to decrease rumen pH and may result in ruminal acidosis (Owens et al., 1998). Grain-milling products such as WCGF have been shown to reduce the incidence of acidosis, but may not eliminate the risk completely (Krehbiel et al., 1995). However, it is unclear if the decreased acidosis of cattle fed GMP is from dilution of starch, greater rumination and saliva production, increased VFA absorption, altered passage rate, or a combination thereof. The ability of a feed to stimulate rumination can be inferred from dietary concentrations of physically effective NDF (peNDF), which is calculated by multiplying the NDF concentration by the proportion of feed particles larger than 4.0 mm (Cardoza, 1985; Kononoff et al., 2003). Spowart (2020) observed greater pH and less rumination min per kg of NDF for cattle consuming diets containing SB and/or WDGS than a no GMP control, suggesting that the NDF in GMP increases rumen pH but stimulates rumination behavior to a lesser degree than traditional roughage sources.

Therefore, additional research is needed to evaluate the physical properties of GMP and how they influence digestion, passage rate, and the rumen environment. Furthermore. WDGS, WCGF, and SB are commonly fed in combination, but this practice has not been extensively evaluated with performance or digestibility research. We hypothesized that inclusion of SB and WDGS in feedlot cattle diets increases ruminal pH, but may have differing impacts on ruminal and total tract nutrient digestion. In addition, there may be synergistic effects from feeding WDGS and SB in combination that

increase digestibility and ruminal pH. Therefore, the objective of this study was to determine the effects of feeding GMP on digestion, passage rate, ruminal pH, ruminal VFA and ammonia concentrations, and rumen particulate quantity and nutrient composition.

Materials and Methods

All procedures involving live animals were approved by the West Texas A&M University Institutional Animal Care and Use Committee (2020.04.003)

For this study, 4 Angus × Hereford steers were used in a 4 × 4 Latin square design with 4 periods and 4 treatments. Each period was 31 d with 21 d for adaptation to dietary treatments and facilities, 5 d for total tract digestibility and passage rate determination, 3 d for evaluation of in situ rumen digestibility, and 1 d for rest before 1 d rumen evacuations. Steers were housed at the WTAMU Research Feedlot in Canyon, Texas, in individual outdoor pens during the adaptation period and covered, concrete tie-stalls with rubber mats during the collection period. Before initiation of the study, steers were adapted to a common finishing diet, fitted with rumen cannulas, and received a ruminal pH bolus (pH Plus Bolus, smaXtec, Graz, Austria). Steers were weighed at the beginning and end of each experimental period (658 ± 33 kg) and assigned to 1 of 4 dietary treatments. Treatments (Table 3.1) consisted of: no GMP (CON), 20% Sweet Bran (SB20), 20% wet distillers grains with solubes (WDGS20), or a combination of 20% Sweet Bran and 10% wet distillers grains with solubes (COMBO). Cattle were fed their respective dietary treatments once daily at 0600 to achieve ad libitum intake by providing a feed allotment 10% above the previous d as-fed intake.

To determine total fecal output and calculate nutrient digestibility, each animal was fitted with an individual fecal collection bag designed to capture total excretion of fecal material. From d 22 through 27, the total amount of feces excreted from each animal was collected, weighed, mixed, and a 10% subsample was retained and frozen. Samples were composited by animal within the 5-d collection period. The amount of each diet offered and refused was measured, and a sample was collected from d 21 to 26 and stored frozen until analysis. An additional sample of each diet was also collected on d 21 and 26 of the experiment to determine particle size and peNDF using the Penn State Particle Separator (PSPS; Kononoff et al., 2003). On d 22, Co-EDTA (200 mL) and approximately 300 g of Yb-labeled steam-flaked corn were dosed as liquid and solid passage rate markers, respectively. Steam-flaked corn was labeled with Yb using the methods described by Waggoner et al. (2009), and Co-EDTA was prepared as described by Udén et al. (1980). On d 22 through 27, approximately 250 g of feces was collected from the rectum of each animal 6, 12, 18, 24, 36, 48, 72, 96, and 120 h after dosing for analysis of Yb. Ruminal fluid samples were collected from the cannula of each animal using a suction strainer and filter flask at 0 (before dosing), 3, 6, 9, 12, 18, 24, 36, and 48 h after dosing from d 22 to 25. Approximately 150 mL of ruminal fluid was collected into conical tubes, placed on ice to halt fermentation, and stored frozen for later analysis of ruminal ammonia, VFA, and Co concentrations.

From d 27 to 30, samples of the respective treatment diet of each animal were incubated in the rumen to determine in situ nutrient disappearance. Samples of each dietary treatment were collected, dried in a forced-air oven (55° C for 48 h) to determine partial DM, and ground through a Wiley mill (Model 4, Thomas Scientific, Philadelphia,

PA) to pass a 2 mm screen. Approximately 5 g of sample were weighed into Dacron bags (10 × 20 cm) and soaked in warm water (39° C) for 20 min immediately before ruminal incubation in reverse order for 0, 3, 6, 9, 12, 24, 36, 48, and 72 h. The h 0 bags were soaked in water, but never placed in the rumen. Three replicates were used per time point per animal in the first period. After the first experimental period, 2 additional replicates were added to ensure an adequate amount of sample was captured to complete nutrient analysis. All bags were removed at 72 h, rinsed with tap water to remove large particulate matter, and rinsed by hand until the water ran clear. After rinsing, bags were dried in a forced air oven at 55°C until no change in weight was detected for 12 h. In situ bags were then stored at room temperature for later analysis of OM (600 °C for 12 h), crude protein (CP; vario MICRO cube, Elementar, Langenselbold, Hesse, Germany), NDF and acid detergent fiber (ADF; Ankom Technology method 5 and 6, respectively; Ankom200 Fiber Analyzer, Ankom Technology, Macedon, NY). Ruminal digestibility was partitioned into the soluble fraction (A), intermediately degradable fraction (B), and the undegradable fraction (C). The soluble fraction was calculated as the average disappearance from the time 0 bag. The undegradable fraction was the amount undegraded at 72 h. The intermediately degraded fraction was calculated as B = 100-A-C. In addition, degradation rate of fraction B was calculated as the slope of the natural log of the percentage nutrient remaining from h 3 to 48.

On d 31, ruminal evacuations were completed to determine the weight and composition of the rumen particulate. The rumen contents were removed from each animal, and particulate and liquid were separated using a 2.0 mm mesh screen as described by Lockard et al. (2021). The weight of particulate was recorded, and a sample

of the particulate matter was dried at 55°C for 72 h and retained for particle size determination, calculation of peNDF, and analysis of DM, OM, ADF, NDF, ether extract (EE), and starch. Particle size and peNDF were determined using a Penn State Particle Separator (PSPS; Lammers et al., 1996; Heinrichs, 2013; Gentry et al., 2016). The particle size distribution of each sample was determined by adding 400 g to the top of the PSPS and shaking for a total of 40 repetitions before weighing the particulate collected on each sieve. Particle separation was completed in triplicate. The peNDF was then determined by multiplying the NDF concentration of the sample on a DM basis by the percentage sample found on the top 3 sieves (particles size > 4.0 mm) corrected for DM of the diet.

Feed, feces, refusals, and rumen evacuations were dried at 55 °C for 48 h and stored at room temperature for further analyses. After grinding the samples through a 2 mm screen using a Wiley mill (Model 4, Thomas Scientific, Philadelphia, PA), samples were analyzed for DM (24 h at 105°C), NDF and ADF, CP, and OM at the West Texas A&M University ruminant nutrition laboratory as described previously. Ether extract and starch concentrations were analyzed by a commercial laboratory (Servi-Tech Laboratories, Hastings, NE). Feed samples were analyzed for particle size and peNDF as described previously using the PSPS.

Ruminal fluid samples were analyzed at the University of Kentucky, Lexington, for ammonia concentrations using the procedure described by Broderick and Kang (1980) and VFA concentrations using gas chromatography (Erwin et al., 1961; Ottenstein and Bartley, 1971; Egert-McLean et al., 2021). Determination of passage rate is currently still in progress and nearing completion. Feces will be analyzed for Yb and ruminal fluid for

Co concentrations using atomic absorption spectroscopy at the New Mexico State University Ruminant Nutrition laboratory. The one-compartment model (Ellis et al., 1982) will be used to determine the passage rate of the solid fractions and fluid dilution rate.

Data was analyzed as a 4 × 4 Latin Square using mixed models (SAS Inst. Inc., Cary, NC). Animal was the experimental unit. The statistical model for digestibility, peNDF, rumen evacuations, and passage rate data included diet as a fixed effect and animal and period as random effects. The model for fermentation end-products collected over time included dietary treatment, hour, and dietary treatment × hour interaction as fixed effects. Period and treatment nested within animal was considered random and hour was used in the repeated statement. Covariance structure was determined by the lowest Akaike's information criteria value. Treatment differences were considered significant when $P \leq 0.05$ and a tendency when $0.05 < P < 0.10$.

Results and Discussion

Diet Particle Size Distribution and peNDF Concentrations

Dietary NDF concentrations were greatest (Table 3.2; $P < 0.01$) for COMBO (22.11%), followed by WDGS20 (20.61%), SB20 (18.89%), and CON (15.66%). There was no difference ($P = 0.89$) in the proportion of feed particles larger than 19.0 mm. However, the 19.0 mm sieve of the PSPS is primarily designed to capture large particle roughages such as corn stalks (Jennings et al., 2020) that were included at 8.0% of DM in all diets. In contrast, the proportion of particles captured on the 8.0 mm sieve was greater ($P < 0.01$) for CON than the diets containing GMP. The CON and SB20 diets had a greater ($P = 0.01$) proportion of particles captured on the 4.0 mm sieve than WDGS20,

and COMBO was intermediate. The diet with the greatest ($P < 0.01$) proportion of particles captured on the 1.18 mm sieve was COMBO, followed by WDGS20 and SB20, and CON was least. This indicates that a large proportion of the GMP was between 1.18 and 4.0 mm in size. The proportion of particles < 1.18 mm was greatest ($P < 0.01$) for WDGS20, intermediate for COMBO, and least for CON and SB20, which also suggests that WDGS may have smaller particle size compared to SB.

Four mm is used as a threshold for peNDF because it is believed that few particles > 4.0 mm can pass out of the rumen to the lower gastrointestinal tract (Cardoza, 1985). Therefore, particles > 4.0 mm may spend longer time in the rumen and therefore, could potentially contribute to papillae stimulation, rumination, and/or formation of the fibrous mat layer. The proportion of particles > 4.0 mm was greatest ($P < 0.01$) for CON, intermediate for SB20, and least for WDGS20 and COMBO. However, the larger particle size of CON may be from steam-flaked corn having a larger particle size compared to GMP. Although there were differences in dietary NDF concentrations among treatments, peNDF did not differ ($P = 0.11$). In a companion study evaluating the effects of GMP inclusion on finishing cattle performance, Spowart (2020) observed the greatest peNDF in COMBO, SB20, and WDGS20 were intermediate, and CON had the least calculated peNDF. However, despite no statistical difference, the numerical values reported for peNDF in the current study (11.48, 11.33, 10.75, and 10.31% for COMBO, SB20, WDGS20, and CON, respectively) mirrored the relationship between treatments observed by Spowart (2020). The inability to capture a statistical difference in the current study may have occurred because fewer samples were collected (n = 8) compared to Spowart (2020), where 25 samples of each diet were evaluated for peNDF. The numerical

differences in peNDF between treatments are contributed by the greater NDF concentrations supplied by SB and WDGS compared to CON in combination with shifts in particle sizes of the diets.

Digestibility

There was no difference ($P = 0.19$) in DMI during the digestibility period for CON, WDGS20, SB20, or COMBO (8041, 8815, 9280, 8618 g; Table 3.3). This agrees with previous studies where cattle consuming diets with WCGF, SB, and WDGS had either similar or greater DMI compared to a corn-based diet without GMP (Firkins et al., 1985; Domby et al., 2014; Spowart, 2020). No difference ($P = 0.22$) in OM intake was observed among treatments. However, NDF intake was greatest ($P < 0.01$) for COMBO, intermediate for WDGS20 and SB20, and least for CON. The differences in NDF intake are driven by the greater NDF concentration contributed by diets that included GMP. According to NASEM (2016), steam-flaked corn, SB, and WDGS contain 8.97, 26.75, and 31.52% NDF on a DM basis, respectively. Therefore, as GMP replaced a portion of the steam-flaked corn in the diet, NDF concentrations increased (14.53, 18.65, 18.13, and 22.24% NDF for CON, WDGS20, SB20, and COMBO). Similarly, ADF concentrations also increased with added GMP (6.70, 7.86, 7.47, and 9.0% ADF for CON, WDGS20, SB20, and COMBO), which resulted in greater ADF consumption for GMP diets compared to CON ($P = 0.01$). There was no difference in EE intake ($P = 0.27$). Intake of CP was greatest ($P = 0.01$) for WDGS20, followed by COMBO, SB20, and CON, which also reflects the CP concentration of each diet. Starch intake was less ($P = 0.03$) for COMBO than WDGS20, SB20, and CON because a greater proportion of steam flaked

corn was replaced with GMP that diluted the starch concentration. The dietary starch content of CON, WDGS20, SB20, and COMBO was 59.63, 50.70, 50.70, and 44.05%, respectively.

Fecal output of DM, OM, NDF, ADF, CP, EE, and starch did not differ ($P \geq 0.12$) among dietary treatments. In addition, total tract digestibility of DM, OM, CP, EE and starch were not different ($P \geq 0.26$) among treatments. However, digestibility of NDF was greatest ($P = 0.05$) for COMBO, intermediate for WDGS20 and SB20, and least for CON. Vander Pol et al. (2009) reported no difference in NDF digestibility between a dry-rolled corn-based diet containing 40.0% WDGS compared to a diet with no WDGS. In steam-flaked corn-based diets, May et al. (2010b) also reported that 0.0%, 15.0%, or 30.0% WDGS inclusion did not affect NDF digestibility. The discrepancy between the results of the current study and those of May et al. (2010b) and Vander Pol et al. (2009) could be because different roughage sources were used in the diet; the current study used ground corn stalks while May et al. (2010b) and Vander Pol et al. (2009) used alfalfa hay, which is a more digestible forage source. However, numerical differences between the 0.0% WDGS and 15.0% WDGS diet in the study by May et al. (2010b) indicate NDF digestibility increased by 6.5 percentage points. Additionally, nutrient composition of WDGS has changed because of the incorporation of fat removal in the milling process. In 2010, May et al. (2010b) reported that WDGS contained 11.9% fat while Spowart (2020) reported that WDGS contained 10.4% fat. Therefore, the reduction in fat content of WDGS may have allowed for greater NDF digestion. In steam-flaked corn-based diets, Montgomery et al. (2004) observed greater NDF digestibility when feeding 40.0%

WCGF compared to 0.0% WCGF which agrees with the current study. Digestibility of ADF was also greater ($P \leq 0.01$) for diets containing GMP compared to CON.

The improvement in NDF and ADF digestibility of diets containing GMP could be caused by shifts in the ruminal microbiome. Although not measured in the current study, the population of cellulolytic bacteria species likely increased as fibrous GMP were used to replace a portion of processed grains containing readily available starch, which could have increased the efficiency of ruminal fiber degradation. Alternatively, greater fiber digestibility could be caused by changes in the proportional fiber composition of the diet. For example, as GMP increased, a greater proportion of the dietary fiber was likely composed of hemicellulose as opposed to lignin because of lower lignin concentrations in GMP compared to corn stalks (NASEM, 2016). When calculated from dietary values for lignin presented in NASEM (2016) CON, WDGS20, SB20, and COMBO had 13.57, 12.03, 8.86, and 8.81% of NDF as lignin, respectively (data not shown).

In situ Digestion

Ruminal DM, CP, NDF, and ADF degradation (Table 3.4) of the soluble fraction (A), intermediately degradable fraction (B), and undegradable fraction (C) were not different ($P \geq 0.36$) among treatments. In addition, the degradation rate of the intermediately soluble fraction was not different ($P \geq 0.42$) between treatments. Quinn et al. (2011) observed no difference in in vitro digestibility of steam-flaked corn-based diets containing either 0.0%, 15.0%, or 30.0% WDGS. Although in situ NDF digestibility was not different between diets in the current study, there was greater total tract NDF digestibility for COMBO compared to CON. This suggests post-ruminal digestion of

NDF may be greater for diets containing GMP. In addition to changes in the overall composition of the NDF and ADF fractions of the diet, it is also possible that the greater proportion of smaller particles associated with diets containing GMP could have shifted digestion towards the lower gastrointestinal tract. Alternatively, because in situ samples were uniformly ground to 2.0 mm, larger particle ingredients in the diet may have had greater ruminal digestion in situ vs. what would occur in vivo, and smaller particle feeds may have remained in the rumen longer. Therefore, it is possible that in situ digestion may not accurately model true ruminal digestion and washes out differences between treatments because of the inability to account for differences in particle size of the individual feed ingredients. Additional research investigating ruminal digestibility and degradation rate of diets containing GMP is necessary to corroborate these findings.

Rumen VFA and NH_3

There was no difference ($P = 0.52$) between treatments for total VFA (Table 3.5) concentrations in the rumen. Total VFA concentrations for CON, WDGS20, SB20, and COMBO were 81.37, 78.74, 84.32, and 89.43 mM, which is less than has been reported in previous research (Sindt et al., 2001; Li et al., 2011; Conway et al., 2012) conducted in cattle consuming corn-based diets. In the present study, DMI/kg BW was less than that reported by Li et al. (2011) and Conway et al. (2012) which may have contributed to the lower total VFA concentrations. In agreement with the current study, Sindt et al. (2001) observed no difference in ruminal total VFA concentration when 0.0% or 28.6% WCGF was fed in steam-flaked corn-based feedlot diets. In addition, total VFA concentration was not affected by inclusion of 25.0% WDGS in dry-rolled barley-based feedlot diets

(Li et al., 2011). Therefore, inclusion of GMP in feedlot diets may not affect the ruminal concentration of total VFA.

There was a treatment × hour interaction ($P \leq 0.05$) for the molar proportions of propionate, butyrate, and valerate. Greater molar proportions of propionate were observed 0, 3, 6, and 9 h after feeding for SB20 compared to COMBO, and COMBO had less propionate 3 and 6 h after feeding compared to CON (Fig 3.1). The dietary concentration of starch was least in COMBO because of greater GMP inclusion, which could have caused the reduction in propionate as greater proportions of ruminally available starch increase propionate production (Zinn et al., 1995). Ranathunga et al. (2010) and Li et al. (2011) similarly observed no difference in the molar proportion of propionate when feeding WDGS in place of steam-flaked corn. Sindt et al. (2001) reported that WCGF decreases propionate (mM/100mol) in steam-flaked corn-based diets, which is inconsistent with the results of the current study. In contrast, Conway et al. (2012) observed greater molar proportions of propionate in a steam-flaked corn-based diets containing 25.0% SB compared to a no GMP control diet fed to ruminally cannulated cattle. These inconsistencies are difficult to explain, but could be due in part to the animal to animal variation within period associated with studies that use individual animal as the experimental unit because of differences in factors such as rumen microbiome, passage rate, or absorptive capacity. The molar proportion of butyrate (Fig 3.2) only differed 36 h after feeding, where COMBO was greater than SB20. The difference at h 36 for butyrate is surprising because there were no differences at h 12, which occurred at the same time of d relative to feeding. Therefore, the differences observed in butyrate concentration (mM/100mol) may be from random variation. Cattle

consuming the CON treatment had greater molar proportions of valerate (Fig 3.3) at h 0 compared to COMBO, and CON was greater at h 0, 18, and 36 compared to WDGS20. There is limited research that reports valerate concentrations in cattle consuming feedlot diets, however, May et al. (2010a) reported that in vitro valerate production was not affected by WDGS inclusion in steam-flaked corn diets. There were no differences ($P \geq 0.25$) in acetate or isovalerate concentrations (mM/100mol) and ammonia concentrations did not differ ($P = 0.62$) among cattle consuming any of the treatment diets. Although a diet × hour effect was observed for the molar proportion of propionate, the acetate:propionate ratio ($P = 0.55$) was not different among cattle receiving any of the dietary treatments.

Ruminal pH

Circadian ruminal pH over a 24 h period is depicted in Fig 3.4. There was diet × hour interaction for ruminal pH ($P = 0.02$). Ruminal pH was lower for COMBO and SB20 than CON and less for COMBO than WDGS at 0200. At 0400, ruminal pH was lower for COMBO than CON and ruminal pH was also less for COMBO than WDGS at both 0400 and 0800. In contrast, ruminal pH of COMBO and WDGS was greater than CON at 1000, and greater for COMBO than CON at 1200. At 2400, both COMBO and SB had greater ruminal pH than CON. Overall, these results suggest that ruminal pH was greater for CON than COMBO immediately before feeding and declined at a faster rate for CON after feeding. From 1400 to 2200, ruminal pH was similar among dietary treatments. The difference in diurnal pH between treatments may be from differences in feeding behavior and/or caused by rapid fermentation of starch from steam-flaked corn compared to the fiber in GMP during peak fermentation. Previously, Corrigan et al.

(2009) observed that addition of WDGS to a corn-based diet (dry-rolled, high-moisture, or steam-flaked) increased eating time per d and decreased meal size. Similar results were observed when cattle were fed SB in steam-flaked corn diets (Parsons et al., 2007). Therefore, if cattle receiving the CON diet consumed feed more rapidly, this could have caused the more pronounced decrease in ruminal pH after feeding. Lower pH after feeding for CON was also observed by Spowart (2020). However, from 2000 h until after feeding the subsequent d, pH did not differ between treatments. There was no difference among treatments ($P \geq 0.24$) in average, minimum, or maximum pH or time below pH of 5.6 (Table 3.6). However, this differs from Spowart (2020) where CON had lower average ruminal pH compared to diets containing GMP. It should be noted that in the current study animals were housed individually, while in Spowart (2020) animals were housed in pens of 9 to 10 animals. Animals housed together may have greater competition for feed and subsequently, higher consumption rates (Gonyou and Stricklin, 1981) thus increasing the risk for reduced ruminal pH and ruminal acidosis (González et al., 2012). The current study agrees with May et al. (2010b) and Luebbe et al. (2012) where no difference in average ruminal pH was observed when WDGS were added to steam-flaked corn-based diets. Allen and Grant (2000) also observed no difference in average rumen pH when WCGF was fed in place of dry-rolled corn. The lack of overall pH differences in the current study are further supported by no difference in total VFA concentrations. In addition, there was no difference in the acetate:propionate ratio among treatments, which has been previously associated with low ruminal pH (Russell, 1998). In contrast, there was a tendency for AUC to be less for CON compared to SB20 and COMBO ($P = 0.07$) which may be from numerically less DMI.

Rumen Evacuations

Results from rumen evacuations are presented in Table 3.7. On d 30 (the d before rumen evacuation samples were collected) there was a tendency ($P = 0.06$) for CON to have less DMI compared to WDGS20, SB20, or COMBO. There was no difference ($P = 0.26$) in DM particulate weight between treatments. Similarly, Allen and Grant (2000) reported replacing dry-rolled corn with WCGF had no effect on ruminal DM content. However, particulate weight per kg of DMI in the current study was greater ($P = 0.01$) for CON cattle compared to all other treatments. Because there was no difference in in situ degradation of nutrients between dietary treatments, physical properties of the diet may have influenced DM particulate retention in the rumen. Larger particle feeds typically spend more time in the rumen, while smaller particle feeds have a faster passage rate (Welch, 1982). The CON diet had the greatest quantity of particles larger than 8.0 mm and 4.0 mm and the least particles smaller than 1.18 mm. Particulate density may also affect where feeds are suspended in the rumen and could influence passage out of the rumen independent of particle size.

There was no difference ($P = 0.19$) in particulate concentration or quantity of OM. In addition, total starch quantity was not different ($P = 0.55$) and starch concentration did not differ ($P = 0.30$) for CON (8.85%), WDGS20 (7.98%), SB20 (7.23%), or COMBO (4.30%). Dietary concentrations of starch were 59.63, 50.70, 50.70, and 44.05% for CON, WDGS20, SB20, and COMBO, respectively. Although not different, the numerical pattern mirrors the starch concentration of the diets. However, the magnitude of difference between treatments may have been influenced by differences in passage rate of the diets. The proportion and total quantity of CP was greatest ($P \leq$

0.03) for WDGS20 compared SB20, COMBO, and CON. Greater CP in the rumen particulate for WDGS20 is likely from greater dietary CP and the greater proportion of ruminal undegradable protein present in WDGS compared to SB and/or cottonseed meal and urea in SB20, COMBO, and CON (NASEM, 2016). The rumen particulate did not differ in (P = 0.11) the concentration of NDF (63.5, 58.0, 65.7, and 68.9% for CON, WDGS20, SB20, and COMBO, respectively) despite large differences in dietary NDF concentrations. However, total g NDF within the rumen particulate was less for SB20 (P = 0.05) compared to CON, WDGS20, and COMBO. In addition, g of ADF was less (P = 0.02) for SB20 compared WDGS20, COMBO, and CON despite no difference (P = 0.21) in proportion of ADF. The difference in ruminal quantity of NDF and ADF for SB20 may be from numerically less total rumen particulate compared to all other treatments or from greater digestion and passage rate of NDF and ADF. However, because in situ digestion was not different between treatments, differences in the rate of fiber digestion are unlikely. Ether extract concentrations were greatest (P = 0.02) for CON and WDGS20, intermediate for SB20, and least for COMBO. The g of EE within the rumen particulate was greater (P = 0.02) for CON and WDGS20 than SB20 and COMBO. This is difficult to explain because dietary EE concentration and total tract digestibility was similar across all treatments.

There was no difference ($P \geq 0.29$) in the proportion of rumen particulate captured on any of the sieves in the PSPS (Table 3.8). The lack of difference in particle size may be from the passage of the small particles out of the rumen and/or because rumination and digestion may have equalized particle size. Therefore, the particles that remain in the rumen may get digested similarly and differences in total tract digestion

may be from differences in passage rate. Previously, Maulfair et al. (2011) and Kononoff and Heinrichs (2003) observed that increasing the particle size of roughage sources such as silage or hay also increased particle size of the ruminal contents 24 h after feeding. However, this data may not directly compare to the current study because roughages have greater retention time in the rumen compared to grains because of larger particle size and decreased digestibility. There was a tendency ($P = 0.10$) for peNDF of the rumen particulate to be greatest for COMBO, intermediate for SB20 and CON, and least for WDGS20. The differences in peNDF are mainly influenced by differences in NDF content of the rumen particulate. The rumen particulate peNDF follows a similar trend as dietary peNDF where COMBO had the greatest numerical value (11.48%) followed by SB20 (11.33%) and was mainly influenced by NDF content as opposed to particle size within the rumen contents.

Implications

Although GMP contain a large proportion of NDF relative to grains, they appear to have similar total tract DM digestibility and greater NDF and ADF digestibility despite no difference in rumen degradability. While total VFA concentration was not affected by GMP, propionate production may be decreased transiently when SB and WDGS are fed in combination compared to a diet without GMP, indicating fermentation patterns may be affected by changes in nutrient composition and particle size of the diet. No difference in average, minimum, or maximum ruminal pH indicates GMP may not improve buffering within the rumen but could alter rumen fermentation patterns to cause a more gradual decline in pH after feeding. In addition, differences in rumen particulate relative to DMI indicated GMP diets may have increased particle passage rate.

Table 3.1: Dietary treatment formulation and nutrient composition

	Treatment Diets[1]			
Item	CON	WDGS20	SB20	COMBO
Ingredient, % of DM				
Corn grain, flaked	76.55	63.92	62.55	53.22
Sweet Bran[2]	0.00	0.00	20.00	20.0
WDGS[3]	0.00	20.0	0.00	10.0
Corn stalks	8.00	8.00	8.00	8.00
Cottonseed meal	6.00	0.00	0.00	0.00
Corn oil	2.45	1.08	2.45	1.78
72 Brix blend	2.50	2.50	2.50	2.50
Supplement	4.50	4.50	4.50	4.50
Nutrient Composition				
Dry matter, %	83.25	62.83	76.98	66.00
Organic matter, %	95.39	94.63	94.57	93.82
Crude protein, %	12.10	15.61	12.20	14.11
NDF,[4] %	14.53	18.65	18.13	22.24
ADF,[5] %	6.70	7.86	7.47	9.00
Ether extract,[6] %	4.70	5.00	4.75	4.93
Starch,[6] %	59.63	50.70	50.70	44.05
ME,[7] Mcal/kg	3.26	3.21	3.21	3.17
NEm,[8] Mcal/kg	2.22	2.20	2.22	2.18
NEg,[9] Mcal/kg	1.54	1.54	1.52	1.50

[1]Control (CON) = no dietary inclusion of grain-milling products; WDGS20 = 20% inclusion of wet distillers grains plus solubles (WDGS); SB20 = 20% inclusion of Sweet Bran; COMBO = combination of WDGS and Sweet Bran
[2]Cargill, Blair, NE
[3]WDGS = wet distillers grains plus solubles
[4]NDF = neutral detergent fiber
[5]ADF = acid detergent fiber
[6]Analyzed by Servi-tech Laboratories (Hastings, NE)
[7]ME = TDN × 0.01642 (NRC, 1988)
[8]NEm = $(1.37 \times ME) - (0.3042 \times ME^2) + (0.051 \times ME^3) - 0.508$ (NRC, 1988)
[9]NEg = $(1.42 \times ME) - (0.3836 \times ME^2) + (0.0593 \times ME^3) - 0.7484$ (NRC, 1988)

Table 3.2: Physically effective NDF of diets with different concentrations of grain-milling products

	Treatment Diets[1]					
Item	CON	WDGS20	SB20	COMBO	SEM	*P*-value
Dietary NDF,[2] % DM	15.66[d]	20.61[b]	18.89[c]	22.11[a]	0.49	<0.01
Sieve size, mm	Retained / Sieve, %					
19.0	0.72	0.79	0.90	0.72	0.19	0.89
8.0	43.67[a]	33.38[b]	37.13[b]	31.60[b]	2.17	<0.01
4.0	21.61[a]	18.27[b]	21.97[a]	19.64[ab]	0.83	0.01
1.18	17.56[c]	23.28[b]	24.96[b]	28.48[a]	1.13	<0.01
Bottom pan	16.45[c]	24.27[a]	15.04[c]	19.57[b]	1.06	<0.01
Particles > 4mm	65.99[a]	52.44[c]	60.01[b]	51.95[c]	2.06	<0.01
Est. peNDF,[3] % of DM	10.31	10.75	11.33	11.48	0.36	0.11

[1]Control (CON) = no dietary inclusion of grain-milling products; WDGS20 = 20% inclusion of wet distillers grains plus solubles (WDGS); SB20 = 20% inclusion of Sweet Bran; COMBO = combination of WDGS and Sweet Bran

[2]NDF = neutral detergent fiber

[3]peNDF = physically effective NDF calculated as (particles > 4mm × dietary NDF)

Table 3.3: Apparent total tract digestibility of diets containing different grain-milling products

	Treatment Diets[1]					
Item	CON	WDGS20	SB20	COMBO	SEM	*P*-value
Intake, g/d						
Dry matter	8041	8815	9280	8618	802.7	0.19
Organic matter	7701	8353	8769	8070	760.2	0.22
NDF[2]	1154^{c}	1625^{b}	1682^{b}	1902^{a}	188.0	<0.01
ADF[3]	525^{b}	688^{a}	686^{a}	762^{a}	68.9	0.01
Crude protein	930^{c}	1349^{a}	1114^{bc}	1210^{ab}	124.5	0.01
Ether extract	372	437	434	412	32.3	0.27
Starch	4908^{a}	4521^{a}	4763^{a}	3829^{b}	416.6	0.03
Fecal output, g/d						
Dry matter	1533.7	1851.0	1853.2	1916.7	250.4	0.26
Organic matter	1246.7	1527.5	1499.2	1498.7	214.5	0.34
NDF[2]	753.7	867.6	926.6	951.3	145.4	0.12
ADF[3]	414.3	419.5	456.7	456.8	56.7	0.66
Crude protein	251.6	324.7	281.3	279.3	35.0	0.43
Ether extract	22.2	28.3	29.6	23.9	3.10	0.30
Starch	13.82	6.39	7.31	6.06	5.50	0.72
Digestibility, %						
Dry matter	80.93	78.94	80.24	78.22	1.60	0.26
Organic matter	83.86	81.64	83.13	81.88	1.55	0.36
NDF	35.54^{b}	45.80^{ab}	45.75^{ab}	51.44^{a}	4.97	0.05
ADF	21.59^{b}	37.80^{a}	34.04^{a}	41.09^{a}	4.33	0.01
Crude protein	72.50	75.74	74.34	77.03	2.83	0.45
Ether extract	93.81	93.40	93.11	94.27	0.85	0.58
Starch	99.74	99.86	99.83	99.85	0.10	0.83

[1]Control (CON) = no dietary inclusion of grain-milling products; WDGS20 = 20% inclusion of wet distillers grains plus solubles (WDGS); SB20 = 20% inclusion of Sweet Bran; COMBO = combination of WDGS and Sweet Bran

[2]NDF = neutral detergent fiber

[3]ADF = acid detergent fiber

[a,b,c,d]Values with superscripts that differ indicates treatments differ at $P \leq 0.05$

Table 3.4: In situ rumen degradable fractions and degradation rates of diets containing different grain-milling products

	Treatment Diets[1]					
Item	CON	WDGS20	SB20	COMBO	SEM	*P*-value
DM Fraction,[2] %						
A	41.44	42.20	39.98	41.67	1.34	0.70
B	43.37	42.64	43.55	42.64	2.14	0.97
C	16.42	15.17	16.47	16.47	1.57	0.82
DM *kd*, %/hr	2.30	2.26	2.13	2.29	0.16	0.88
CP Fraction, %						
A	52.34	50.55	52.06	55.64	3.28	0.74
B	41.93	39.32	36.16	35.04	3.83	0.46
C	9.10	10.13	11.78	8.54	2.35	0.54
CP *kd*, %/hr	2.73	2.30	2.00	2.61	0.35	0.42
NDF Fraction, %						
A	10.40	11.78	10.29	10.71	1.45	0.87
B	29.46	22.41	26.30	26.13	3.41	0.36
C	61.22	64.65	63.42	64.84	4.08	0.87
NDF *kd*, %/hr	0.62	0.64	0.54	0.61	0.11	0.92
ADF Fraction, %						
A	18.47	17.51	17.05	17.91	2.41	0.98
B	16.98	13.60	16.61	14.20	2.69	0.53
C	63.60	68.61	66.35	67.42	4.02	0.75
ADF *kd*, %/hr	0.40	0.43	0.36	0.34	0.11	0.94

[1]Control (CON) = no dietary inclusion of grain-milling products; WDGS20 = 20% inclusion of wet distillers grains plus solubles (WDGS); SB20 = 20% inclusion of Sweet Bran; COMBO = combination of WDGS and Sweet Bran

[2]Fraction A = soluble fraction (disappearance from in situ bag at h 0); fraction C = ruminally undegradable fraction (amount remaining in the in situ bag at h 72); fraction B = intermediately degradable fraction (100%-A-C); *kd* = degradation rate of fraction B

Table 3.5: Volatile fatty acid and ammonia concentrations of diets containing different grain-milling products

	Treatment Diets[1]					*P*-value		
Item	CON	WDGS20	SB20	COMBO	SEM	Diet	Hour	Diet × Hour
Total VFA,[2] mM	81.37	78.74	84.32	89.43	5.02	0.52	<0.01	0.13
VFA, mM/100mM								
Acetate	46.28	49.73	47.05	49.29	1.20	0.36	<0.01	0.25
Propionate	36.01	34.81	39.03	31.88	1.69	0.36	<0.01	<0.01
Butyrate	10.29	10.29	8.45	12.26	1.50	0.43	0.86	0.05
Isovalerate	3.05	2.90	2.58	3.05	0.63	0.75	<0.01	0.15
Valerate	3.57	1.43	2.10	2.30	0.82	0.39	0.10	0.03
Acetate:Propionate	1.36	1.50	1.24	1.66	0.21	0.55	<0.01	0.09
NH_3, mM	4.01	5.72	5.59	6.48	1.12	0.51	0.10	0.62

[1]Control (CON) = no dietary inclusion of grain-milling products; WDGS20 = 20% inclusion of wet distillers grains plus solubles (WDGS); SB20 = 20% inclusion of Sweet Bran; COMBO = combination of WDGS and Sweet Bran
[2]VFA = Volatile fatty acid

Table 3.6: Ruminal pH measurements of diets containing different grain-milling products between d 22 and 27

	Treatment Diets[1]					*P*-value		
Item	CON	WDGS20	SB20	COMBO	SEM	Diet	Day	Diet×Day
Ruminal pH								
Average	5.80	5.78	5.74	5.71	0.03	0.28	0.65	0.68
Minimum	5.36	5.34	5.25	5.29	0.04	0.29	0.80	0.41
Maximum	6.39	6.50	6.48	6.38	0.09	0.72	0.33	0.26
Time below pH 5.6, min/d	391	494	559	610	69.5	0.24	0.32	0.74
AUC, pH×min	60.82^{y}	81.05^{xy}	109.71^{x}	104.61^{x}	11.13	0.07	0.37	0.61

[1]Control (CON) = no dietary inclusion of grain-milling products; WDGS20 = 20% inclusion of wet distillers grains plus solubles (WDGS); SB20 = 20% inclusion of Sweet Bran; COMBO = combination of WDGS and Sweet Bran

^{x,y}Values with superscripts that differ indicate treatments differ at $0.05 < P \leq 0.10$

Table 3.7: Impacts of grain-milling products on dry matter intake, rumen particulate weight, and particulate composition

	Treatment Diets[1]					
Item	CON	WDGS20	SB20	COMBO	SEM	*P*-value
Dry matter intake, kg	9218[y]	10579[x]	10742[x]	10333[x]	608	0.06
Dry particulate weight, kg	2577	2912	2160	2724	398	0.26
Dry particulate weight, g/g DMI	0.19[a]	0.09[b]	0.12[b]	0.11[b]	0.03	0.01
Nutrient content of fiber mat, %						
Organic matter	94.79	94.47	94.39	94.79	0.46	0.19
Crude protein	14.28[b]	18.02[a]	12.63[b]	13.05[b]	0.91	<0.01
Neutral detergent fiber	63.50	58.00	65.67	68.90	4.04	0.11
Acid detergent fiber	34.01	28.98	30.87	32.62	1.95	0.21
Ether extract	3.35[a]	3.61[a]	2.20[ab]	1.25[b]	0.82	0.02
Starch	8.85	7.98	7.23	4.30	2.56	0.30
Nutrient content of fiber mat						
Organic matter, g	2443	2669	2040	2559	335	0.18
Crude protein, g	365[b]	498[a]	284[b]	354[b]	65.5	0.03
Neutral detergent fiber, g	1626[a]	1713[a]	1336[b]	1879[a]	176	0.05
Acid detergent fiber, g	873[a]	864[a]	630[b]	886[a]	86.2	0.02
Ether extract, g	0.94[a]	0.98[a]	0.60[b]	0.34[b]	0.29	0.02
Starch, g	2.37	1.96	2.16	1.18	0.89	0.55

[1]Control (CON) = no dietary inclusion of grain-milling products; WDGS20 = 20% inclusion of wet distillers grains plus solubles (WDGS); SB20 = 20% inclusion of Sweet Bran; COMBO = combination of WDGS and Sweet Bran

[a,b]Values with superscripts that differ indicate treatments differ at $P \leq 0.05$

[x,y]Values with superscripts that differ indicate treatments differ at $0.05 < P \leq 0.01$

Table 3.8: Impacts of grain-milling products on dry matter intake, rumen particulate weight, and particulate composition

	Treatment Diets[1]					
Item	CON	WDGS20	SB20	COMBO	SEM	*P*-value
Rumen contents NDF,[2] % DM	63.50	58.00	65.67	68.90	4.04	0.11
Sieve size, mm	Retained / Sieve, %					
19.0	0.44	0.92	0.65	0.70	0.18	0.29
8.0	17.62	19.06	17.65	21.64	3.65	0.77
4.0	25.68	25.43	26.39	25.49	1.31	0.90
1.18	37.48	37.15	38.17	34.62	2.00	0.60
Bottom pan	18.78	17.44	17.14	17.55	0.21	0.93
Particles > 4mm	43.74	45.42	44.70	47.83	3.58	0.85
Est. peNDF [3]% of DM	27.93^{xy}	23.57^{y}	29.24^{xy}	33.18^{x}	3.17	0.10

[1]Control (CON) = no dietary inclusion of grain-milling products; WDGS20 = 20% inclusion of wet distillers grains plus solubles (WDGS); SB20 = 20% inclusion of Sweet Bran; COMBO = combination of WDGS and Sweet Bran

[2]NDF = Neutral detergent fiber

[3]peNDF = physically effective NDF calculated as (particles > 4mm × Dietary NDF)

[x,y]Values with superscripts that differ indicate treatments differ at $P \leq 0.10$

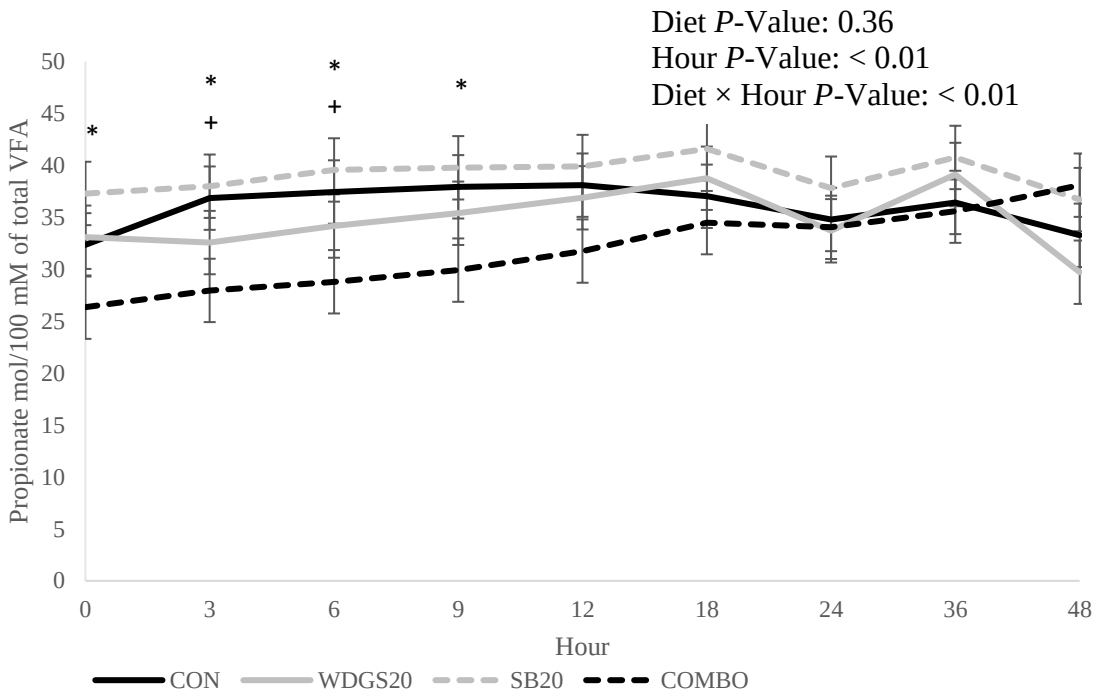

Figure 3.1: Molar proportion of propionate in rumen fluid after feeding diets containing different grain-milling products.
Control (CON) = no dietary inclusion of grain-milling products; WDGS20 = 20% inclusion of wet distillers grains plus solubles (WDGS); SB20 = 20% inclusion of Sweet Bran; COMBO = combination of WDGS and Sweet Bran; *COMBO differs from SB $P \leq 0.05$; +COMBO differs from CON $P \leq 0.05$

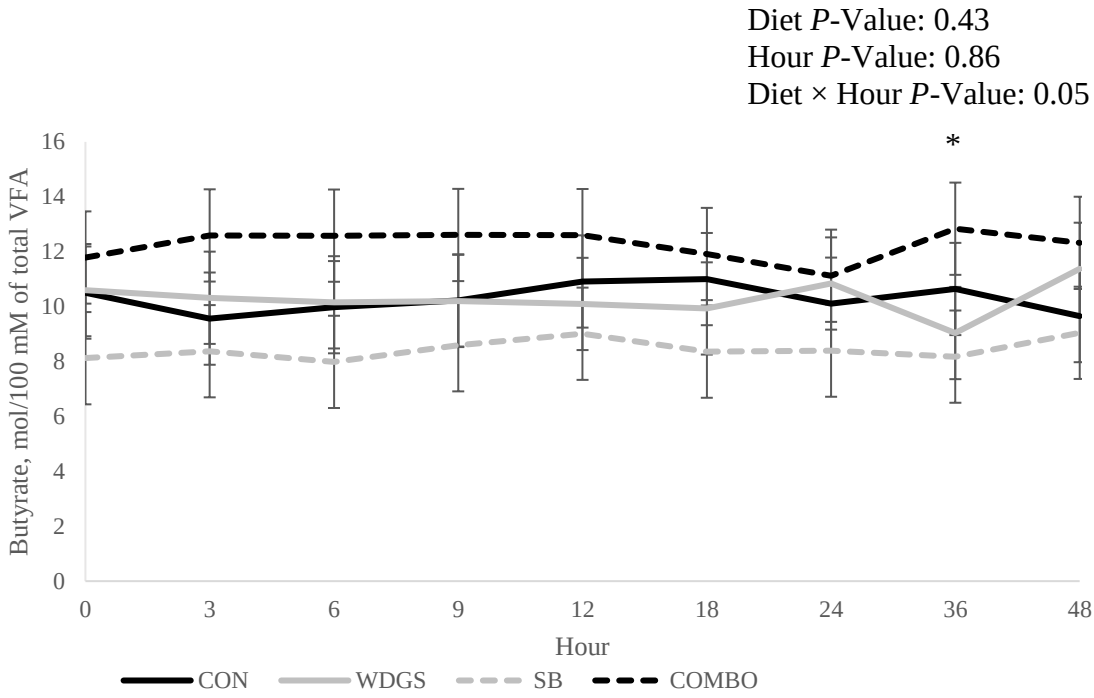

Figure 3.2: Molar proportion of butyrate in rumen fluid after feeding diets containing different grain-milling products.
Control (CON) = no dietary inclusion of grain-milling products; WDGS20 = 20% inclusion of wet distillers grains plus solubles (WDGS); SB20 = 20% inclusion of Sweet Bran; COMBO = combination of WDGS and Sweet Bran; *COMBO differs from SB $P \leq 0.05$

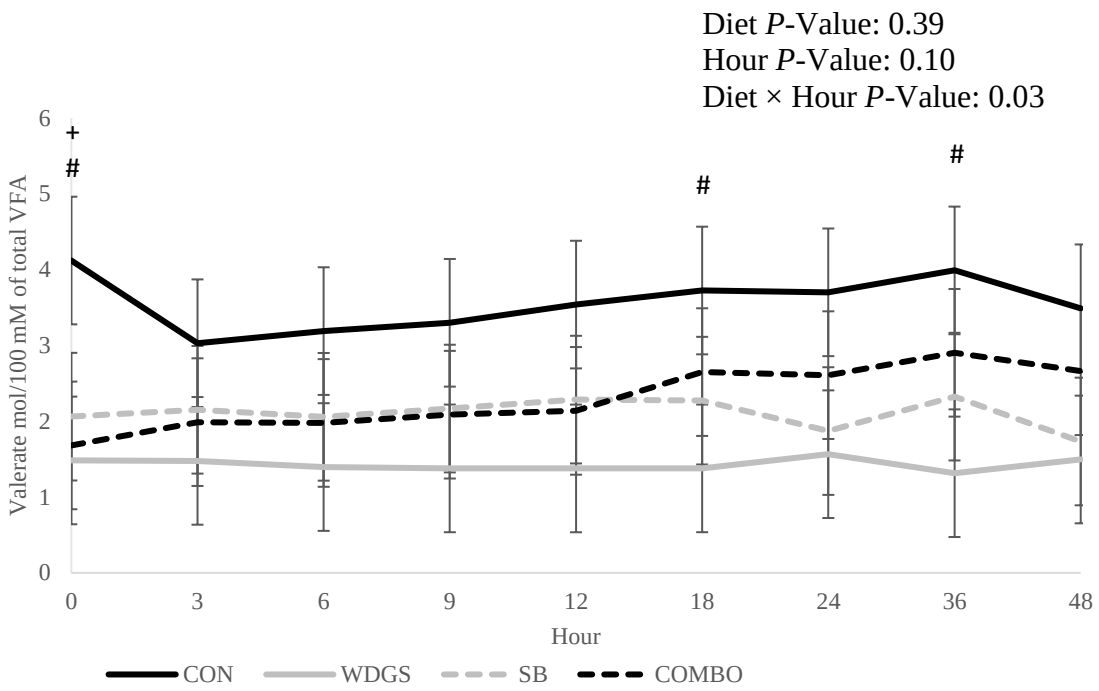

Figure 3.3: Molar proportion of valerate in rumen fluid after feeding diets containing different grain-milling products.
Control (CON) = no dietary inclusion of grain-milling products; WDGS20 = 20% inclusion of wet distillers grains plus solubles (WDGS); SB20 = 20% inclusion of Sweet Bran; COMBO = combination of WDGS and Sweet Bran; +COMBO differs from CON $P \leq 0.05$; #CON differs from WDGS20 $P \leq 0.05$

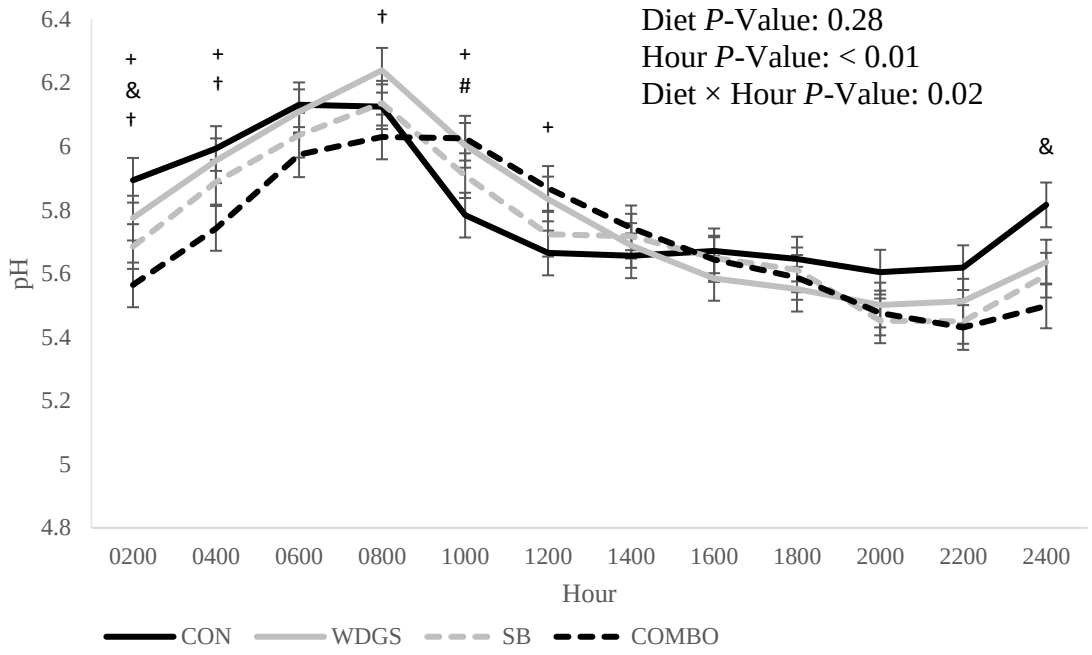

Figure 3.4: Circadian pH of cattle consuming steam-flaked corn-based diets containing grain-milling products or a control diet.
Control (CON) = no dietary inclusion of grain-milling products; WDGS20 = 20% inclusion of wet distillers grains plus solubles (WDGS); SB20 = 20% inclusion of Sweet Bran; COMBO = combination of WDGS and Sweet Bran; *COMBO differs from SB20 $P \leq 0.05$; + COMBO differs from CON $P \leq 0.05$; #CON differs from WDGS20 $P \leq 0.05$; &SB20 and CON differ $P \leq 0.05$; †COMBO and WDGS20 differ $P \leq 0.05$

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CHAPTER IV

THE IMPACT OF CHANGES IN FINISHING DIETS AND GROWTH TECHNOLOGIES ON ANIMAL GROWTH PERFORMANCE AND THE CARBON FOOTPRINT OF CATTLE FEEDING: 1990 TO 2020

Abstract

Both dietary ingredients and technology used in the feedlot cattle industry have evolved in the past 30 years. As consumer concern for the sustainability of the feedlot cattle production increases, it is important to understand how production efficiency and greenhouse gas emissions have changed in this period. For this study, a model was developed to represent feedlot diets and technologies used in 1990 vs. 2020 and evaluate changes in growth performance and carbon footprint. Dietary changes from 1990 to 2020 included the use of grain milling product feeds while decreasing corn and dry roughage inclusion rates. In 1990, available technologies included estradiol-only implants and monensin as a feed additive; whereas in 2020 use of combination implants including both trenbolone acetate and estradiol, monensin, and ractopamine hydrochloride (in the final 28 to 42 d) were common. In both 1990 and 2020 use of available technologies increased final body weight (BW), average daily gain (ADG), feed efficiency, and hot carcass weight (HCW) compared to no technology. From 1990 to 2020 initial BW, final BW, ADG, gain to feed ratio, and HCW, and dry matter intake increased. Total days on feed (DOF) also increased by 44 days from 1990 to 2020. Compared to no technology, use of

technologies in both 1990 and 2020 decreased total greenhouse gas emissions per animal (CO_2e). Because cattle had greater DOF in 2020 than 1990, all sources of greenhouse gas emissions per animal increased. However, when expressed as CO_2e/kg BW gain, emissions have decreased by 4.4% because of greater total BW gain in 2020. Feedlots in 2020 produced 47.5% more BW gain with 1.4% less cattle, while only increasing total CO_2e by 39.5%, indicating changes in technologies and diet formulations have improved efficiency and reduced the carbon footprint of feedlot cattle production in the past 30 years.

Introduction

As the global population grows and demand for beef increases, management practices must evolve to accommodate changes in feedstuff availability, enhance growth efficiency, and address consumer concerns regarding the environmental sustainability of livestock production. To facilitate these enhancements, research has focused on developing technologies and animal management techniques to improve growth performance and accommodate the needs of an ever-changing beef industry. For example, between 1990 and 2020 there have been distinct changes in feedlot cattle diets and an increase in the availability and use of growth promoting technologies. Grain-milling products (GMP) such as wet corn gluten feed and distillers grains have become common ingredients in feedlot cattle diets (Samuelson et al., 2016), yet these ingredients were scarcely available in 1990. Availability and use of growth promoting technologies such as implants, ionophores, and β-adrenergic agonists (βAA) have also changed significantly over the past 30 yr as research has been conducted to refine the management practices surrounding their administration and develop new products.

Consumers are continually expressing greater concern for the effect that beef cattle production has on the environment and how this may impact sustainability of the beef production system. Methane (CH_4), CO_2, and N_2O are greenhouse gasses emitted as waste products from inefficiencies of ruminal fermentation, as metabolic byproducts, and from degradation of manure. Calculating a carbon footprint (C-footprint) adjusts each of the greenhouse gasses to a common CO_2 equivalent (CO_2e) to represent the total potential for global warming (GWP).

Changes in diets and the use of growth promoting technologies have improved growth performance of beef cattle compared to natural beef production systems (Wileman et al., 2009). In addition, these improvements in growth performance have increased feed efficiency and reduced the environmental impact of raising cattle in feedlots (Stackhouse-Lawson et al., 2013). Our objective was to estimate the impacts of current feedlot diets and technologies on animal growth performance and the C-footprint of cattle feeding between 1990 and 2020.

Materials and Methods

Because no live animals were used, this research was not evaluated by the Institutional Animal Care and Use Committee at West Texas A&M University. For this study, a model was developed to represent typical feedlot finishing diets (Table 4.1) fed to cattle in 1990 and 2020 using dietary ingredients that had a C-footprint reported in the literature (Adom et al., 2012). The diets contained steam-flaked corn, alfalfa hay, soybean meal, tallow, and supplement in 1990 and in 2020 wet distillers grains plus solubles (WDGS) replaced a portion of steam-flaked corn and all of soybean meal. Steam-flaking was used in both years because it was the most widely used processing

method for corn according to Galyean (1996) and Samuelson et al. (2016). The 20.0% of dietary dry matter (DM) inclusion of WDGS in the 2020 diet was selected based on the most recent consulting nutritionist survey conducted in 2015 (Samuelson et al., 2016). Technologies reported in the 1990 model included no technology, growth promoting implants (estrogen only), ionophores, and the use of both implants and an ionophore in combination. In contrast, the 2020 model included no technology, implants (estrogen and androgen combination), ionophores, implants and ionophores in combination, βAA, and the combination of implants, ionophores, and βAA. Ractopamine hydrochloride (RH) was used to model the performance improvements associated with βAA administration because it is the only βAA currently used in the United States. Monensin sodium was selected to describe the effects of ionophores in both 1990 and 2000 because it was reported to be the most widely used ionophore in feedlot cattle diets (Russell and Strobel, 1989; Samuelson et al., 2016). While not every possible combination of technologies is presented, those reported in the model represent commonly used technologies in the feedlot industry in the last 30 yr.

For the 1990 model, a review of feedlot cattle studies published in the *Journal of Animal Science* between 1990 and 1995 and closeout records from the 1997 Kansas State University Focus on Feedlots Reports (Kuhl, 1997) were conducted to establish values for comparison of growth performance under different management conditions. Manuscripts were excluded if they contained treatments that used programed feeding, where cattle were fed to achieve a certain ADG and therefore ad libitum intake was not achieved. In addition, manuscripts that did not contain growth performance measurements were excluded. The 1997 Kansas State University Focus on Feedlots

Reports were used because they represented the earliest publically available date for cattle fed in the 1990's. A total of 9 publications and 3 Kansas Focus on Feedlots Reports were used in a weighted average to calculate initial and final body weight (BW) and average daily gain (ADG) from the selected study treatment means (Lewis et al., 1990; Zinn, 1990; Xiong et al., 1991; Zinn, 1991; Ham et al., 1994; Bauer et al., 1995; Krehbiel et al., 1995b; Ladely et al., 1995; Ludden et al., 1995). Baseline dry matter intake (DMI) was determined using the DMI prediction equation proposed in NASEM (2000, DMI = 4.54 + 0.0125 * initial BW). Gain-to-feed ratio (G:F) was calculated by dividing the ADG by DMI. These values were used to model baseline growth performance for cattle receiving both an implant and monensin. Performance (final BW and ADG) for cattle receiving an implant only, monensin only, and no technology (no implant, no monensin) was then back-calculated by removing the improvements in performance associated with each technology from the baseline.

Initial BW was not adjusted based on the different technologies used. However, final BW was reduced by 35 kg when implants were not used (no technology and monensin only) in accordance with the NASEM (2000). The DMI was decreased by 6% for the non-use of implants (NASEM, 2000) and increased by 4% when monensin was not included in the diet (Galyean et al., 1992). The ADG was decreased by 1.5% for cattle that did not receive monensin (NASEM, 2000) and 17% (Duckett and Andrae, 2001) for cattle that did not receive estrogenic implants. The performance changes associated with estrogenic implants were chosen from Duckett and Andrae (2001) because they represented the available technology in 1990, as use of an implant containing estrogen only was a common management practice during this time. The

effects of both monensin and implant on DMI and ADG were assumed to be additive. The total number of days on feed (DOF) was calculated for each group by dividing the total BW gain by the ADG and is similar to the selected reference studies. Dressing percentage for the all technology group was set at 63.0% of final BW (personal communication, Ty Lawrence). In the groups that did not receive an estrogenic implant, dressing percentage was increased by 0.16% points (Reinhardt and Wagner, 2014). Hot carcass weight was calculated by multiplying the dressing percentage by the final BW.

To model growth performance of cattle fed in 2020, baseline values were determined using a literature search of feedlot research published in the *Journal of Animal Science* between 2015 and 2020, and monthly closeout reports from the 2020 Kansas Focus on Feedlots (Waggoner, 2020). Manuscripts were eliminated from the data pool if monensin, a combination implant, or ractopamine hydrochloride was not used. A total of 10 journal articles were used (Russell et al., 2016; Schwandt et al., 2016; Stokes et al., 2016; Thompson et al., 2016; Genther-Schroeder et al., 2018; Müller et al., 2018; Budde et al., 2019; Teixeira et al., 2019; Warner et al., 2020; Wellmann et al., 2020) and a weighted average between the journal articles and the Kansas reports was used for initial BW, final BW, and ADG. Dry matter intake was calculated using the equation $DMI = 3.830 + 0.0143 \times ISBW$ described for use in feedlot steers by the NASEM (2016) where ISBW is initial shrunk BW. Baseline values represented the use of all available technologies in 2020 (monensin, a combination implant, and ractopamine hydrochloride). From these values, the performance for the monensin, implant and monensin, implant, and no technology groups were calculated by removing the performance enhancements associated with each technology.

In the groups that did not receive an implant in 2020, final BW was decreased by 7.46% and ADG was decreased by 20.0% as reported for implants containing a combination of androgenic and estrogenic hormones by Duckett and Andrae (2001). For the non-implanted cattle, G:F was decreased by 15.6% (Duckett and Andrae, 2001). For the cattle not fed monensin, there were no adjustments to initial or final BW (Duffield et al., 2012). Average daily gain of cattle not fed monensin was decreased 2.5%, and DMI was increased by 3.2% as described by Duffield et al. (2012). Based on previous research conducted by Beck et al. (2014), additive effects were assumed when using implants and monensin in combination.

Ractopamine hydrochloride was assumed to be fed during the final 28 d before slaughter according to practices commonly used by feedlot nutritionists (Samuelson et al., 2016) and within label recommendations. Excluding RH decreased final BW by 1.3% and ADG by 15.3% compared to diets with RH (Gruber et al., 2007). The model did not adjust DMI for cattle fed RH, which agrees with the majority of published literature (Schroeder et al., 2004; Abney et al., 2007; Quinn et al., 2008; López-Carlos et al., 2010).

The effects of RH, monensin, and implants on animal performance were also assumed to be additive in the 2020 model (Bryant et al., 2010). Dressing percentage for the all technology group was increased to 64.0% in the 2020 model (personal communication, Ty Lawrence). Based on data published by Quinn et al. (2016), the dressing percentage of cattle not fed ractopamine hydrochloride was decreased by 0.34% points. In addition, if cattle were not provided a combination implant dressing percentage was decreased by 0.32% points (Reinhardt and Wagner, 2014).

A C-footprint analysis was also conducted and included carbon dioxide equivalent (CO_2e) sources: enteric CH_4, manure CH_4, and nitrous oxide (N_2O); indirect N_2O production from feedyard ammonia emissions, processing of grain, and transport of feed and manure (Cole et al., 2020b). The C-footprint of feed equipment and facilities was not included in our analyses. Animal respiratory CO_2 emissions and net emissions of soil-C from manure application were assumed to be zero. Animal respiration CO_2e is not a net source of greenhouse gas (GHG; Steinfield et al., 2006; Cole et al., 2020b) and there is only a marginal decrease in soil-C on land used to produce crops the animals consumed and where manure was applied and respiratory losses are derived (Schlesinger and Amundson, 2018; Cole et al., 2020b).

All GHG emissions were converted to constant CO_2e. We used the GWP of 1 for CO_2, 25 for CH_4, and 298 for N_2O (IPCC, 2006; IPCC 2019). In our calculation of the C-footprint, we estimated the GWP of natural gas used in the steam flaking process to be 25 × CO_2. A 5 region C-footprint analysis of crops fed to dairy cattle was conducted by Adom et al. (2012). The analysis included the C-footprint of herbicides, fertilizers, etc. that were used in crop production, but the C-footprint of equipment used in the farming process was not included. The C-footprint reported by Adom et al. (2012) varied by region, thus the average of the Great Plains and Midwest regions were used in the current C-footprint analysis because most cattle on feed in the U.S. are fed within these regions. Therefore, the following geometric mean C-footprints were used: 1) corn grain, 390 kg CO_2e/1,000 kg DM; 2) alfalfa hay, 200 kg CO_2e/1,000 kg of DM; 3) soybean meal, 460 kg CO_2e/1,000 kg DM; 4) miscellaneous feed additives used the same value as soybean meal (460 kg CO_2e/1,000 kg DM); and 5) WDGS, 330 kg CO_2e/1,000 kg DM. It is

likely that there are differences in the C-footprint of ingredients produced in 1990 vs. 2020; however, these differences are not known with certainty and the C-footprints used in the analyses were those reported by Adom et al. (2012).

The C-footprint of distillers grains production is variable, depending on production methodology and assumptions used in the calculations (Kim and Dale, 2002; Searchinger et al., 2008; Hünerberg et al., 2014). The proportions of the total C-footprint for grain ethanol production can be assigned to ethanol and distillers grains based on mass, energy content, or economic value. Therefore, it is unclear what proportion of the C-footprint of ethanol should be allotted to the ethanol industry and what proportion should be allotted or credited when using an ethanol GMP in cattle feeding, such as WDGS. To equally distribute the C-footprint of WDGS across both industries by mass we assigned 50% of the C-footprint to the ethanol industry and 50% to the beef industry (total C-footprint of WDGS is 660 kg CO_2e/1,000 kg DM). Therefore, in the present C-footprint analysis, we assumed the C-footprint of WDGS was 330 kg CO_2e/1,000 kg DM.

Enteric CH_4 emissions were calculated using the feedlot enteric CH_4 model used in the USDA-OCE 2014 publication (Powers et al., 2014). The model assumes that the Ym (CH_4 production as a percentage of gross energy intake) is 3.0% (IPCC, 2006); however, adjustments are made based on ionophore inclusion, supplemental fat inclusion, grain type, and grain concentration. In the instance where monensin was included in the diet, the Ym was adjusted down in the equation for enteric CH_4. Methane production in g/d is then calculated from the adjusted Ym.

Manure CH_4 production was determined from volatile solid (VS; i.e. organic matter [OM]) excretion using the methods of IPCC (2006, 2019) where CH_4 production =

VS excretion × the maximum potential CH_4 emission (Bo) × the CH_4 conversion factor (MCF). The MCF is the percentage of Bo emitted and is based on manure handling factors and environmental conditions. For our calculations, VS excretion was estimated from DMI and OM digestibility (assumed to be 72% for these diets), and we assumed the diets contained 95% OM. Assuming the environmental conditions were a drylot in a temperate environment, a Bo of 0.19 m^3/kg VS and an MCF of 1.5% was used (IPCC, 2006, 2019).

Nitrogen excretion was calculated as the difference in N intake and N retention from ADG and BW (NASEM, 2016). Direct N_2O emissions from manure were estimated to be 2.0% of N excreted (IPCC 2006, IPCC 2019); whereas the indirect N_2O emissions were estimated assuming that 65.0% of the N excreted was lost as ammonia (Todd et al., 2008), and subsequently that 1.0% of the ammonia-N was lost as N_2O (IPCC 2006, IPCC 2019). The amount of enteric N_2O emissions only accounts for less than 0.5% of total CO_2e (Parker, et al., 2018; Cole et al., 2020a). The quantity of manure collected and transported to be field applied was estimated based on Buttrey et al. (2012), where the quantity of manure DM collected from treatment pens was reported. We estimated the DM content of the collected manure to be 65.0%, which was used to calculate the total quantity of manure collected and land applied. For simplicity, we assumed that all manure was transported a common distance of 20 km.

The C-footprint of transporting feed grains to the feedlot and to collect and transport manure to fields for application were calculated assuming a constant energy cost of 149.6 kg CO_2e/t-km (Hünerberg et al., 2014). We estimated that all feedstuffs excluding WDGS were transported an average of 200 km to the feedlot. Wet distillers

grains plus solubles are typically not trucked long distances to be fed, thus we assume they were hauled 50 km. The subsequent manure was hauled an average of 20 km, and the average distance to haul feed from the mill to the feed bunk was 3.2 km/1,000 kg feed DM. Our estimates were based on a 50,000-animal capacity feedlot with 130 ha of cattle pen area. The feed delivery logistics that we used were described by da Silva et al. (2019) and Ponce et al. (2019), who estimated bulk densities of the diet, DM concentration, and assumed a DMI.

Results and Discussion

Because the performance and C-footprint values reviewed in this study are based on deterministic model estimates, no statistical analysis was conducted. Therefore, all data comparisons discussed will include consideration of numerical differences only.

Dietary Changes from 1990 to 2020

The ingredient and nutrient composition of feedlot diets in 1990 vs. 2020 is presented in Table 4.1. One of the major dietary changes of note from 1990 compared to 2020 is the inclusion of fibrous GMP as a replacement for more expensive sources of energy and CP such as steam-flaked corn and soybean meal. High concentrations of digestible fiber and protein present within these feedstuffs allow a portion of the high-starch grains traditionally used in feedlot diets to be replaced, thus in some instances improving growth performance of cattle (Hussein and Berger, 1995; Buttrey et al., 2013; Ponce et al., 2019) while potentially mitigating ruminal acidosis (Krehbiel et al., 1995a). Although distillers grains were fed in limited amounts 100 yr ago, the increased demand for grain alcohol as a fuel source has made this feedstuff more widely available

(Klopfenstein et al., 2008). More recently, increased use of artificial sweeteners and oils has also increased the availability of wet corn gluten feed from the wet milling of corn.

Because the use of ethanol GMP such as WDGS has increased, the cost per unit of dietary CP has decreased, thereby resulting in the 2020 feedlot diets having greater CP compared to 1990 (15.42 vs. 12.50% CP on a DM basis for 2020 and 1990, respectively). In a survey conducted by Galyean (1996), dietary CP ranged from 12.5 to 14.4% of DM and by 2016 Samuelson et al. (2016) reported recommended CP concentrations ranged from 13.0 to 14.3% of DM in finishing diets. The slightly greater CP used in the 2020 model than that reported by Samuelson et al. (2016) is likely because urea was added to the diet in an effort to meet cattle requirements for RDP when feeding diets using WDGS as the sole GMP. However, Samuelson et al. (2016) also identified a maximum tolerable concentration of 20.0% CP in finishing cattle diets and suggested that it is possible that some nutritionists were using greater than the recommended CP concentrations described previously because of the increased inclusion of high CP GMP such as WDGS. Therefore, the authors felt the CP concentration of 15.42% was within the acceptable range for the 2020 diet.

In addition to changes in dietary CP, differences in both fat and starch concentrations from 1990 to 2020 are likely a function of incorporating WDGS into the diet. For example, dietary fat concentrations have increased from 1990 to 2020 (5.17 vs. 6.87%), despite similar concentrations of added fat from tallow, yellow grease, or other fat sources. According to NASEM (2016) steam flaked corn, soybean meal, and WDGS contain 3.19%, 1.88%, and 10.84% fat respectively, suggesting that the higher fat concentration in the 2020 diet is a function of the greater contribution of fat from WDGS,

as this GMP replaced both steam-flaked corn and soybean meal in the diet. In contrast, dietary starch concentrations decreased (66.67% and 51.35% starch in 1990 and 2020, respectively) as WDGS replaced steam-flaked corn in the diet. The process of ethanol production uses starch as the main substrate for fermentation, thereby decreasing starch and concentrating the remaining fiber, protein, and fat within residual GMP such as WDGS (Bothast and Schlicher, 2005). Another consequence of the addition of GMP to the current diets is greater concentrations of dietary phosphorus, which required greater inclusion of a supplementary source of calcium to maintain a 2:1 ratio of Ca:P. Overall, the concentration of CP, fat, and fiber has increased and starch has decreased between 1990 and 2020 resulting in greater net energy concentrations in 2020 compared to 1990.

Technology Effects on Cattle Growth and Emissions

Administration of anabolic implants is a common management practice used to increase ADG of feedlot cattle and has been widespread since the development of diethylstilbestrol in 1957 (Raun and Preston, 2002). Just before 1990, trenbolone acetate (TBA) was approved for use in growth promoting implants for feedlot cattle (FOIA, 1987). Trenbolone acetate is a synthetic anabolic steroid that has 3 to 5 times the androgenic activity and 8 to 10 times the anabolic activity of testosterone (Bouffault and Willemart, 1983). A common management practice today includes the use of combination implants containing both estrogen and TBA. The most recent survey describing implant use in beef cattle indicates that 92.3% of all feedlot cattle receive at least 1 implant during their lifetime (USDA-NAHMS, 2013). Growth promoting implants increased ADG, final BW, hot carcass weight (HCW), DMI, and G:F in both 1990 (Table 4.2) and in 2020 (Table 4.3). In 1990 dressing percentage was decreased when an implant

was used. However, the use of combination implants in 2020 increased dressing percentage. Use of estrogenic and/or androgenic compounds increases DMI, which could increase gut fill and subsequently reduce dressing percentage (NASEM, 2000). However, when used alone or in combination with estrogen, greater protein deposition within the carcass from administration of TBA could offset the contribution of gut fill and increase dressing percentage (Duckett and Andrae, 2001). Furthermore, because the use of implants increased ADG at a similar proportion to the increase in final BW, the total number of DOF was comparable (0 additional DOF in 1990 and 1 in 2020) between cattle receiving either no technology or implants in both 1990 and 2000. The greater DMI in 1990 and 2020 with the use of implants caused manure production, N excretion, and enteric CH_4 production to increase. However, when calculated per kg of total BW gain (data not shown), manure production, N excretion, and enteric CH_4 production all decreased.

Ionophores are a feed additive used to improve feed efficiency (Goodrich et al., 1984) and animal health by decreasing the risk for subclinical acidosis (Stock et al., 1995; McGuffey et al., 2001; Birkelo, 2003; Erickson et al., 2003). Ionophore use has been widespread throughout the feedlot industry for many years (Galyean, 1996; Samuelson et al., 2016). Monensin sodium is the most commonly used ionophore (Samuelson et al., 2016) and was originally approved for use in beef cattle in 1975 (Goodrich et al., 1984). In addition to growth performance and health benefits, monensin has the potential to reduce CH_4 emissions (Tedeschi et al., 2003; McGinn et al., 2004; Tedeschi, 2011; Hemphill et al., 2018). Increased growth performance and decreased CH_4 production observed in cattle consuming monensin are accomplished primarily via the reduction of

gram-positive bacteria in the rumen (Goodrich et al., 1984; Cheng et al., 1998; Birkelo, 2003). Monensin does not directly inhibit methanogen growth, but inhibits H_2-producing bacteria and limits the total H_2 available for methane production (Chen and Wolin, 1979). Furthermore, monensin reduces CH_4 production by inhibiting the decomposition of formate that is produced during the breakdown of pyruvate (Van Nevel and Demeyer, 1977).

When cattle were fed monensin as the only performance enhancing technology, final BW and HCW were not different compared to no technology for either of the time periods evaluated. In 1990 and in 2020, feeding monensin increased ADG by 0.01 kg. Inclusion of monensin in the model also decreased DMI by 0.34 kg and 0.24 kg in 1990 and 2020, respectively. The minor change in ADG combined with decreased DMI resulted in a 5.6% increase in G:F in 1990 and 2.7% in 2020 when monensin was used compared to no technology. The improvement in G:F decreased the DOF by 3 d in 1990 and 1 d in 2020. The reduction in DMI resulted in decreased manure production, N intake, and enteric CH_4. Likewise, monensin has been reported to decrease the dietary gross energy lost as CH_4 in beef cattle (Ranga Niroshan Appuhamy et al., 2013; Hemphill et al., 2018).

When used together, the effects of both a growth promoting implant and monensin were additive. Therefore, final BW of cattle in the implant and monensin group increased by 35.0 kg in 1990 (Table 4.2) and 45.0 kg in 2020 (Table 4.3) compared to no technology. Using both implants and monensin increased ADG by 0.27 kg in 1990 and 2020. Implants typically increase DMI and monensin decreases DMI, thus using both technologies together resulted in a slightly increased DMI in 1990 (8.55 vs. 8.73 kg) and

in 2020 (8.89 vs. 8.98 kg) when compared to not using technologies. As implants and monensin both increase G:F when used independently, the G:F is further increased in relation to no technology when the 2 technologies are used in combination. Because of these improvements in efficiency, enteric CH_4, excreted N, and manure output were all decreased when implants and monensin were used in combination.

Most recently, provision of a βAA for the last 28 to 42 d of the finishing period has become prevalent in the feedlot industry (Samuelson et al., 2016). β-adrenergic agonists increase lean tissue growth by binding to β-adrenergic receptors present in the plasma membrane of both muscle and adipose tissue, which initiates a signaling cascade that results in lean tissue hypertrophy (Lynch and Ryall, 2008). The mechanism of lean muscle growth is not fully understood, but could be because of increased protein synthesis, decreased protein degradation, or both (Smith et al., 1989). Ractopamine hydrochloride was first approved in 2003, and in 2020 was the only βAA used in the United States.

In the period between 1990 and 2020, the use of RH became a common cattle management strategy and therefore was added as an additional technology in the 2020 model that could not be reported in the 1990 model. Ractopamine hydrochloride compared to no technology increased final BW by 1.3%, increased ADG by 1.5%, and increased G:F by 2.7%. In addition, dressing percentage was increased when RH was fed com[pared to no technology (63.3% vs. 63.7%). When all 3 technologies were used in 2020, DMI increased slightly compared to no technology and ADG was improved by 24.1%, resulting in a 22.7% increase in G:F, which decreased DOF by 3 d. The dressing percentage of cattle administered all technologies increased by 1.0% compared to no

technology. The improvements in growth performance and feed efficiency associated with the use of all technologies decreased enteric CH_4 g/d by 3.0% and L/kg of DMI by 3.9% compared to no technology. In addition, use of all technologies in 2020 decreased N excretion per animal by 1.6%. MacDonald et al. (2009) indicated that use of implants, monensin, and a β-agonist decreased estimated enteric methane per animal by 7.6% and manure nitrogen of cattle by 5.7% when fed a 12.0 % forage and 12.5% CP diet for 150 d. The greater difference observed by Macdonald et al. (2009) may be caused by greater DMI (9.36 kg). These data indicate sustainability of feedlot cattle production has improved through the use of technologies by decreasing the outputs that contribute to GWP.

Impacts of the Overall Production System on Cattle Growth and Emissions (1990 vs. 2020)

Because of the differences in management practices and available technologies incorporated into the cattle management system from 1990 to 2020, direct comparisons of production outcomes between 1990 and 2020 should be interpreted with caution. However, the use of all technologies (implant and monensin in 1990 and implant, monensin, and RH in 2020) best represents the practices used on the majority of feedlots and should be representative of the cattle fed in each time period. Therefore, comparisons between 1990 and 2020 will only describe the combination of all available technologies within each year. From 1990 (Table 4.2) to 2020 (Table 4.3) the initial BW, final BW, and HCW increased by 7.5%, 22.4%, and 24.3% respectively. In addition to the increase in final BW, ADG increased from 1.48 kg/d to 1.65 kg/d with an increase in DMI from 8.55 kg to 8.98 kg. This resulted in a 8.2% increase in G:F. Although a greater ADG was

demonstrated in 2020 compared to 1990, the number of DOF was increased by 44 d to achieve the 95.0 kg of additional BW gain produced in 2020.

Daily enteric CH_4 production was less for cattle in feedlots in 1990 (79.49 g/d) compared to 2020 (84.85 g/d) because of less DMI in 1990. Reporting CH_4 as a proportion of DMI removes differences in intake and represents how diets impact CH_4 emissions. When CH_4 is expressed as L/kg of DMI to account for differences in DMI, the cattle fed in 2020 produced slightly more CH_4/kg DMI than cattle in 1990 (13.20 vs 12.72 L/kg of DMI) because the 2020 diet had greater calculated gross energy (NASEM, 2016) than the 1990 diet. Additionally, total fat and NDF concentrations in the diet increased from 1990 to 2020. It has been documented that increasing the dietary fat concentration can reduce CH_4 production (NASEM, 2016; Drehmel et al., 2018). However, increased NDF concentrations can increase CH_4 production (Hales et al. 2014). The equations used in this model for enteric methane production (Powers et al., 2014) did not account for differences in dietary analysis. Total N intake throughout the feeding period was greater in 2020 (39.66 kg/animal) compared to 1990 (23.57 kg/animal), thus resulting in greater total N excretion in 2020 compared to 1990 (35.59 kg/animal vs. 20.25 kg/animal). The greater N intake in 2020 vs. 1990 is because of the greater dietary CP as a result of inclusion of GMP in the 2020 diet. The increased DOF and daily DMI, and the inclusion of WDGS resulted in a 36.4% increase in total manure DM output per animal across the feeding period and 36.5% increase in as-is total manure per animal.

Technology Effects on Total Carbon Footprint

Because CH_4 and other GHG emissions have different impacts on the environment, it is important to convert them to a CO_2e equivalent basis. All emissions

sources in 1990 (Table 4.4) and in 2020 (Table 4.5) increased when implants were used because of increased DMI. The increased DMI is supported by the equations established by Fox et al. (1992) indicating hormonal implants containing estrogenic compounds increase DMI. Therefore, in 1990 and 2020, implants increased total CO_2e/animal by 6.0% and 5.0% respectively. Although total emissions were increased with the use of implants, when expressed per unit of BW gain, implants decreased kg of CO_2e/kg of BW gain by 0.73 kg in 1990 and 0.64 kg in 2020. Because dressing percentage was decreased in 1990 and increased in 2020 for implants, the decrease in kg of CO_2e/kg of HCW was 0.6% and 2.8% in 1990 and 2020, respectively. Stackhouse et al. (2012) calculated that steers that received an implant in both the stocker and feedlot system had reduced CO_2e/animal compared to cattle raised using a natural program that did not administer implants over their entire lifetime.

As described previously, monensin decreased DMI and slightly increased ADG in both 1990 and 2020 compared to no technology. The increased ADG with no change in final BW resulted in 3 and 1 less DOF in 1990 and 2020 respectively. The decreased DMI and fewer DOF associated with monensin decreased the amount of CO_2e from all sources, resulting in a reduction of total kg of CO_2e/animal by 7.8% in 1990 and by 4.5% in 2020. The proportional decrease is the same when expressed as kg of CO_2e/kg of BW gain when monensin is used because monensin did not increase the amount of BW gain during the feeding period.

When implants and monensin were fed in combination in 1990, all emissions were either decreased or similar when compared to the no technology group when expressed per animal and per kg of BW gain. In 2020, all emissions decreased per animal

and resulted in total emissions decreasing when expressed as kg of CO_2e/animal compared to no technology. When implants and monensin were used in combination, the kg of CO_2e/kg of BW gain was decreased from the no technology group by 22.0% in 1990 and by 20.3% in 2020. This indicates that in addition to the overall decrease in emissions when monensin and implants are used together, more BW gain is also obtained. This suggests that as cattle growth becomes more efficient, environmental impact decreases. The addition of RH in the 2020 model had little effect on kg of CO_2e/animal because RH had no effect on DMI or DOF. However, because RH increases ADG with no effect on DMI or DOF, an additional decrease in kg of CO_2e/kg of BW gain is captured. Thus, when all technologies were used in 2020, the kg of CO_2e/kg of BW gain was decreased by 24.0% compared to no technology. Because the only available technologies in 1990 were monensin and implants, the 22.0% decrease in CO_2e/kg of BW gain stated previously represents the impact of all technologies used in 1990. According to the IPCC (2006), growth technologies such as hormonal implants and ionophores have a technical reduction potential in North America of 9.0% and is one of the larges reduction potentials in the world. The use of all available technologies in 1990 and 2020 reduced kg of CO_2e/kg HCW by 7.8% and 12.1%. In addition, the use of growth promoting technologies in 2020 has had a larger impact on the CO_2e/kg of BW gain in 2020 than in 1990 when compared to the use of no technologies in each year.

Impacts of the Overall Production System on Total Carbon Footprint (1990 vs. 2020)

Overall, sources of emissions that have GWP from cattle and manure increased from 1990 (Table 4.4) to 2020 (Table 4.5) when expressed on a CO_2e/animal basis and was caused by the 44 additional DOF and greater DMI in 2020. Corn grain in 1990

produced 351.16 kg CO_2e/animal and by 2020 increased by 16.8% to 409.99 kg CO_2e/animal. The decrease in inclusion rate of corn from 76.4% to 65.4% likely helped to offset the increased DMI and longer DOF that caused an increase in the C-footprint associated with growing corn. Soybean meal was removed from the diet from 1990 to 2020, thus eliminating its contribution. However, WDGS were added as a GMP feed in the time between 1990 and 2020 and contribute 106.09 kg CO_2e/animal. Therefore, total crop production contribution of CO_2e/animal increased from 439.27 kg in 1990 to 586.42 kg in 2020. If expressed on a CO_2e/100kg of feed DM; in 1990 feed production contributed 37.27 CO_2e/100 kg of feed DM and in 2020 contributed 36.48 CO_2e/100 kg of feed DM (data not shown), indicating the impact of feed production has decreased. In addition, the proportion of total CO_2e associated with feed has decreased from 46.0% (Table 4.6) to 43.4% (Table 4.7) but still has the greatest impact on the overall C-footprint.

The CO_2e/animal of feed transport to the feedlot has increased from 42.43 kg to 58.31 kg from 1990 to 2020 because animals are fed for an additional 44 DOF. Similarly, manure transport away from the feedlot increased from 1.24 to 1.69 kg CO_2e/animal because of the greater amount of manure produced, which is a result of the increased DOF in the 2020 model. The impact of natural gas and electricity required to steam-flake corn has also increased from 1990 (27.01 kg CO_2e/animal and 14.86 kg CO_2e/animal, respectively) to 2020 (31.54 kg CO_2e/animal and 17.35 kg CO_2e/animal, respectively) because of the increase in dietary DMI per animal that was achieved from an increase in DOF. Although corn inclusion decreased from 1990 to 2020, total corn consumption per animal increased by 150.80 kg when comparing the all technology groups.

Overall, cattle in 1990 produced 955.21 kg CO_2e/animal compared to 1350.92 kg CO_2e/animal in 2020. These values are similar to those reported for California beef production by Stackhouse-Lawson et al. (2012). However, it is important to note these values are not scaled to the quantity of HCW produced. When using all available technologies, in 1990 cattle produced 2.83 kg CO_2e/kg HCW compared to 3.22 kg CO_2e/kg HCW in 2020. Because initial BW did not increase to the same extent as HCW (7.5% vs. 24.3%) there is a disproportionate amount of additional BW gain required in 2020 compared to 1990 within the feedlot. Therefore, to compare more evenly across year, C-footprint can also be expressed per unit of BW gain. The feedlot contributed 4.78 kg CO_2e/kg BW gain in 1990 and in 2020 that was decreased by 4.4% to 4.58 kg CO_2e/kg BW gain. The reduction in CO_2e/kg BW gain is supported by the IPCC (2014) indication that global kg of CO_2e/kg of beef has reduced from 1960 to 2010 by about 1.0 kg. It is not surprising that the IPCC (2014) has a slightly greater reduction in CO_2e/kg than the present study, because it incorporates all segments of the beef production system. In addition, there were fewer growth promoting technologies available in 1960, causing the decrease from 1960 to 2010 to be more pronounced than that reported in the current model.

Although it is outside the scope of this study, it should be noted that overall cattle age at slaughter has decreased between 2001 and 2016 despite greater DOF (Lawrence et al., 2001; Eastwood et al., 2017). Dentition analysis is the most accurate demonstration of the reduction in animal age. The earliest record of dentition data in the U.S. was in 2001 (Lawrence et al., 2001), where it was observed that 75.4% of cattle had no permanent incisors at slaughter. More recently in the 2016 National Beef Quality Audit, Eastwood et

al. (2017) reported that 80.5% of cattle had no permanent incisors at slaughter. As such, if cattle are harvested at a younger age, total C-footprint per animal will likely be reduced over the total cattle life cycle.

Furthermore, as cattle spend more time in the feedlot, the amount of time spent in the cow-calf and stocker segments of the beef industry are reduced as a proportion of their total life. According to Stackhouse-Lawson et al. (2012), the feedlot produced 3.1 and 1.56 times less CO_2e/kg of BW gain than the cow-calf and stocker operations, respectively. Cattle spent 212 d in the cow-calf phase, 182 d in the stocker phase, and 121 d in the feedlot. Stackhouse-Lawson et al. (2012) indicated that if the stocker operation was removed, there is a potential decrease in total CO_2e of 6.5% over the entire beef production system. In addition, more growth promoting technologies can be applied in the feedlot compared to the cow-calf operation, allowing for greater reductions in CO_2e.

When this model is extrapolated to the 33.24 million cattle harvested in 1990 (USDA-ERS, 2020), feedlots produced a total of 29.88 billion kg of CO_2e in 1990. In contrast, in 2020, 1.4% fewer cattle (USDA-ERS, 2020) were harvested but produced a total of 43.16 billion kg of CO_2e. As cattle spend a greater proportion of their life in the feedlot more of their life time emissions will be assigned to that segment of the industry. However, because cattle produced in 2020 had 47.5% more BW gain and 24.3% more HCW, the feedlot segment has reduced the quantity of emissions that contribute to GWP compared to the amount of beef produced, as evidenced by a 4.4% decrease in CO_2e/kg BW gain.

Implications

Based on the estimates reported in this study, incorporating the use of growth promoting technologies into the beef feedlot production system improves performance of finishing cattle. While concerns regarding the use of products such as implants, ionophores, and βAA have become prevalent in recent years, previous research indicates that these conventional management practices improve feedlot cattle production (Maxwell et al, 2014) and decrease the environmental impact (Stackhouse et al., 2012). The present study also suggests that these management strategies decrease the C-footprint of beef feedlots. From 1990 to 2020 feedlots have increased BW gain more than the increase in kg of CO_2e, resulting in a decrease of CO_2e/kg of BW gain by 4.4%. The disproportionate increase in BW gain compared to CO_2e indicates that feedlots are decreasing the environmental impact intensity and improving efficiency, while continuing to meet the protein needs of a growing population. Therefore, current management practices that include the use of growth promoting technologies in combination with improved production practices have increased performance of beef cattle, reduced the environmental impact per kg of BW gain, and positively impacted the sustainability of beef production over the past 30 yr.

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Table 4.1: Ingredient and nutrient composition of typical feedlot finishing diets fed in 1990 and 2020

Item	1990 Diet	2020 Diet
Ingredient, % of DM		
Steam-flaked corn	76.4	65.4
Alfalfa hay, mature	13.0	9.0
Wet distillers grains plus solubles	-	20.0
Soybean meal	5.0	-
Tallow	2.5	2.5
Supplement	3.1	3.1
Tabular nutrient estimate, DM basis		
Crude protein, %	12.50	15.42
Fat, %	5.17	6.87
Starch, %	66.67	51.35
Neutral detergent fiber, %	14.96	15.93
Calcium, %	0.64	0.82
Phosphorus, %	0.25	0.35
NE_m,[1] Mcal/kg	2.22	2.34
NE_g,[1] Mcal/kg	1.53	1.63

[1]Based on tabular values reported by NASEM (2016)

Table 4.2: Growth performance model for feedlot cattle finished using technologies available in 1990

Item	No technology	Imp[1]	Mon[2]	Imp & Mon
Initial BW, kg	335	335	335	335
Final BW, kg	500	535	500	535
Days on feed, d	137	137	134	135
ADG, kg	1.21	1.46	1.23	1.48
DMI, kg	8.55	9.08	8.21	8.73
G:F	0.142	0.161	0.150	0.170
Dressing percentage, %	63.16	63.00	63.16	63.00
HCW, kg	316	337	316	337
	Enteric CH_4			
g/d	80.96	85.98	74.75	79.49
L/kg DMI	13.22	13.22	12.72	12.72
	Total N balance during entire feeding period			
N intake, kg	23.43	24.88	22.00	23.57
N excreted, kg	20.56	21.53	19.13	20.25
Ammonia-N, kg	15.23	16.17	14.30	15.32
	Total Manure excretion during entire feeding period			
Manure, kg DM/animal	273	290	256	275
Manure, kg as-is/animal	420	446	394	422

[1]Cattle received a growth promoting implant that contained estradiol twice during the finishing period.
[2]Cattle received monensin.

Table 4.3: Growth performance model for feedlot cattle finished using technologies available in 2020

Item	No Technology	Imp[1]	Mon[2]	Imp & Mon	RH[3]	Imp, Mon, RH
Initial BW, kg	360	360	360	360	360	360
Final BW, kg	602	647	602	647	610	655
Days on Feed, d	182	183	181	179	185	179
ADG, kg	1.33	1.56	1.34	1.60	1.35	1.65
DMI, kg	8.89	9.28	8.65	8.98	8.94	8.98
G:F	0.150	0.172	0.154	0.179	0.154	0.184
Dressing percentage, %	63.34	63.66	63.34	63.66	63.68	64.00
HCW, kg	381	412	381	412	388	419
			Enteric CH_4			
g/d	87.36	91.20	81.74	84.85	87.85	84.85
L/kg of DMI	13.72	13.72	13.20	13.20	13.72	13.20
			Total N balance during entire feeding period			
N intake, kg	39.92	41.90	38.63	39.66	40.81	39.66
N excreted, kg	36.14	37.97	35.00	35.65	37.11	35.59
Ammonia-N, kg	25.95	27.23	25.11	25.78	26.52	25.78
			Total manure excretion during entire feeding period			
Manure, kg DM/ animal	377	396	365	375	385	375
Manure, kg as-is/animal	580	609	561	576	593	576

[1]Cattle received a growth promoting implant that contained trenbolone acetate and estradiol twice during the feeding period.
[2]Cattle received monensin.
[3]Cattle received ractopamine hydrochloride the last 28 d of feeding

Table 4.4: Carbon footprint (kg CO_2e/animal for the entire feeding period) of feedlot cattle finished using different technologies in 1990

Item	No technology	Imp[1]	Mon[2]	Imp & Mon
		Animal and manure		
Enteric CH_4	277.30	294.49	250.43	268.27
Manure N_2O	122.51	128.35	114.03	120.68
Manure CH_4	18.50	19.65	17.38	18.61
Indirect N_2O	22.69	24.10	21.31	22.83
		Crop production		
Corn	349.02	370.65	327.80	351.16
Alfalfa hay	30.46	32.34	28.60	30.64
Soybean meal	26.94	28.61	25.30	27.11
Other	30.17	32.04	28.34	30.36
		Transport		
Feed	42.17	44.79	39.61	42.43
Manure	1.23	1.31	1.16	1.24
		Grain processing energy		
Natural gas	26.85	28.51	25.22	27.01
Electricity	14.77	15.68	13.87	14.86
		Total production		
Total CO_2e	962.61	1020.52	893.04	955.21
Kg CO_2e /kg HCW	3.05	3.03	2.83	2.83
Kg CO_2e /kg BW gain	5.83	5.10	5.41	4.78
		Total reactive N		
Kg/animal	15.54	16.50	14.59	15.63
g/kg HCW	49.20	48.94	46.20	46.37
g/kg BW gain	94.17	82.48	88.43	78.14

[1]Cattle received a growth promoting implant that contained estradiol twice during the finishing period.
[2]Cattle received monensin.

Table 4.5: Carbon footprint (kg CO_2e/animal for the entire feeding period) of feedlot cattle finished using different technologies in 2020

Item	No Technology	Imp[1]	Mon[2]	Imp & Mon	RH[3]	Imp, Mon, RH
			Animal and manure			
Enteric CH_4	397.50	417.22	369.85	379.72	406.33	379.72
Manure N_2O	215.39	226.33	208.58	212.50	221.20	212.09
Manure CH_4	25.55	26.82	24.73	25.39	26.12	25.39
Indirect N_2O	38.66	40.58	37.41	38.41	39.52	38.41
			Crop production			
Corn	412.68	433.15	399.33	409.99	421.84	409.99
Alfalfa hay	29.12	30.57	28.18	28.93	29.77	28.93
Wet distillers grains plus solubles	106.79	112.08	103.33	106.09	109.16	106.09
Other	41.68	43.75	40.33	41.41	42.60	41.41
			Transport			
Feed	58.70	61.61	56.80	58.31	60.00	58.31
Manure	1.70	1.79	1.65	1.69	1.74	1.69
			Grain processing energy			
Natural gas	31.74	33.32	30.72	31.54	32.45	31.54
Electricity	17.46	18.33	16.89	17.35	17.85	17.35
			Total production			
Total CO_2e	1376.99	1445.55	1317.81	1351.33	1408.58	1350.92
Kg CO_2e /kg HCW	3.61	3.51	3.46	3.28	3.63	3.22
Kg CO_2e /kg BW gain	5.68	5.04	5.45	4.72	5.65	4.58
			Total reactive N			
Kg/animal	26.49	27.80	25.63	26.31	27.08	26.31
g/kg HCW	69.44	67.55	67.26	63.93	69.77	62.77
g/kg BW gain	109.32	97.01	106.05	91.81	108.54	89.19

[1]Cattle received a growth promoting implant that contained trenbolone acetate and estradiol twice during the finishing period.
[2]Cattle received monensin.
[3]Cattle received ractopamine hydrochloride in the last 28 d of feeding
[4]For carbon footprint of wet distillers grains plus solubles, 50% was applied to the ethanol industry and 50% to the wet distillers grains plus solubles.

Table 4.6: Carbon footprint (% of total C-footprint) of feedlot cattle depending on technology use in 1990

Item	No technology	Imp[1]	Mon[2]	Imp & Mon
		Animal and manure		
Enteric CH_4	28.81	28.86	28.04	28.09
Manure N_2O	12.73	12.58	12.77	12.63
Manure CH_4	1.92	1.93	1.95	1.95
Indirect N_2O	2.36	2.36	2.39	2.39
		Feed production		
Corn	36.26	36.32	36.71	36.76
Alfalfa hay	3.16	3.17	3.20	3.21
Soybean meal	2.80	2.80	2.83	2.84
Other	3.13	3.14	3.17	3.18
		Transport		
Feed	4.38	4.39	4.44	4.44
Manure	0.13	0.13	0.13	0.13
		Grain processing energy		
Natural gas	2.79	2.79	2.82	2.83
Electricity	1.53	1.54	1.55	1.56
		Summary		
Enteric	28.81	28.86	28.04	28.09
Manure	17.01	16.86	17.10	16.97
Feed production	45.35	45.43	45.92	45.99
Transport	4.51	4.52	4.56	4.57
Grain processing	4.32	4.33	4.38	4.38

[1]Cattle received a growth promoting implant that contained estradiol twice during the finishing period.
[2]Cattle received monensin.

Table 4.7: Carbon footprint (% of total C-footprint) of feedlot cattle depending on technology use in 2020

Item	No Technology	Imp[1]	Mon[2]	Imp & Mon	RH[3]	Imp, Mon, RH
			Animal and manure			
Enteric CH_4	28.87	28.86	28.07	28.10	28.85	28.11
Manure N_2O	15.64	15.66	15.83	15.73	15.70	15.70
Manure CH_4	1.86	1.86	1.88	1.88	1.85	1.88
Indirect N_2O	2.81	2.81	2.84	2.84	2.81	2.84
			Feed production			
Corn	29.97	29.96	30.30	30.34	29.95	30.35
Alfalfa hay	2.12	2.11	2.14	2.14	2.11	2.14
Wet distillers grains plus solubles	7.76	7.75	7.84	7.85	7.75	7.85
Other	3.03	3.03	3.06	3.06	3.02	3.07
			Transport			
Feed	4.26	4.26	4.31	4.32	4.26	4.32
Manure	0.12	0.12	0.13	0.13	0.12	0.13
			Grain processing energy			
Natural gas	2.31	2.30	2.33	2.33	2.30	2.33
Electricity	1.27	1.27	1.28	1.28	1.27	1.28
			Summary			
Enteric	28.87	28.86	28.07	28.10	28.85	28.11
Manure	20.31	20.32	20.54	20.45	20.36	20.42
Feed production	42.87	42.86	43.34	43.40	42.84	43.41
Transport	4.39	4.39	4.44	4.44	4.38	4.44
Grain processing	3.57	3.57	3.61	3.62	3.57	3.62

[1]Cattle received a growth promoting implant that contained trenbolone acetate and estradiol twice during the finishing period.
[2]Cattle received monensin.
[3]Cattle received ractopamine hydrochloride the last 28 d of feeding
[4]For carbon footprint of wet distillers grains with solubles, 50% was applied to the ethanol industry and 50% to the wet distillers grains plus solubles.

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