IMPACTS OF ADDED ROUGHAGE ON FEEDLOT PERFORMANCE, DIGESTIBILITY, RUMINAL FERMENTATION, AND RUMINAL PH OF STEERS FED WHEAT-BASED DIETS

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Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Two studies were conducted to evaluate the inclusion of additional roughage in wheat-based diets containing modified distillers' grains with solubles on feedlot performance (Study 1) and digestibility, ruminal pH, and ruminal fermentation characteristics (Study 2). Study 1 used 72 steers (391.6 ± 46.3 kg) and study 2 used 4 ruminally and duodenally cannulated steers (393.4 ± 33.0 kg). Feedlot performance and carcass characteristics, excluding marbling, were not affected by increasing roughage ($P \geq 0.20$). Ruminal pH increased linearly ($P < 0.01$) as rate of roughage inclusion increased. Concentrations of acetate and butyrate increased, and propionate decreased in a linear fashion ($P < 0.01$), increasing acetate and butyrate to propionate ratio ($P < 0.01$) with increasing dietary roughage. Our data indicate that increasing roughage inclusion in wheat-based diets including modified distillers' grains with solubles increased ruminal pH and shifted ruminal fermentation patterns without affecting feedlot performance.

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LIST OF ABBREVIATIONS

ADF	Acid detergent fiber
ADG	Average daily gain
BW	Body weight
CP	Crude protein
DDGS	Dry distillers’ grains with solubles
DM	Dry matter
DMI	Dry matter intake
G:F	Gain to feed ratio
HCW	Hot carcass weight
MDGS	Modified distillers’ grains with solubles.
NDF	Neutral detergent fiber
OM	Organic matter
OMI	Organic matter intake
VFA	Volatile fatty acid
WDGS	Wet distillers’ grains with solubles

CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

Introduction

The United States produced 1.83 billion bushels of wheat in 2020, with wheat ranking as the third greatest grain produced behind corn and soybeans (USDA-ERS, 2021). In 2018, North Dakota ranked first in the United States for wheat production with a total harvest of 363 million bushels of wheat (USDA NASS, 2019). Negative connotations exist regarding utilizing wheat as an energy source in feedlot cattle diets primarily regarding increased risk of acidosis (Kreikemeier et al., 1987; He et al., 2015). Wheat is a high starch, highly fermentable grain source, that if not fed with proper management can lead to digestive disorders, poor performance, and decreased feedlot profitability.

Weather conditions are the number one factor influencing agriculture production. North Dakota faces harsh environments from bitter cold to extreme heat, and floods to severe droughts. These weather conditions can leave farmers with limited feed options for their cattle; but at the same time also provide opportunity to access low quality feeds at decreased costs. Vomitoxin is one of the most common mycotoxins that contaminates wheat (Rotter et al., 1996). Cold, humid environments can lead to the production of vomitoxin (deoxynivalenol) in wheat. Deosynivalenol can affect immunity in livestock and potentially decrease livestock production (Côté et al., 1984; Whitlow and Hagler, 2005). U.S. Food and Drug Administration limits vomitoxin fed at 10 ppm on an 88% dry matter basis (FDA, 2010). Although research has demonstrated that feedlot cattle can safely consume approximately 18 milligrams of vomitoxin per kilogram of dry matter (DiCostanzo and Murphy, 2021). Ergot is also a common disease that can be found in wheat caused by fungi (Lorenz and Hoseney, 1979). Ergot intake should be less than 0.1% of the total diet (Osweiler, 2014; Friskop et al., 2018). Ergot can lead to vasoconstriction, potentially causing loss of ears, tail, and hooves (Craig et al., 2015) as well as increased breathing rates, increased temperature, excessive salivation and an overall decrease in performance (Realini et al., 2005).

Understanding the limitations of feeding low quality feeds, and further defining conditions under which alternative feeds can be included in feedlot diets are critical to making producer recommendations. The purpose of this literature review is to explore the use of wheat as an energy source to feedlot cattle. Discussion on the inclusion of additional roughage and modified distillers' grains with solubles (**MDGS**) is also be presented, as well as context on the implications of management on digestive disorders.

Literature Review

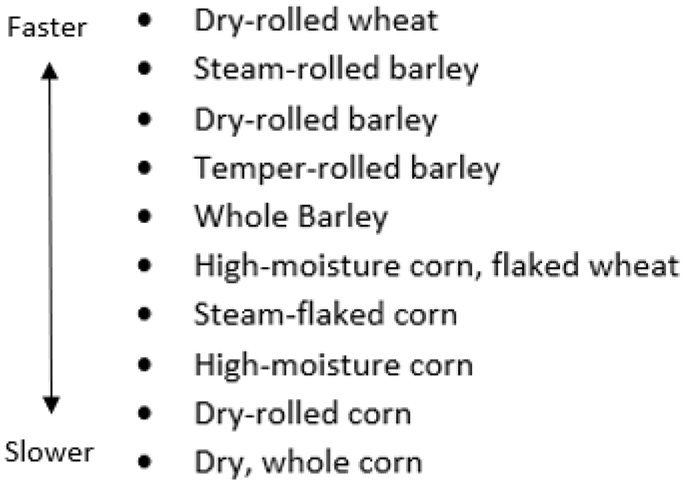
Grain Source in Feedlot Finishing Diet

Corn is the most commonly used feed grain in cattle feedlot diets followed by wheat, sorghum, and barley (Vasconcelos and Galyean, 2007). Opportunity for increasing wheat inclusion in feedlot diets often occurs in the case of least cost ration formulations when product availability is high due to the presence of lower quality wheat arising from adverse growing conditions. In an adaptation trial where steers were fed either corn or wheat-based diets, as wheat increased to 42.87%, dry matter intake (**DMI**) decreased and intake did not increase until day 4 of being fed the 42.87% wheat diet (Fulton et al., 1979). While ruminal pH of cattle fed corn diets rarely dropped below a pH of 5.4, steers fed wheat diets had more variable pH values and a greater occurrence of pH dropping below 5.2 with a 42.87% wheat finishing diet (Fulton et al., 1979) potentially explaining the reduction in intake. Research with high concentrate diets with a combination of dry-rolled corn and dry-rolled wheat found that yearling steers gained more when fed 60% and 90% corn compared with diets containing greater amounts of wheat, increasing wheat inclusion rate also increased feed to gain ratio of steers (Oltjen et al., 1966). For these steers, performance was similar for the first 70 days; however, for the last 28 days cattle fed the high-wheat diets had decreased intake (Oltjen et al., 1966). Similar to Oltjen et al. (1966), Liu et al. (2016) performed a study with increasing wheat and reported apparent digestibility of dry matter (**DM**), organic matter (**OM**), and crude protein (**CP**) increased with greater wheat inclusion. However, a more rapid decrease in ruminal pH occurred for steers fed the 100% wheat diet than for steers fed diets containing corn (Liu et al., 2016). As wheat inclusion increased acetate to propionate ratio increased (Liu et al., 2016). However, He et al. (2015) reported that when wheat replaced barley in a feedlot finishing diet, volatile fatty acid (**VFA**) concentration and acetate to propionate ratio were unaffected. Kreikemeier et al. (1987) found cattle to be more efficient when the diet contained a combination of corn and wheat rather than either of the grains alone.

Kreikemeier et al. (1987) found no quality grade differences in cattle fed corn, wheat, or a combination of corn and wheat, however, cattle fed 100% wheat diets had less backfat at the time of slaughter than cattle that were fed 100% corn. Another trial with corn, wheat, and corn/wheat diets, feeding greater amounts of wheat lead to a significant decrease in average daily gain (**ADG**) but did not result in differences in carcass data (Oltjen et al., 1966). A review from Owens and Gardner (2000) reported cattle fed wheat-based finishing diets had a lesser marbling to subcutaneous fat ratio compared to cattle fed corn or milo-based diets. Cattle fed a steam-flaked corn diet and a steam-flaked wheat diet showed no difference in carcass traits except for kidney pelvic heart fat, which was lesser in the steam-flaked wheat diet (Zinn, 1992). As current data do not provide a common outcome of carcass characteristics from cattle fed wheat-based diets, additional research is needed to confirm the impacts of wheat grain in feedlot rations.

Grain Processing

The purpose of grain processing is to reduce particle size to increase available dietary energy supply (Gomes et al., 2020). Cereal grains are generally the primary source of energy in feedlot diets. Type of grain and method used for grain processing determine the energy availability. Grain processing methods are continuously being adapted and upgraded in cattle feeding operations. A few common grain processing methods include dry-rolled, high-moisture, steam-flaked and temper-rolled (Lardy and Dhuyvetter 2016; Owens et al., 1997). Different methods of grain processing are customizable for an operation to increase feeding speed and improve labor costs. As feedlots expand, processing methods may change (Sprague, 2006). Some processing methods have appeared to improve the palatability and utilization of grain (Hale et al., 1973). Some processing methods cause the rate of digestion to be more rapid than others, depending on the moisture and particle size (Figure 1.1). The expected outcomes of grain processing include, improved feed conversion and digestibility, increased intake, increased ADG, maximized grain utilization, and minimized feed waste (Sprague, 2006).



- Dry-rolled wheat
- Steam-rolled barley
- Dry-rolled barley
- Temper-rolled barley
- Whole Barley
- High-moisture corn, flaked wheat
- Steam-flaked corn
- High-moisture corn
- Dry-rolled corn
- Dry, whole corn

Figure 1.1. Ranking of rate of digestion by grain and processing method. Figure adapted from Lardy and Dhuyvetter (2016)

Cereal grains are made up of a thick, outer layer protecting the inner germ and endosperm (Figure 1.2). The primary purpose of grain processing is to break down the outer layer and allow microbes access to the starch within the endosperm (Hale et al., 1973; McAllister et al., 2006). Grain processing increases utilization of starch and improved efficiency of gain when used with proper management (Hale et al., 1973). When corn is processed, the site of digestion is changed where very little starch is digested in the small intestine (Freitas et al., 2021). Fine grinding can enhance the extent of digestion ruminal disappearance of starch (Hale et al., 1973). Over processing grains increases the proportion of fine particles, allowing access to the starch granules too rapidly, increasing ruminal fermentation, leading to a decrease in ruminal pH and resulting in ruminal acidosis (Safaei and Yang, 2017).

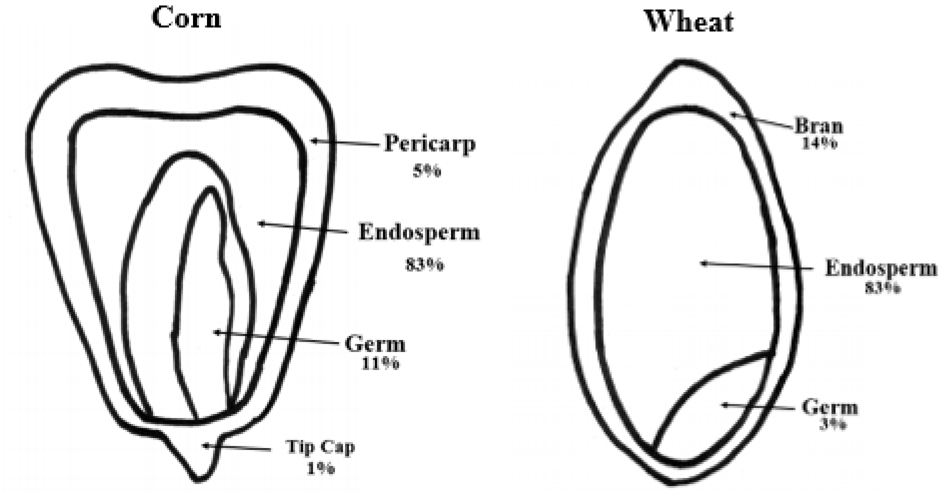


Figure 1.2. Corn vs wheat grain components. Adapted from Kumar et al. (2011) and Gwirtz and Garcia-Casal (2013).

Processing grain increases the starch digestibility improving growth and performance of feedlot cattle (Galyean et al., 1979; Zinn et al., 2002). Different processing methods alter the site and extent of digestion of starch (Zinn et al., 2002). Ruminal bacteria are responsible for most of the fermentation in the rumen, along with ruminal protozoa aiding in the digestion of starch granules (Huntington, 1997). Along with processing method, particle size is a crucial component in grain processing to ensure efficiency as well as avoiding the production of fines leading to rapid fermentation and digestive disorders. Particle size may partially determine differences in site of digestion. Utilizing dry rolling as a processing method reduces the particle size and increases fermentation rate, however steam flaking grain provides an even smaller particle size and further increases fermentation rate than other processing methods (Owens, 2005). Owens et al. (1997) suggests a coarser particle size can shift site of starch digestion from the rumen to the small intestine. Depending on the extent of disruption to the protective protein matrix, enzymes have easier access to the starch granules, increasing the digestibility of corn and improving starch utilization (Hale et al., 1973; Zinn et al., 2002).

Galyean et al. (1981) found a greater utilization of starch with in situ ruminal incubation of steam-flaked corn and high-moisture corn than dry-ground corn. Along with shifting the site of starch digestion to the rumen, steam-flaked corn increased both ruminal and total tract starch disappearance over dry-rolled or dry-ground grain (Owens, 2005). A review by Huntington (1997) reported that gelatinization improves uniformity meaning steam-flaked corn decreases variation compared to dry-rolled corn.

Kreikemeier et al. (1990) found that in situ ruminal starch digestion was 3.5 times faster for dry-rolled wheat than in steam-rolled wheat. Stock et al. (1990) found cattle fed dry-rolled wheat were more acidotic based on lower feed intakes and reduced daily gains. This was confirmed by the fast rate of starch disappearance in vitro (Stock et al., 1990). A study replacing barley with wheat, showed an increase in dietary starch and a decrease in CP, neutral detergent fiber organic matter, and acid detergent fiber organic matter (He et al., 2015).

The rate at which starch breaks down into glucose varies with grain type and processing methods (Freitas et al., 2021). Grain that is higher in moisture tends to have a greater starch availability that can potentially lead to digestive upset (Owens et al., 1986). Using a combination of moisture and heat to process grain has shown to increase VFA production than dry processing methods (Theurer et al., 1986). Processing grains increases the fermentation rate, increasing the availability of free glucose, number of ruminal bacteria, VFA production and decreasing ruminal pH (Owens et al., 1998).

Dietary Roughage Inclusion

Feedlot Performance

Roughage inclusion is an important component in finishing diets as it can offset the risk of acidosis in feedlot cattle. A typical finishing feedlot diet contains 5% to 15% roughage on a DM basis (Owens, 1987). Samuelson et al. (2016) reported that 8% to 10% roughage inclusion was the typical range used by feedlot nutritionists for both summer and winter; however, some nutritionists reported they increase roughage inclusion to 10% to 12% in the winter. Galyean and Defoor (2003) stated that the DMI of cattle fed a high concentrate diet is largely affected by roughage source and inclusion level in the diet. To maintain energy intake, cattle may consume more feed when a high concentrate diet is diluted by roughage (Galyean and Defoor, 2003).

Increased DMI is a common observation in trials with increasing roughage. When roughage inclusion increased from 0% to 9%, DMI increased for steers fed high moisture corn and dry-rolled grain sorghum (Stock et al., 1990). Kreikemeier et al. (1990) found DMI increased when dietary roughage increased from 0% to 15%. However, Kreikemeier et al. (1990) found a quadratic response in daily gain with the fastest gains at 5% and 10% roughage, while Stock et al, (1990) found the greatest ADG when dietary roughage was included at 3% and 6% roughage. Quadratic responses in DMI may be an indication of high amounts of acid causing intake to fluctuate (Galyean and Defoor, 2003) which may be an outcome of low dietary roughage inclusion. While these trials showed an increase in DMI when roughage was increased (Stock et al., 1990; Kreikemeier et al., 1990), Calderon-Cortes and Zinn (1996) observed no difference in DMI with increasing roughage from 8% to 16%, but, ADG and feed efficiency both decreased with increasing roughage. Another study from Stock et al. (1990) showed feed intake increased when dietary roughage increased from 0% to 7.5% in dry-rolled corn, dry-rolled grain sorghum, and dry-rolled wheat feedlot finishing diets. Steers that were fed 7.5% roughage in the dry-rolled corn, and dry-rolled wheat diets tended to gain faster than steers fed 0% roughage. However, as dry-rolled grain sorghum increased in the diet, the 7.5% roughage diets caused feed the efficiency to decrease. Hales et al. (2014) found no difference in DMI when alfalfa hay inclusion increased from 2% to 14 % in a finishing diet. With increasing alfalfa hay as a roughage source from 2% to 6%, final body weight (**BW**) tended to increase in a trial by Hales et al. (2013) but tended to decrease when alfalfa hay increased from 6% to 14%. Hales et al. (2013) also found gain to feed ratio (**G:F**) increased as alfalfa hay increased from 2% to 6% but decreased as alfalfa hay increased from 6 to 14%, due to an increase of ADG as alfalfa hay increased from 2% to 6% and a decrease in ADG with as roughage increased from 6% to 14%. Providing traditional inclusion rates of dietary roughage is a potential management strategy to aid in the prevention of digestive disorders and potentially improve performance.

Carcass Traits

Increasing alfalfa hay in a ration had no effect on hot carcass weight (**HCW**), marbling score, or percentage of steers grading choice and above, although dressing percent showed a quadratic response, decreasing at 2% and 10% alfalfa hay and increased at 14% roughage (Hales et al., 2013). Kreikemeier et al. (1990) reported cattle having heavier carcasses when fed 5% to 10% roughage diets rather than steers from 0% or 15% roughage diets which is consistent with results from Benton et al. (2015) who observed tendencies in cattle fed 0% roughage to have the light HCW. Calderon-Cortes and Zinn (1996) observed an increase in carcass fat when roughage inclusion was increased from 8% to 16% with a coarser grind size. Consistent with Calderon-Cortes and Zinn (1996), Stock et al. (1990) also found a greater fat thickness in cattle fed 7.5% roughage over 0% roughage.

Ruminal Characteristics

Starch digestibility decreased when roughage increased from 0% to 6% but showed tendencies to increase at 9% roughage (Stock et al., 1990). As Calderon-Cortes and Zinn (1996) decreased roughage in the diet, ruminal digestibility of OM, acid detergent fiber (**ADF**), starch, and microbial efficiency were not affected, however digestible energy increased. As dietary roughage increased, total VFA increased from hours 2 to 6 post feeding, potentially due to the increased rate of starch digestion (Kreikemeier et al., 1990). Ruminal pH tended to decline more rapidly for steers that were feed 3 times the net energy requirements for maintenance over 2 times (Kreikemeier et al., 1990). As expected, Calderon-Cortes and Zinn (1996) observed an increase in ruminal pH with increasing levels of roughage.

Distillers' Grains with Solubles Inclusion

Grain coproducts from both dry and wet milling processes have become a popular, starch-free addition to feedlot finishing rations that offers increased fiber, protein, and fat (Vasconcelos and Galyean, 2007; Klopfenstein et al., 2008). A survey performed by Vasconcelos and Galyean (2007) reported grain coproduct included in finishing diet range from 5% to 50% but grain coproducts are most commonly fed at 10% to 20% (Samuelson et al., 2016). Farlin et al. (1981)

found wet distillers' grains to have more energy than corn, relative to feed value. Hales et al. (2012) suggested a reduced need for additional dietary roughage when ethanol coproducts are included in finishing diets as they can replace a portion of the high concentrate grains.

Feedlot Performance

Depenbusch et al. (2009) found that when comparing diets containing steam-flaked corn with no distillers' grains with solubles and diets with alfalfa hay with wet distillers' grains with solubles (**WDGS**) or dry distillers' grains with solubles (**DDGS**), DMI, ADG, or G:F were not different. Likewise, May et al. (2010) also found no difference in DMI, ADG, and G:F when DDGS inclusion increased from 0% to 25%. Conversely, Buckner et al. (2007) reported the heaviest final BW and greatest ADG were found when steers were fed 20% DDGS diets, but steers fed 30% and 40% DDGS were still greater in final BW and ADG than the control diet which included 0% DDGS. Hales et al. (2015) found cattle to consume more dry matter when being fed 25% WDGS in a dry-rolled corn diet when compared to cattle fed 40% WDGS. Larson et al. (1993) found WDGS fed at 40% in a finishing diet increased feed efficiency by 14% more than corn. When including 40% WDGS or DDGS in the diet replacing corn, Ham et al. (1994) found WDGS and DDGS increased relative feed value by 47% and 24%, respectively, over corn. These results were confirmed by Klopfenstein et al. (2008) that found improvements in ADG and DMI in cattle fed 40% or less of DDGS. Ponce et al. (2019) reported cattle gaining weight more rapidly when fed 15% WDGS over 30% WDGS. Leupp et al. (2009) found OMI to be the greatest in feedlot finishing diets containing 15% DDGS and the lowest in 60% DDGS diets.

Carcass Traits

Carcass weight and rib fat, along with marbling score, yield grade, and quality grade were not different between diets with and without distillers' grains with solubles (Depenbusch et al., 2009). However, Berger and Singh (2010) reported heavier carcass weights, more backfat, and increased yield grades in cattle fed 25% DDGS, 40% DDGS or 40% modified distillers' grains with solubles (**MDGS**) diets over cattle fed a diet containing dry-rolled corn. Although, maximizing carcass weight and 12th rib fat in steers fed 40% DDGS rather than 40% MDGS (Berger and Singh, 2010). As 30% WDGS diets caused a lower ADG, this also led to a lighter HCW than the cattle fed 15% WDGS diets (Ponce et al., 2019). Ponce et al. (2019) also reported greater dressing percent in cattle fed the control diet which included 0% WDGS over both the 15% and 30% WDGS diets. Marbling score, quality grade, and fat over the 12th rib were not affected by additional DDGS in the finishing ration (May et al., 2010).

Ruminal Characteristics

Hales et al. (2015) found fecal energy losses, as well as digestible energy to be higher in finishing diets that include 25% WDGS over 40% WDGS. Metabolizable energy was not different in finishing diets containing 25 and 45% WDGS (Hales et al., 2015). Hales et al. (2015) reported a tendency for 45% WDGS diets to be more digestible than 25% WDGS diets. As DDGS increased in the diet from 0% to 60%, fecal OM decreased, while apparent and true ruminal OM digestion also decreased (Leupp et al., 2009). Both starch intake and fecal starch excretion was higher in 35% WDGS finishing diets over 45% WDGS finishing diets (Hales et al., 2015).

Ruminal Acidosis

Digestive disorders are one of the largest hurdles that feedlots operations have to face when feeding cattle a highly fermentable diet (Britton and Stock, 1991). As high grain diets are used to achieve maximum productivity (Vasconcelos and Galyean, 2007), digestive disorders can often arise from poor management during dietary adaptation to high grain diets. Not only do digestive disorders affect the health of cattle, but they decrease rate of gain, increase cost of gain, and reduce income within an operation.

Ruminal acidosis is a common digestive disorder in cattle that follows the ingestion of excess starch from readily fermentable carbohydrates leading to rapid production and absorption of acids (Elam, 1976; Britton and Stock, 1991). Economically, producers prefer to finish cattle rapidly and maximize feed efficiency (Elam, 1976), however, doing so may result in acidosis due improper adaptation of the rumen. Increasing the grain concentration in cattle fed high forage diets disrupts the microbial environment, causing lactate to build up (Britton and Stock, 1991). Roughage is an important factor when managing acidosis. As roughage increases in the diet, production of saliva is increased, carrying buffers to the rumen, increasing ruminal pH (Allen, 1997; Weiss et al., 2017). Acidosis can be separated into subacute and acute acidosis, depending on the severity (Owens et al., 1998). According to Elam (1976), signs of acidosis can vary due to severity. Common, exterior signs may be excessive weight loss, diarrhea, mucus in feces dehydration, incoordination, and potentially death. When the rumen is stable and functioning normally, ruminal pH is usually in the range of 5.8 to 6.5, in cattle that are adapted to a high-grain diet (Nagaraja and Titgemeyer, 2007). Drops in pH for a short amount of time, after consumption of a high grain diet are completely normal. However, Nagaraja and Titgemeyer (2007) state that it is unknown how long ruminal pH can stay below suboptimal levels, ≤ 5.5 before becoming detrimental to the animal’s health. After eating, solid portions of the feed stays in the rumen for approximately 48 hours for fermentation before moving through to the omasum (Parish et al., 2017). The ruminal flora is made up of bacteria, fungi and protozoa that work to break down fibrous feed into carbohydrates that produce VFAs. Some of the bacteria will break down cellulose and other bacteria break down starch. Ruminal fermentation produces VFAs including, acetate, butyrate, and propionate. Volatile fatty acids are absorbed into blood supply through the ruminal wall which is lined with papillae that works to increase the surface area for maximum absorption (Owens et al., 1998).

Subacute acidosis is more common in a feedlot setting and less severe but is considered to be more of an economic problem (Slyter et al., 1976). While subacute acidosis may be difficult to recognize, the major signs include a decreased intake and performance (Britton and Stock, 1991). A drop in ruminal pH to approximately 5.6 is considered subacute acidosis and 5.2 becomes acute acidosis (Owens et al., 1998). According to Britton and Stock (1991), almost every animal in a feedlot setting will go through subacute acidosis at some point during the adaptation period to a high grain diet. Signs of subacute acidosis include, kicking at the belly, panting, and diarrhea.

Acute acidosis is more detrimental to an animal's health as it follows the excess consumption of readily fermented carbohydrates and leading to a rapid, more drastic decrease in ruminal pH to 5.2 and lower (Owens et al., 1998). Acute acidosis is more noticeable than subacute acidosis as symptoms are more severe such as, not eating, wondering aimlessly, and sometimes may not be able to stand (Britton and Stock, 1991). Several other disorders can come from ruminal acidosis. Severe or acute acidosis can lead to sudden death syndrome and brain damage leading to polioencephalomalacia, however, can be offset by thiamine injection (Stock and Britton 1991). During ruminal acidosis, the acid build up can cause the lining of the rumen to become damaged, leading to bacteria entering the blood stream, essentially causing liver abscesses (Britton and Stock, 1991). Along with rumen wall damage, as ruminal pH declines bacteriolysis and tissue degradation causes vasoconstriction, reducing oxygen and nutrient flow to extremities resulting in laminitis (Nocek, 1996). Cattle fed wheat had the largest percent of condemned livers due to abscesses (Oltjen et al., 1966); further demonstrating the potential links between feeding greater concentrations of wheat and acidosis.

Offsetting the risk of digestive disorders in feedlot cattle fed high grain diets may be accomplished by additional roughage, which regulates starch fermentation in the rumen and accumulation of volatile fatty acids (Turgeon et al., 2010). When distillers' grains with solubles are included in a high grain diet at 20% DM or greater, the risk of acidosis may be decreased as well as the need of excess roughage (Klopfenstein et al., 2008). Ruminal buffers and neutralizers such as sodium bicarbonate, calcium carbonate, and magnesium oxide can be included in diet formulation to aid in maintaining a stable ruminal pH. Ruminal stability is greater with whole shelled corn and added roughage than processed grains (Owens et al., 1997). According to Zinn et al. (2002), feeding cattle steam-flaked corn will lead to a drop in ruminal pH 4 hours post feeding, lower than cattle fed dry-rolled corn or whole shelled corn. Steam flaking corn results in lower density which increases the rate of starch digestion. Steam-flaked corn decreases the acetate to propionate ratio of the rumen causing a decrease in methane energy loss during fermentation (Zinn et al., 2002). Maintaining a consistent flake size with feeding steam-flaked corn is a crucial management practice to avoid ruminal acidosis. Fluctuation in flake size may cause DMI intake to be inconsistent leading to digestive disorders (Owens et al., 1997; Zinn et al., 2002).

Conclusions

While corn is the most common grain utilized in feedlot finishing diets, other energy sources are available to the beef cattle industry. Grains such as wheat, barley, and sorghum coupled with different inclusion levels of dietary roughage and ethanol coproducts can be effectively utilized in finishing cattle nutrition. Management is a key component in maintaining an efficient and healthy feedlot, especially when incorporating different energy sources. Grain processing is important in ensuring maximum efficiency in the turnover rate of a feedlot but can also hinder an operation if not properly managed. Digestive disorders such as ruminal acidosis can have large, negative impacts on a feedlot as a result of poor management. Being able to properly manage the multitude of factors involved in ruminal adaptation, regulation, and fermentation will allow for use of low-cost alternative grains including low-quality wheat and other grain sources.

There is a need for more scientific literature pertaining to the use of low-quality wheat in feedlot diets with different levels of dietary roughage inclusion, as well as modified distillers' grains with solubles. With this additional research, resources will be available for producers to be able to rely on in the case of needing to utilize an alternative grain source, while still avoiding digestive disorders and improving performance.

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CHAPTER 2. IMPACTS OF ADDED ROUGHAGE ON FEEDLOT PERFORMANCE, DIGESTIBILITY, RUMINAL FERMENTATION, AND RUMINAL PH OF STEERS FED WHEAT-BASED DIETS

Abstract

Two studies were conducted to evaluate the inclusion of additional roughage in wheat-based diets containing modified distillers' grains with solubles (**MDGS**) on feedlot performance (Study 1) and digestibility, ruminal pH, and ruminal fermentation characteristics (Study 2). Study 1 used 72 steers (391.6 ± 46.3 kg) assigned to 1 of 12 pens, 3 pens per treatment, to evaluate performance and carcass characteristics. Dietary treatments were 1) control; 10% roughage, 2) 12% roughage, 3) 14% roughage, and 4) 16% roughage. Study 2 utilized 4 ruminally and duodenally cannulated steers (393.4 ± 33.0 kg) in a 4 × 4 Latin Square with similar dietary treatments as Study 1. Feed intake was recorded, and fecal output calculated using chromic oxide. Ruminal pH and fermentation were assessed with ruminal fluid samples. Feedlot performance and carcass characteristics, excluding marbling, were not affected by increasing roughage ($P \geq 0.20$). There was a tendency for marbling to linearly decrease ($P = 0.10$) with increasing roughage inclusion. Increasing inclusion rate of dietary roughage had no effect on organic matter intake (**OMI**; $P = 0.80$) when expressed in either kg/d or % of BW. Intake and total tract digestibility of neutral detergent fiber (**NDF**) and acid detergent fiber (**ADF**) were not affected by treatment ($P \geq 0.23$). However ruminal NDF digestibility increased in steers fed 12% and 14% roughage compared to those fed 10% or 16% ($P = 0.06$, quadratic). Ruminal pH increased linearly ($P < 0.01$) as rate of roughage inclusion increased. Concentrations of acetate and butyrate increased, and propionate decreased in a linear fashion ($P < 0.01$), increasing acetate and butyrate to propionate ratio ($P < 0.01$) with increasing dietary roughage. Our data indicate that increasing roughage inclusion in wheat-based diets including MDGS increased ruminal pH and shifted ruminal fermentation patterns without affecting feedlot performance.

Key words: beef cattle, distillers' grains, roughage inclusion, ruminal pH, wheat

Introduction

Wheat can be used as an alternative grain in feedlot diets; however, the rapid fermentation rate of wheat increases the risk of acidosis (Kreikemeier et al., 1990; Bock et al., 1991). Cattle fed high-grain diets are at risk of digestive disorders, which can be offset with an increased amount of roughage in the diet (Wise et al., 1968; Owens et al., 1998; Gentry et al., 2016). Rate of roughage inclusion in the diet can affect dry matter intake (**DMI**), average daily gain (**ADG**) and gain to feed (**G:F**) if provided in excess (Galyean and Defoor, 2003). Survey data indicated that 8% to 12% roughage inclusion is typical for feedlots (Samuelson et al., 2016). Less roughage may cause a reduced rate of gain as a result of digestive disorders (Gentry et al., 2016; Galyean and Hubbert, 2014). Increased roughage inclusion increases ruminal pH, minimizing the risk of digestive upset (Weiss et al., 2017).

Research on feeding wheat with ethanol coproducts is limited. Including wet distillers' grains with solubles (WDGS) in combination with highly fermentable grains such as dry-rolled corn helps to increase the ruminal pH (Hales et al., 2014). With the absence of starch in distillers' grains with solubles the occurrence of acidosis should be reduced, reducing the amount of roughage needed in a diet (Krehbiel et al., 1995; Farran et al., 2006; Klopfenstein et al., 2008). The objective of this study was to evaluate the impacts of including additional roughage on feedlot performance, as well as ruminal fermentation and pH of steers fed wheat-based feedlot rations including 30% modified distillers' grains with solubles (**MDGS**). Our hypothesis is that increasing roughage inclusion in wheat-based diets including MDGS would decrease feedlot performance and reduce digestibility while increasing ruminal pH.

Materials and Methods

This study was approved by the North Dakota State University Institutional Animal Care and Use Committee prior to initiation of study procedures (#A20065).

Study 1

To accomplish the objective of this study, 72 steers (391.6 ± 46.3 kg) were assigned to one of 12 pens (n = 3 pens per treatment). Steers were stratified by body weight and randomly assigned to pen with pen randomly assigned to treatment. Pens were stocked at a similar density, approximately 58.3 m^2 of pen space per animal. Treatments were assigned randomly to pen. Dietary treatments consisted of 1) control; 10% roughage, 2) 12% roughage, 3) 14% roughage, and 4) 16% roughage. As wheat decreased by 2% between treatments, it was replaced by 2% wheat straw. Final finishing diet composition and nutrient content are presented in Table 2.1.

Upon arrival, cattle were weighed on two consecutive days, averaged for initial body weights and were sorted into pens. All calves received a growth promoting implant Synovex Choice (Zoetis Inc, Parsippany, NJ) at the initiation of the study. Diets were developed to adapt cattle in 5 equal steps from a moderate roughage to a high concentrate diet over a period of 28 days. Steers were fed for a total of 119 days. Feed was provided to target clean bunks every morning. At the conclusion of the feeding period, cattle were weighed on two consecutive days to determine final body weight and shipped to a commercial abattoir for slaughter and subsequent carcass data collection. Hot carcass weights were collected within 30 min of exsanguination. Ribeye area, 12th-rib fat, and marbling score were measured via automated camera imaging, while quality grade was assigned by USDA grader. All carcass data reported were provided by the abattoir.

Table 2.1. Ingredient and nutrient composition of diets fed to steers in the feedlot study.

	Percentage Roughage Inclusion[1]			
	10	12	14	16
Ingredients, % DM				
MDGS	30.0	30.0	30.0	30.0
Dry-Rolled Wheat	42.1	40.1	38.1	36.1
Grass Hay	5.0	5.0	5.0	5.0
Dry-Rolled Corn	15.0	15.0	15.0	15.0
Wheat Straw	5.0	7.0	9.0	11.0
Limestone	1.5	1.5	1.5	1.5
Supplement[2]	1.4	1.4	1.4	1.4
Nutrient Composition				
Dry matter, %	71.9	71.6	72.3	69.6
Crude Protein, %	19.5	18.9	18.6	18.9
NEg[3], Mcal/kg	1.38	1.36	1.34	1.32
NDF, %	30.2	30.0	31.2	32.2
ADF, %	11.1	11.4	12.5	13.2

[1] Treatment based on dietary roughage inclusion: 10 = 10% roughage; 12 = 12% roughage, 14 = 14% roughage, and 16 = 16% roughage.

[2] The supplement contained 81.1% grain screenings, 7.5% calcium carbonate, 3.8% molasses, 6.5% vitamin and trace mineral premixes, and 1.2% monensin premix. The supplement was fed to provided 330 mg of monensin $\text{steer}^{-1}\cdot\text{d}^{-1}$.

[3] Net Energy values estimated based on NASEM (2016).

Study 2

Animal Diets and Treatments

Four ruminally and duodenally cannulated steers (393.4 ± 33.0 kg) were used in a 4 × 4 Latin square design to evaluate the impacts of added roughage in a wheat-based diet containing 30% MDGS to feedlot cattle. Treatments were based on increasing amount of roughage in the diet and consisted of 1) control; 10% roughage, 2) 12% roughage, 3) 14% roughage, and 4) 16% roughage. As wheat decreased by 2% between treatments, it was replaced by 2% wheat straw. This ration composition differed from the feedlot study ration as silage was the main source of roughage for the digestibility portion of the study instead of a combination of grass hay and wheat straw (Table 2.2). Steers were housed in individual stations (2.13 m × 1.73 m). Steers were fed a total mixed ration, two times a day at 0700 and 1900 and had continuous access to water. Feed was provided at a rate equal to DMI (kg/d) = 3.830 + [0.0143 × (BW × 0.96)] as suggested (NASEM, 2016). Feed offered was adjusted at the start of each period. Orts, when present, were collected at 0700 each day prior to feeding.

Table 2.2. Ingredient and nutrient composition of diets fed to steers in the digestibility study.

	Percentage Roughage Inclusion[1]			
	10	12	14	16
Ingredients, % DM				
MDGS	30.0	30.0	30.0	30.0
Dry-Rolled Wheat	36.7	34.7	32.7	30.7
Corn Silage	20.0	20.0	20.0	20.0
Dry-Rolled Corn	10.0	10.0	10.0	10.0
Wheat Straw	0.0	2.0	4.0	6.0
Limestone	0.8	0.8	0.8	0.8
Supplement[2]	2.5	2.5	2.5	2.5
Nutrient Composition				
Dry matter, %	64.5	64.7	64.3	64.4
Crude Protein, %	16.0	15.7	16.3	16.2
NEg[3], Mcal/kg	1.38	1.36	1.33	1.31
NDF, %	41.1	42.3	43.1	41.8
ADF, %	14.6	14.8	18.9	16.6

[1] Treatment: 10 = 10% roughage included as corn silage assuming 50:50 of roughage to concentrate in corn silage, 12 = 10% roughage from corn silage and 2% straw, 14 = 10% roughage from corn silage and 4% straw, and 16 = 10% roughage from corn silage and 6% straw.

[2] The supplement contained a minimum of 10% CP, 1.5% crude fat, 17.5% Ca, 0.1% P, 6.5% salt, 1.1% Mg, 0.1% K, 400mg/kg Cu, 1400 mg/kg Zn, 176,400 IU/kg vitamin A, 44,100 IU/kg of vitamin D, 727 IU/kg vitamin E, and contained 1102g/metric ton monensin.

[3] Net Energy values estimated based on NASEM (2016).

Sample Collection

Each collection period consisted of a 7-d adaptation period and 7-d collection period. Feed and ort samples were collected once daily on d 7 through d 14 and composited for each steer and period. Chromic oxide (8 g) was placed into gelatin capsules and ruminally dosed at time of feed delivery from d 4 to d 12 as an external marker. Duodenal fluid (100 mL) and fecal grab samples were collected on d 10 through d 12 in a manner to allow for collection of a sample for every hour in a twelve-hour period (0700 to 1900). Duodenal samples were composited within each steer and period and froze at -20°C until analysis. Fecal samples were immediately frozen and stored at -20°C before being composited, mixed with a stand mixer (Model H-600, Hobart Manufacturing Co., Troy, OH).

Ruminal fluid was collected on day 13 at -2, 0, 2, 4, 6, 8, 10, and 12 h relative to morning feeding. Following the -2 h collection, 200 mL of CoEDTA (2,636 mg/L) was dosed via ruminal cannula for determination of the ruminal fluid dilution rate. Using a suction strainer, 100 mL of ruminal fluid was collected, and pH was recorded using a pH meter probe (symphony B10P; VWR International, LLC., Radnor PA). Ruminal fluid was then acidified with 1 mL of 7.2N Sulfuric acid and stored at -20°C until analysis for concentrations of cobalt, ammonia, and volatile fatty acids. Calculations for fluid parameters followed procedures outlined by Galyean et al. (2010).

Laboratory Analysis

Feed, orts, and fecal samples were all dried in a forced air oven (55°C; The Grieve Corporation, Round Lake, IL) for a minimum of 72 h. Dried samples were ground using a Wiley Mill (Arthur H. Thomas Co., Philadelphia, PA) to pass a 2-mm screen. Duodenal samples were freeze dried (Virtis Genesis 25LL, The Virtis Company Inc., Gardiner, NY) and ground in a Wiley mill to pass a 1-mm screen. Diet, ort, and duodenal samples were analyzed for dry matter, ash, crude protein, phosphorus, and calcium (methods 934.01, 942.05, 2001.11, 965.17, and 968.08, respectively; AOAC, 2010). Concentrations of neutral detergent fiber (Van Soest et al., 1991; as modified by Ankom Technology, Fairport, NY) and acid detergent fiber (Goering and Van Soest, 1970, as modified by Ankom Technology) were determined using an Ankom 200 Fiber Analyzer (Ankom Technology, Macedon, NY). Cobalt was analyzed by methods described by Uden et al. (1980) with an air-plus-acetylene flame using atomic absorption spectroscopy (Model: 3030B; Perkin Elmer, Inc., Wellesley, MA)

Statistical Analysis

Data were analyzed with PROC MIXED (SAS Ins. Inc., Cary, N.C.). Pen was the experimental unit for Study 1. Individual animal data [BW, average daily gain (**ADG**), and carcass characteristics] were averaged within pen to create pen values. Study 2 was analyzed as a 4 × 4 Latin square design. The model included period and treatment as fixed effects. Data over time were analyzed as repeated measures, and the model included period, treatment, and time. The treatment × time interaction was initially included but was not significant for any variables and was therefore removed from the model. Covariant structures were tested, and Simple was used based on fit statistics. Means were separated based on increasing roughage inclusion rate using linear, quadratic, and cubic contrast statements. P-values ≤ 0.05 were considered significant, and P-values > 0.05 and ≤ 0.10 were considered tendencies.

Results

Feedlot Study

Steer BW, DMI, ADG, and G:F were not affected by roughage inclusion ($P \geq 0.42$; Table 2.3). Likewise, HCW, ribeye area, back fat, quality and yield grade were unaffected by roughage inclusion rate ($P \geq 0.20$). There was a tendency for marbling to linearly decrease ($P = 0.10$) with increasing roughage inclusion.

Digestibility Study

Increasing inclusion rate of dietary roughage had no effect on OMI ($P = 0.80$; Table 2.4) when expressed on a kg/d or % of BW basis. There were tendencies for a quadratic response in total tract digestibility of organic matter ($P = 0.08$) and, fecal output of organic matter ($P = 0.09$) with increased roughage. Intake, fecal output, duodenal flow and digestibility of CP were unaffected by treatment ($P \geq 0.29$; Table 2.5). Intake, duodenal flow, fecal flow, total tract digestibility of NDF were not affected by treatment ($P \geq 0.22$; Table 2.6). Ruminal digestibility of NDF digestibility increased in steers fed 12% and 14% roughage compared to those fed 10% or 16% ($P = 0.06$, quadratic). Intake, fecal output, ruminal, and total digestibility of ADF were not affected by treatment ($P \geq 0.21$). Duodenal flow of ADF tended to increase linearly ($P = 0.10$) with increasing roughage. Ruminal pH increased while total VFA production (mM) decreased linearly with increasing roughage ($P < 0.01$; Table 2.7). Ruminal acetate and butyrate proportion increased while propionate proportion decreased linearly with increased inclusion of roughage ($P < 0.01$). The ratio of acetate+butyrate:propionate increased linearly with added roughage in the diet ($P > 0.01$). Fluid dilution rate, fluid volume, fluid turnover rate and fluid flow rate were not affected by treatment ($P \geq 0.38$).

Table 2.3. Impacts of added roughage on feedlot performance and carcass characteristics of feedlot cattle fed wheat-based diets.

	Treatment[1]					*P*-Value[2]			
	10	12	14	16	SEM	Trt	L	Q	C
Feedlot Performance									
Initial weight, kg	391.0	391.2	386.9	393.4	2.66	0.42	0.85	0.25	0.24
Final weight, kg	650.2	645.7	635.1	646.8	10.17	0.74	0.65	0.44	0.55
Average daily gain, kg/d	2.20	2.14	2.05	2.19	0.074	0.50	0.72	0.21	0.48
Dry matter intake, kg/d	13.2	13.1	13.0	13.2	0.36	0.97	0.94	0.70	0.83
Gain:feed	0.17	0.16	0.16	0.17	0.008	0.87	0.83	0.48	0.73
Carcass Characteristics									
Hot carcass weight, kg	381.2	380.2	369.4	383.2	4.84	0.26	0.84	0.17	0.15
Ribeye area, cm^2	83.3	81.0	80.2	81.7	1.08	0.29	0.27	0.12	0.91
Marbling[3]	499	439	455	445	15.7	0.11	0.10	0.12	0.20
Back fat, cm	1.10	1.18	1.20	1.22	0.09	0.75	0.34	0.69	0.88
Quality grade[4]	10.4	9.8	10.0	10.0	0.19	0.20	0.17	0.16	0.30
Yield grade	3.1	3.3	3.3	3.4	0.13	0.58	0.26	0.56	0.63

[1] Treatment: 10 = 5% grass hay and 5% straw; 12 = 5% grass hay and 7% straw; 14 = 5% grass hay and 9% straw; and 16 = 5% grass hay and 11% straw.

[2] *P*-values: Overall effect of treatment (Trt), linear (L), quadratic (Q), and cubic (C) contrasts

[3] Marbling score based on 400 = Small00.

[4] Quality grade based on Low Choice (Ch-) = 10, High Prime (Pr+) = 15.

Table 2.4. Impacts of added roughage on organic matter (OM) intake, flow, and digestion in steers fed wheat-based diets.

	Treatments[1]					*P*-value[2]			
OM	10	12	14	16	SEM	Trt	L	Q	C
Intake									
kg/d	9.38	9.29	9.15	9.44	0.401	0.96	0.97	0.64	0.80
% of BW	2.24	2.20	2.17	2.24	0.060	0.80	0.93	0.37	0.78
Duodenal flow, kg/d									
Bacterial	0.13	0.12	0.13	0.16	0.039	0.99	0.63	0.60	0.99
Apparent feed	3.93	3.76	3.74	4.48	0.402	0.56	0.40	0.29	0.75
Total	4.06	3.87	3.86	4.84	0.434	0.58	0.41	0.31	0.76
Fecal output, kg/d	2.49	2.20	2.27	2.62	0.156	0.30	0.55	0.09	0.92
Digestibility, % of intake									
True ruminal	56.41	58.53	57.85	51.27	3.507	0.50	0.34	0.26	0.85
Total tract	73.26	76.28	75.07	72.41	1.358	0.27	0.56	0.08	0.67

[1] Treatment: 10 = 10% roughage included as corn silage assuming 50:50 of roughage to concentrate in corn silage, 12 = 10% roughage from corn silage and 2% straw, 14 = 10% roughage from corn silage and 4% straw, and 16 = 10% roughage from corn silage and 6% straw.

[2] *P*-values: Overall effect of treatment (Trt), linear (L), quadratic (Q), and cubic (C) contrasts.

Table 2.5. Impacts of added roughage on CP intake, flow, and digestion in steers fed wheat-based feedlot diets.

	Treatments[1]					*P*-value[2]			
CP	10	12	14	16	SEM	Trt	L	Q	C
Intake, kg/d	1.79	1.73	1.72	1.72	0.076	0.89	0.55	0.68	0.93
Intake, % of BW	0.43	0.41	0.41	0.41	0.016	0.80	0.47	0.54	0.97
Duodenal flow, kg/d									
Bacterial	0.51	0.49	0.45	0.51	0.058	0.88	0.87	0.55	0.65
Apparent feed	1.03	0.98	1.00	1.17	0.097	0.54	0.37	0.28	0.83
Total	1.54	1.47	1.45	1.68	0.143	0.29	0.57	0.33	0.74
Fecal output, kg/d	0.47	0.42	0.44	0.50	0.039	0.47	0.55	0.17	0.95
Microbial efficiency	15.26	14.20	13.26	16.95	2.290	0.71	0.70	0.34	0.68
Digestibility, % of intake									
Apparent ruminal	12.97	15.00	15.98	2.29	7.882	0.62	0.41	0.36	0.71
True ruminal	41.57	43.48	41.89	31.75	5.387	0.46	0.25	0.31	0.84
Total tract	73.53	75.70	74.66	70.64	1.730	0.29	0.26	0.12	0.98

[1] Treatment: 10 = 10% roughage included as corn silage assuming 50:50 of roughage to concentrate in corn silage, 12 = 10% roughage from corn silage and 2% straw, 14 = 10% roughage from corn silage and 4% straw, and 16 = 10% roughage from corn silage and 6% straw.

[2] *P*-values: Overall effect of treatment (Trt), linear (L), quadratic (Q), and cubic (C) contrasts

.

Table 2.6. Impacts of added roughage on NDF and ADF intake, flow, and digestion in steers fed wheat-based feedlot diets.

	Treatments[1]					*P*-value[2]			
Item	10	12	14	16	SEM	Trt	L	Q	C
NDF									
Intake, kg/d	4.09	4.26	4.18	4.28	0.164	0.26	0.53	0.85	0.60
Intake, % of BW	0.98	0.99	1.00	1.00	0.033	0.98	0.73	0.93	0.91
Duodenal flow, kg/d	1.36	1.28	1.38	1.75	0.151	0.22	0.11	0.18	0.90
Fecal output, kg/d	1.45	1.38	1.34	1.58	0.087	0.33	0.39	0.13	0.57
Digestibility, % of intake									
Ruminal	66.42	70.10	67.59	59.58	2.589	0.12	0.09	0.06	0.95
Total tract	63.93	65.24	66.18	61.91	1.905	0.48	0.57	0.19	0.59
ADF									
Intake, kg/d	1.47	1.47	1.84	1.70	0.158	0.35	0.18	0.65	0.27
Intake, % of BW	0.35	0.35	0.43	0.40	0.030	0.21	0.13	0.57	0.16
Duodenal flow, kg/d	0.56	0.61	0.61	0.81	0.088	0.28	0.10	0.41	0.58
Fecal output, kg/d	0.72	0.69	0.68	0.88	0.068	0.24	0.17	0.15	0.51
Digestibility, % of intake									
Ruminal	59.40	57.87	63.87	52.73	5.365	0.57	0.58	0.40	0.34
Total tract	49.56	50.72	61.07	47.69	4.385	0.23	0.82	0.15	0.14

[1] Treatment: 10 = 10% roughage included as corn silage assuming 50:50 of roughage to concentrate in corn silage, 12 = 10% roughage from corn silage and 2% straw, 14 = 10% roughage from corn silage and 4% straw, and 16 = 10% roughage from corn silage and 6% straw.

[2] *P*-values: Overall effect of treatment (Trt), linear (L), quadratic (Q), and cubic (C) contrasts.

Table 2.7. Effects of added roughage on ruminal fluid pH, total VFA concentrations, acetate, propionate, and butyrate proportions, and ruminal fluid kinetics in steers fed wheat-based feedlot diets.

	Treatment[1]					*P*-value[2]			
Item	10	12	14	16	SEM	Trt	L	Q	C
pH	6.03	6.08	6.20	6.23	0.041	0.02	<0.01	0.82	0.37
Ammonia, m*M*	12.6	12.1	12.9	11.9	0.74	0.75	0.69	0.73	0.36
Volatile Fatty Acids									
Total, m*M*	139.1	128.9	119.6	120.6	3.53	<0.01	<0.01	0.15	0.56
Acetate, %	49.7	49.5	52.6	53.9	0.67	<0.01	<0.01	0.30	0.11
Propionate, %	27.8	29.2	23.1	22.0	1.29	<0.01	<0.01	0.38	0.06
Butyrate, %	11.0	10.9	12.9	13.0	0.59	0.05	<0.01	0.84	0.14
A+Bu:Pr[3]	2.46	2.37	3.06	3.11	0.15	<0.01	<0.01	0.64	0.06
Fluid Kinetics[4]									
FDR, %h	8.95	9.09	8.03	8.51	0.82	0.80	0.54	0.84	0.48
Volume, L	66.15	70.45	80.25	81.57	7.74	0.48	0.16	0.85	0.70
FTO, h	11.99	11.06	12.80	11.82	1.01	0.69	0.79	0.98	0.28
FFR, L/h	5.59	6.40	6.47	6.88	0.49	0.38	0.12	0.70	0.63

[1] Treatment: 10 = 10% roughage included as corn silage assuming 50:50 of roughage to concentrate in corn silage, 12 = 10% roughage from corn silage and 2% straw, 14 = 10% roughage from corn silage and 4% straw, 16 = 10% roughage from corn silage and 6% straw.
[2] P-values: Overall effect of treatment (Trt), linear (L), quadratic (Q), and cubic (C) contrasts.
[3] Acetate to propionate ration.
[4] FDR = Fluid dilution rate (%h), FTO = fluid turnover time (h), FFR = fluid flow rate (L/h).

Discussion

In our feedlot study, DMI and ADG was unaffected by roughage inclusion in steers fed wheat at 36% to 42% of dietary DM. Bock et al. (1991) found a decrease in ADG, final weight, and HCW in steers fed wheat at concentrations greater than 26.9% (DM basis). Differences in our results can be explained by the increasing concentration of wheat inclusion in the diet of 0% to 80.5% (Bock et al., 1991) compared to our consistent, smaller range of wheat inclusion being 36% to 42% wheat. A study by Kreikemeier et al. (1987) reported in vitro starch digestion was more rapid for wheat than corn, potentially leading to acute acidosis and decreased intake in feedlot cattle. We did not provide a non-wheat control treatment in the current study therefore the comparing the impacts of wheat on steer performance are not possible; however, DMI (13.1 ± 0.36 kg/d) and ADG (2.15 ± 0.07 kg/d) do not appear to indicate negative impacts of the study diets on steer performance.

Hales et al. (2014) found no difference in DMI when alfalfa hay increased from 2% to 14% in steers fed high concentrate diets. Although our feedlot study data showed no effect of increasing dietary roughage from 10% to 16% on ADG, previous research reported increased ADG when alfalfa hay increased from 2% to 6% but decreased ADG when alfalfa hay increased from 6% to 14% (Hales et al., 2013). Increased dietary roughage potentially led to an increase of buffers entering the rumen and offsetting acidosis (Weiss et al., 2017), increasing intake and ADG. Similar to Hales et al. (2013), in the current feedlot study HCW and other carcass characteristics were not affected by increased roughage inclusion in the diet. Differences is results from Hales et al. (2013; 2014) and the current feedlot study could most likely be due to the differences in roughage or grain sources and inclusion level.

Similar to our digestibility study data, Weiss et al. (2017) found that roughage inclusion at 5% to 10% did not affect DMI or OMI. While Weiss et al. (2017) used ground corn stalks, our study used a combination of corn silage and wheat straw, as well as a combination of grass hay and wheat straw as roughage source. Unlike our digestibility study data, Hales et al. (2014) reported a linear increase in NDF intake when alfalfa hay was increased in the diet from 2% to 14% of DM. While, Weiss et al. (2017) found increasing tendencies in fecal output of NDF and ADF with increasing roughage from 5% to 10%, the current study found no effect of increasing roughage from 10% to 16%. Similarly, Crawford et al. (2008) found no effect on fecal output of NDF with increasing the level of roughage across treatments of 3.8%, 7.6% and 11.4% corn silage.

With increasing roughage inclusion, Benton et al. (2015), found a linear increase in NDF intake and percent digestibility of NDF while the current study found tendencies of decreasing NDF intake and percent digestibility of NDF. Differences in results are likely caused by different roughage source and inclusion rate of 3% corn stalks, 4% alfalfa, 6% corn stalks or 8% alfalfa, compared to our roughage inclusion of 10% to 16% silage.

Similar to the current study, Crawford et al. (2008) reported no difference in duodenal flow and ruminal digestion of nutrients when roughage inclusion increased in the diet. With increasing levels of dry distillers' grains from 0% to 60%, Leupp et al. (2009) found tendencies of a quadratic response in duodenal flow of OM. Our results indicated an increase in fecal OM output across treatments while Leupp et al. (2009) found a decrease fecal OM output. These differences in results may be explained by different levels of DDGS as the current study fed 30% MDGS across treatments.

In feedlot diets, roughage inclusion is a crucial component to maintain ruminal pH above 5.5 and decrease cases of digestive upset. As anticipated, our data indicated that ruminal pH increased with greater roughage inclusion. Both Weiss et al. (2017) and Sindt et al. (2003) found increases in ruminal pH with increasing roughage from 5% to 10% and 0% to 6%, respectively. Much like the current study, it was expected that ruminal pH would increase as roughage was included at 10% to 16%. Increasing ruminal pH with an increase in roughage can potentially be explained by increased chewing time, essentially increasing saliva that carries buffers to the rumen (Weiss et al., 2017). Grain processing is another important component when considering effectiveness of feeding wheat to feedlot cattle. As a potential result of grain processing without the production of fines, we did not experience a pH that dropped below the subacute acidosis level of 5.6 (Owens et al., 1998).

Including distillers' grains with solubles can reduce the amount of roughage needed in the diet (Klopfenstein et al., 2008; Krehbiel et al., 1995; Farran et al., 2006). Adding distillers' grains with solubles reduces the amount of starch in the diet while increasing fiber, protein, and fat which reduces the need for excess roughage (Klopfenstein et al., 2008). Both portions of the current study include 30% MDGS across treatments, potentially offsetting a decrease in ruminal pH and avoiding subacute acidosis.

Similar to our study, Chibisa et al. (2020) found an increase in ruminal acetate and butyrate along with the acetate to propionate ratio while increasing dietary roughage. Chibisa et al. (2020) also found a quadratic decrease in the propionate proportion with increasing roughage. Axe et al. (1987) found a decrease in acetate to propionate ratio and acetate proportion but an increase in propionate proportion and total VFA concentration with increasing wheat concentration in the diet from 0% to 80%. Data from Axe et al. (1987) potentially differ from our digestibility study data due to a difference in wheat concentration in the diet. Wheat in our diet was included a much smaller rate 30.7% to 36.7%.

Conclusions

Our data indicate that increasing roughage inclusion in wheat-based diets including MDGS increased ruminal pH and shifted ruminal fermentation patterns without affecting feedlot performance. Feedlot performance data indicate that feedlot producers feeding combinations of MDGS and wheat may not need to increase roughage inclusion. As our current study used a small number of feedlot cattle additional research would be needed to validate these results. Further, more research should evaluate feeding wheat in combination with MDGS to lightweight feedlot cattle, as these cattle are likely less adapt to consuming grain and will consume finishing diets longer than the heavier weight cattle in our current study. Additional research is also necessary to confirm if decreased carcass quality is a common outcome from cattle fed wheat-based diets.

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