USING WHOLE COTTONSEED TO REPLACE DRIED DISTILLERS GRAINS PLUS SOLUBLES AND PRAIRIE HAY IN FINISHING CATTLE RATIONS BALANCED FOR PHYSICALLY EFFECTIVE NEUTRAL DETERGENT FIBER

By

KASI N. SCHNEID

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Thesis Approved:

Dr. Blake Wilson

Thesis Adviser

Dr. Andrew Foote

Dr. Paul Beck

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Abstract: Two experiments were conducted to determine the effects of replacing prairie hay and dried distillers grains plus solubles (DDGS) with whole cottonseed (WCS) in finishing diets balanced for physically effective neutral detergent fiber (peNDF) on animal performance, carcass characteristics, plasma metabolites (glucose, lactate, urea nitrogen, non-esterified fatty acids), and ruminal characteristics. In experiment 1, heifers (n = 103) and steers (n = 104) were blocked by BW within sex and allocated to 1 of 2 experimental treatments using a randomized complete block design (6 pens per treatment) with 17 (n = 10 pens) or 18 (n = 2 pens) animals per pen. Treatments included a control diet (CON; prairie hay, DDGS, dry-rolled corn, and liquid supplement), and a WCS diet (CTN; WCS, dry-rolled corn, and molasses). Both diets contained a vitamin and mineral supplement and urea at the same concentration. Cattle fed the CTN diet tendened to have a greater final BW (P = 0.10), had greater overall ADG, G:F, HCW, fat thickness, and USDA yield grade and had a more neutral fecal pH ($P \leq 0.05$) compared to cattle fed the CON diet. The cattle fed the CON diet had a greater final fecal consistency score, plasma urea nitrogen ($P \leq .01$), and tended to have a greater plasma lactate concentration (P = 0.06). In experiment two, 4 ruminally cannulated Holstein steers were randomly allocated to the 2 treatment diets from experiment 1. There was a treatment × time interaction for rumen fluid lactate (P = 0.0002) with the cattle fed the CON treatment having a greater concentration at h 2. Rumen fluid pH was affected by time (P = 0.02), but not treatment (P = 0.22). The cattle fed the CON treatment had a greater acetate:propionate ratio, butyrate, and valerate proportions ($P \leq 0.04$) and had a tendency for a greater acetate proportions (P = 0.06). The cattle fed the CTN treatment had a greater propionate proportion (P = 0.03). These experiments suggest that WCS can replace the roughage and byproduct protein and fat source within a finishing diet while simultaneously resulting in increased growth and feed efficiency while maintaining an acceptable rumen environment.

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CHAPTER I

REVIEW OF LITERATURE

Introduction

The United States (U.S) is the third largest cotton producing country in the world behind India and China (USDA, 2022). In 2020, during the height of the COVID-19 pandemic, the U.S. produced an average of 19.9 million bales of cotton. In 2021, the cotton harvest decreased to 15.0 million bales, but is expected to increase once again in 2022 to approximately 17.6 million bales (USDA, 2022). A vast majority of the cotton produced in the U.S. is grown in the "Cotton Belt" states. These states are located in the south and stretch from Virginia to California with Texas being the leading cotton producer. In 2020, Texas alone produced 4.75 million bales of cotton, which was more than twice that of the second leading state of Georgia at 2.18 million bales of cotton (Shahbandeh, 2022). Although cotton is most commonly thought of as a source of fiber used in textiles, cotton production results in numerous co-products or byproducts that can be used as feedstuffs by livestock producers.

Types of cotton production

The most valuable component of cotton is the cotton fiber. The global demand for cotton fiber continues to increase, and the U.S. has continued to be the leading exporter

of cotton since 2010 (USDA, 2022). In order to produce cotton fiber, cotton bales must go through a series of processes that result in many of the various cotton co-products and byproducts. For instance, when the cotton fiber is harvested during ginning, the remaining materials include gin trash, gin motes, cotton burrs, and whole cottonseed. Whole cottonseed can then be further processed into cottonseed oil, which is commonly sold for human consumption due to the ability of the oil to extend the shelf life of processed foods. However, whole cottonseed can also be sold as a livestock commodity as is or can be further processed into delinted cottonseed, cottonseed hulls, cotton linters, and cottonseed meal. Cotton textile milling produces additional byproducts of cleaning and carding waste, cotton mill sweeps, and cotton meal dust. Of these co-products and byproducts, the most commonly utilized by the livestock industry as feedstuffs are whole cottonseed, gin trash, cottonseed hulls, cottonseed meal, and cotton burrs.

When a co-product or byproduct is purchased to be utilized as livestock feed, the nutritive value of the product will determine the product's role and value. For example, cottonseed meal is high in protein, while cottonseed hulls are a good source of fiber, and whole cottonseed can provide substantial fat. Whole cottonseed is commonly utilized by dairy producers due to the ability to provide substantial fat, protein, and fiber as a result of the physical and chemical makeup of whole cottonseed. The ability of whole cottonseed to provide this unique nutritional value is derived from the fiber within the lint and cottonseed hulls, fat from oil within the seed, and protein from the intact cottonseed meal. The cottonseed hulls, meal, and oil can all be sold as individual commodities, but

purchasing whole cottonseed reduces processing and labor costs, allowing producers to have a multipurpose commodity within rations, and potentially decreasing the storage and handling needed for 3 separate commodities. It is the ability of whole cottonseed to provide valuable nutrition to ruminants that creates demand from producers to purchase this commodity that is normally marketed at higher prices compared to other less nutrient dense cotton byproducts such as gin trash or cottonseed hulls.

Feeding whole cottonseed

Whole cottonseed has the ability to provide fat, protein, and fiber within total mixed rations or supplements for both dairy and beef cattle. Due to the high percentage of TDN, whole cottonseed is commonly handled as a concentrate, but the fiber levels are comparable to that of a roughage (whole cottonseed = 47.8 ± 6.96 % NDF and alfalfa hay = 41.7 ± 8.53 % NDF; NASEM, 2016; Arieli, 1998). However, some producers refrain from feeding whole cottonseed due to concerns regarding gossypol toxicity. Gossypol levels can vary depending on the species of cotton and are associated with a negative impact on fertility in reproductive cattle and potential toxicity (Randel et al, 2011). Other concerns when feeding whole cottonseed to cattle is the increased level of fat present if whole cottonseed is fed in excess of recommended feeding levels. With high concentrate rations, such as typical feedlot rations, being vulnerable to gossypol toxicity due to cumulative exposure and increased intake (Morgan, 1989) as well as the increased level of fat, feeding levels of whole cottonseed are recommended to not exceed 15.0% of diet dry matter (DM; Rogers et al, 2002; Preston and Bartle, 1989).

A survey of consulting feedlot nutritionists conducted by Vasconcelos and Galyean (2007) reported recommended feeding levels for added fat between 0.0% and 4.5% of the diet DM and total fat between 6.0% and 10% in finishing rations. If whole cottonseed is fed above the recommended 15.0% inclusion rate within a feedlot diet there is a potential for a decrease in dry matter intake (DMI), as well as a decrease in fiber digestion as a result of the increased level of fat (Rogers et al, 2002). Moore et al. (1986) compared feeding a control diet of wheat straw, cottonseed meal, and cottonseed hulls to a diet that included 30% of whole cottonseed (DM) and predominantly wheat straw. The authors reported the cattle consuming the diet with 30% WCS had a 5% decrease in digestion of acid detergent fiber (ADF) and a 16.5 g per kg of BW decrease in DMI. Other researchers have demonstrated this effect of increased dietary fat decreasing DMI. Research conducted by Zinn and Plascencia (2004) altered the feeding rate of tallow (3, 6, and 9% of DM) to feedlot steers and reported a linear decrease in DMI, average daily gain (ADG), and gain to feed ratio (G:F) with increasing fat in the diet.

According to NASEM (2016), whole cottonseed has a predicted composition of 92.6% DM, 93.0 % TDN, 19.5% fat, 47.8% NDF, 22.9% CP, and 4.10% ash (DM). Due to variation across regions and cottonseed varieties, it is recommended that all producers feeding whole cottonseed analyze their specific shipment of whole cottonseed. An example of this variation was described by Rogers et al (2002) who reported low-lint whole cottonseed containing between 50 to 100 g/kg less fiber, and greater levels of fat and protein than linted counterparts.

According to a more recent consulting feedlot nutritionist survey in 2016, feedlot finishing rations are high in concentrates with grain inclusion typically 60% DM or greater (Samuelson et al., 2016). The 60% inclusion of grain in finishing rations has reportedly decreased from the stated 78.3% DM inclusion reported in the previous consulting feedlot nutritionist survey conducted by Vasconcelos and Galyean (2007). The decrease in grain use in finishing rations is primarily due to the increased use of grain byproducts over that period. As a rule, grain byproducts are commonly used within these diets as a less expensive way to meet animal protein and energy requirements. Samuelson et al. (2016) reported that primary grain byproducts are commonly included in feedlot receiving and finishing rations at anywhere between 10-20%. Common grain byproducts such as dried distillers grains plus solubles (DDGS) were included as the primary or secondary byproduct for 38.6% of consulting feedlot nutritionist (Samuelson et al., 2016).

Research has been conducted supporting whole cottonseed's ability to replace portions of fat, fiber, and protein within feedlot diets. However, there is limited research examining whole cottonseed's potential ability to replace the protein and fat from commonly used byproducts such as DDGS while being the sole source of fiber in finishing feedlot rations.

Physically effective neutral detergent fiber

An analysis devised by Van Soest and reported in the USDA handbook by Goering and Van Soest (1970), was created to determine the neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin content of forages and roughages. Lignin and ADF are suggested to be indicators of relative digestibility, but NDF is often utilized as a potential indicator of intake among roughages (Church, 1988). Introduced by Mertens (1997) to refine the concept of effective fiber, physically effective neutral detergent fiber (peNDF) is related solely to particle size and effectiveness to stimulate chewing (NASEM, 2016).

Physically effective neutral detergent fiber is expressed as a percent of NDF and therefore has a range of 0 to 100% (Mertens, 1997). To calculate peNDF, the percentage of NDF is multiplied by the physically effective factor (pef) of a feedstuff. To determine the pef of feedstuffs, sieving methods described by Heinrichs and Jones (2016) are commonly used for both forage and total mixed rations (TMR). Heinrichs and Jones (2016) describe the methods of the Penn State Shaker Box which consists of 4 stacked sieves the varying pore sizes stacked with the largest pores on top and the smallest pores on the bottom (19.05, 7.87, 4.06, 0.0 mm). Approximately 1.42 L of desired feed is placed into the top sieve before the entirety of the box is placed on a flat surface and shaken 5 times before being rotated a quarter turn and shaken again. This process repeats until a total of 40 shakes have been completed. It is expected that the smaller particles will fall through the pores of the sieve above until the particles are too large to continue to fall. The particles that are left in the sieves, with the exception of the bottom sieve, will

be used to determine the final pef. For lactating dairy cattle consuming a TMR, the desired percentage for total pef is 60 to 70 percent with the percentage remaining on each sieve being as follows: Upper sieve (19.05 mm) = 2 to 8%, middle sieve (7.87 mm) = 30 to 50%, lower sieve (4.06 mm) = 10 to 20%, and the bottom sieve (0.0 mm) = 30 to 40% (Heinrichs and Jones, 2016).

Due to peNDF not accounting for the digestibility or the absorption of the feed, peNDF is limited in feedlot settings as a predictor of rumen pH (NASEM, 2016). Sarhan and Beuchemin (2015) evaluated 8 empirical models to predict rumen pH in beef cattle and reported considerably less (<50%) variation in rumen pH when accounting for peNDF compared to the 71% variation in dairy cattle reported by Mertens (1997).

In recent years, the price of forage has increased due to various weather phenomena. Snyder (2012), suggested alternative commodities that can replace portions of the forage in TMR, one of which being whole cottonseed. It has been reported that including a low starch byproduct such as whole cottonseed within the ration may in turn decrease the required level of peNDF in the diet due to the lower starch fermentability of these ingredients. This can be beneficial for cattle producers since peNDF levels can alter the efficiency of cattle by promoting increased DMI.

An experiment conducted by Yang and Beauchmin (2006), determined the effects of increasing peNDF in a TMR fed to dairy cattle. The experiment suggested that a peNDF of around 13.8% from barley silage resulted in a decrease digestibility of dry

matter, organic matter, and starch, however, cattle fed a ration with 10.5% peNDF resulted in greater digestibility of overall DM when compared to cattle fed a ration with 11.8% peNDF and 13.8% peNDF. Warner et al. (2020a) included whole cottonseed and cotton gin trash as the primary roughage sources to replace prairie hay and to provide peNDF in a beef cattle finishing ration. As a result, the cotton byproduct diet had a slightly greater peNDF percentage than the control (control = 8.80%, cotton byproduct = 9.82%). The cotton byproduct treatment resulted in lower fecal scores and greater DMI compared to the control treatment likely due to the greater peNDF percentage in the cotton byproduct diet. Although whole cottonseed provides a substantial amount of the peNDF within the diet and has the potentially to be the sole source of peNDF, there is a lack of published research evaluating this practice.

Based on the published research, whole cottonseed seems to possess qualities that are useful within a finishing feedlot diet. Furthermore, due to the chemical and physical composition, whole cottonseed could potentially be used to replace both the byproduct protein and fat source while potentially providing sufficient peNDF for proper digestion and rumination as the sole source of roughage.

Impact of whole cottonseed on performance and carcass characteristics

Performance

The experiment by Warner et al. (2020a), evaluated the effects of using cotton byproducts (whole cottonseed at 15% DM and gin trash at 7% DM) to provide the

majority of the protein, fat, and fiber within a finishing diet. The experiment analyzed performance measures such as body weight (BW), ADG, DMI, and G:F, and reported the cattle consuming the diet containing cotton byproducts had a greater final BW (632 kg), ADG (2.09 kg/d), and DMI (12.4 kg/d) compared to the control treatment (614 kg BW, 1.95 kg ADG, 11.7 kg/d DMI). The decreased ADG and DMI for steers fed the control diet and the greater ADG and DMI of the steers fed cotton byproducts resulted in no difference in efficiency (G:F) between the 2 treatments. The greater ADG and tendency for greater final BW of the steers fed cotton byproducts was attributed to the greater DMI of the cotton byproduct treatment. In contrast, during the receiving period there was a tendency for the control treatment to have a greater DMI which was suggested to be due to possible palatability issues and recognition of the control treatment compared to the cotton byproduct treatment as cattle were previously grazing Bermuda grass pasture prior to feedlot arrival.

Cranston et al. (2006) conducted a series of 3 experiments investigating the effects of whole cottonseed and cottonseed byproducts on performance and carcass characteristics of finishing beef cattle. Experiment 1, compared a steam-flaked corn finishing diet to 2 treatment diets. One treatment diet included 15.10% whole cottonseed and the other included 7.12% cottonseed meal, 2.32% cottonseed oil, and 11.68% cottonseed hulls (DM). This experiment compared the 2 cotton treatment diets to one another, and compared the average of the 2 cotton treatment diets to the control diet. There was no difference in final BW between the control treatment and the average of the

cottonseed treatments. The steers fed the whole cottonseed treatment had the greatest DMI, but there was no difference in final BW or ADG reported among treatments. With no difference in BW and a decreased DMI for animals on the control diet, the calculated G:F was greater for the control treatment compared to the 2 treatments containing whole cottonseed or cotton byproducts. The greater DMI was reportedly due to the greater percentage of NDF in the cotton treatment with whole cottonseed and byproduct treatments having 12% and 9% greater NDF compared to the control treatment, respectively. The effect of NDF on DMI was described in a review conducted by Galyean and Defoor (2003), which indicated that DMI of feedlot cattle could be predicted based on the NDF supplied by the roughage in the diet.

In the second experiment by Cranston et al. (2006), a steam-flaked corn control diet was compared to 2 treatment diets. One treatment diet included whole cottonseed (15.26% DM) and the other treatment diet included pelleted cottonseed (15.02% DM). All treatment diets were balanced for NDF and performance and carcass characteristics results were analyzed. Similar to the first experiment, this experiment reported no difference among treatments for overall BW or ADG, but a difference was present for DMI with the control treatment consuming more feed than the cotton treatments. A greater G:F was reported for the cotton treatments when compared to the control treatment, but when carcass adjusted performance was calculated, the difference in G:F was no longer present. The lack of difference in BW and ADG and the greater DMI of the control diet was suggested to be a result of the treatments being balanced for NDF.

By balancing the treatments for NDF, the control treatment was potentially lower in energy density, which may have effected the overall DMI of those cattle.

Dry Matter Intake

For cattle consuming mostly forage diets, dry matter intake (DMI) is usually regulated by bulk fill within the rumen. In feedlot rations, roughage within finishing diets is normally limited to an inclusion rate of between 6 and 12% DM (Samuelson et al., 2016). Although roughage makes up a small percentage of finishing feedlot diets, the inclusion is critical to the animals' health for prevention of digestive disorders and to optimize net energy (NE) intake (Galyean and Hubbert, 2014). Unlike cattle consuming high forage diets, DMI for cattle consuming a high concentrate ration is not limited by bulk fill. Due to the small inclusion rate of roughage within feedlot rations, feedlot cattle intake is suggested to be controlled by energy demand and supply metabolic fuels. The fuels referenced include such as non-esterified fatty acids (NEFA), lactate, VFA (mainly propionate), and glycerol. Although physical regulation is less likely due to the small inclusion rate of forages, NDF content of rations have been reported influencing DMI (Allen, 2000).

Galyean and Defoor (2002), analyzed 11 feedlot trials to determine the effects of roughage level and source on DMI. From the 11 trials using 48 treatment means, the results suggested that NDF can be used to predict DMI in finishing beef cattle and may also be a useful method to determine alternative roughage sources within the ration. The

correlation between NDF and DMI is suggested to be due to the high starch content within the feedlot rations potentially causing greater overall fermentability within the rumen (Galyean and Abney, 2006).

According to NASEM (2016), whole cottonseed is suggested to have an NDF percentage of around 47.8 ± 6.96 % (DM), which is less than common forage roughage sources such as prairie hay (66.6 ± 4.83 % NDF, DM). In research conducted by Cranston et al. (2006), when comparing a standard feedlot ration to a ration containing whole cottonseed, there was an increase in DMI as NDF increased in the diets in experiment 1. In experiment 2, when the standard feedlot ration and the cotton treatments were balanced for NDF, there was no difference in DMI.

Warner et al. (2020a) compared a finishing ration containing prairie hay and Sweet Bran to a ration with cotton gin trash, which is more comparable in NDF to prairie hay, and whole cottonseed. The diet with the cotton byproducts resulted in an increased NDF and peNDF for the cotton byproduct treatment and the cattle consuming this diet having a greater DMI. Warner et al. (2020a) suggested the increase in DMI for the cattle consuming the cotton byproduct diet was due to the greater peNDF. There is a correlation between effective neutral detergent fiber (eNDF) and peNDF, and eNDF is suggested to potentially be an effective predictor of DMI (Galyean and Defoor, 2002). However, peNDF is suggested to not have an effect on DMI, only fiber digestion (Yang et al., 2002). However, there is limited research evaluating the roll of peNDF in finishing cattle

rations overall as well as the peNDF value of non-forage roughage sources, like whole cottonseed.

Carcass Characteristics

There have been conflicting carcass characteristic results for cattle consuming finishing diets containing whole cottonseed. Warner et al. (2020a) reported cattle being fed a diet containing 15% whole cottonseed had a greater hot carcass weight (HCW) and fat thickness, and a tendency for greater calculated USDA yield grade (USDA YG), dressing percentage, and kidney, pelvic, and heart fat (KPH). The greater carcass fat was reportedly due to the treatments having a difference in fat metabolism even though the treatments were reported to have similar energy values. The lack of difference in ribeye are (REA) further supported the idea that cattle fed whole cottonseed were gaining most of the additional weight in the form of fat rather than lean tissue.

Huerta-Leidenz et al. (1990) compared a finishing ration that replaced small amounts of whole corn, cottonseed meal, and cottonseed hulls with 15 or 30% whole cottonseed. No difference was reported for any carcass characteristics between the 15% whole cottonseed treatment and the 30% whole cottonseed treatment. However, adjusted HCW, REA, and USDA YG decreased with increasing levels of whole cottonseed.

In experiment 1 conducted by Cranston et al. (2006), no differences were reported for HCW, KPH, or quality grade. There was no difference in dressing percentage (DP) or marbling score between the 2 cotton byproduct treatments. When compared to the cotton

treatments, cattle fed the control diet had a greater DP and marbling score. The treatment containing whole cottonseed had a greater fat thickness and yield grade when compared to the other cotton byproduct treatment, but was not different when compared to the control treatment. The reasoning for the differences in carcass characteristics were not immediately known, but could be explained by energy density and fiber concentrations in the treatment diets. In experiment 2, Cranston et al. (2006) compared a steam-flaked corn control diet to 2 treatment diets, 1 which contained whole cottonseed and another that contained pelleted cottonseed, all 3 diets were balanced for percent NDF. No differences were reported for any carcass characteristics among treatments. The lack of difference in carcass characteristics for experiment 2 is supported by the explanation given for experiment 1. In experiment 1, authors suggest the differences were related to the differing energy density and fiber concentrations of the diet which experiment 2 later balanced for and reported no differences in carcass characteristics.

Given the results of these performance studies, whole cottonseed can be included in a feedlot diet at 15% and potentially result in equal or greater BW, ADG, or carcass characteristics when compared to standard feedlot finishing rations. However, when feeding whole cottonseed, DMI can vary depending on the diet nutrient composition, specifically the NDF and potentially peNDF values of the rations.

Impact of whole cottonseed on plasma metabolites

Urea Nitrogen

Urea is a product of the metabolic breakdown of protein. When an animal consumes digestible protein, the protein can either be digested to become microbial cell protein in the rumen, or travel to the small intestine where the protein will be degraded and absorbed via the portal vein (Hammond, 1996). If rumen degradable protein is fed in excess, the excess nitrogen can cause an increase in ruminal ammonia (Kang-Meznarich and Broderick, 1981). The ammonia that was unable to be used as a nitrogen source by the bacteria within the rumen is then absorbed through the rumen wall and enters the portal vein to be transported to the liver. Once the ammonia reaches the liver, the ammonia is converted into urea to be recycled back to the gut or saliva, or is excreted in the urine. If urea cannot be utilized efficiently, urea will begin to accumulate causing increased urea levels within bodily fluids. Due to this diffusion of ammonia, researchers are able to measure urea concentrations within the body by analyzing blood (plasma or serum) or milk collected from the animal in order to monitor protein status and nitrogen utilization (Melendez et al., 2003).

Urea nitrogen analyzed via whole blood is commonly reported as the acronym, BUN. The concentration of BUN can be altered by many different factors but normally is within the range of 10 to 30 mg/dL (Melendez et al., 2003). Urea nitrogen analyzed via blood plasma is commonly reported as the acronym, PUN. The PUN concentration can range from 3.33 and 4.51 mMol/L in feedlot cattle (Van Bibber-Krueger et al., 2017). Concentration of PUN is highly correlated with the concentration of BUN (r = 0.958;

Melendez et al., 2003), with both concentrations having the ability to be used in solving for the other unknown concentration by using the following equation:

$$PUN = (1.021 \times BUN) + 0.399$$

The fluctuation of urea nitrogen concentrations can be influenced by the animal's efficiency of utilizing dietary crude protein (Broderick and Clayton, 1996), varying inclusion rate of dietary crude protein, increasing muscle protein degradation, or decreasing protein accretion (Gleghorn et al., 2004). For finishing cattle, it is vital to ensure cattle are consuming sufficient protein to optimize growth potential. According to the Samuelson et al. (2016) consulting feedlot nutritionist survey, the average concentration of crude protein in receiving and finishing rations is between 13.4% and 14.5% of DM. This range is similar to that reported by Vasconcelos and Galyean (2007) in the previous feedlot nutritionist survey. Samuelson et al. (2016) also reported that corn-products, such as wet or dry corn distillers grains, were the most common protein source used by feedlot nutritionists. The preferred secondary protein source was oilseed meals, such as cottonseed meal, and wheat byproducts. These preferred commodities differed from the previous survey by Vasconcelos and Galyean (2007), where 31% of the survey population preferred soybean meal and cottonseed meal as the primary protein source.

Warner et al. (2020a) analyzed PUN concentrations of feedlot cattle fed whole cottonseed and gin trash compared to a control diet. The authors observed a treatment ×

day interaction with the greatest PUN concentrations being on d 0 with a concentration around 5 mmol/L. Concentrations gradually decreased until d 28, with a concentration around 2 mmol/L (transition period), and then once again gradually increased until d 140 to around 4 mmol/L (finishing period). Differences were reported on d 28 and 56, with the control treatment having greater PUN concentrations. It was proposed that the overall trend observed for both treatments was attributed to changes in DMI associated with each period, with greater DMI contributing to greater PUN concentrations. The cause of this was speculated to be that the cattle receiving the cotton byproduct treatment had a decreased amino acid catabolism resulting in a lower PUN concentrations.

The PUN concentrations reported by Warner et al. (2020a) for finishing feedlot cattle consuming a standard ration and a cotton byproduct ration were similar to those of Van Bibber-Krueger et al. (2017), who analyzed PUN concentrations of finishing heifers supplemented with ractopamine hydrochloride and Zn. The range of the heifers supplemented with ractopamine hydrochloride and Zn was reported to be between 3.33 and 4.51 mmol/L, while the steers being fed cotton byproducts was between 3.80 to 3.99 mmol/L during d 112 to the finishing period.

Glucose/Energy

Glucose acts as the primary source of energy utilized in the body by certain tissues such as the nervous system, mammary gland, fetal tissue, adipose tissue, and muscle (Bergman, 1973). Glucose concentrations within blood (plasma or serum) can be

used as an indicator to determine if an animal is in a positive or negative energy balance during various feeding or fasting periods (Fahey Jr and Berger, 1993). In ruminants, the primary precursor for glucose is the volatile fatty acid (VFA), propionate (Leng and Annison, 1962), and amino acids (Bergman, 1973). According to Leng et al. (1967), a majority of the carbon (45 to 63%) used to synthesize glucose is derived from propionate, and around 32% of the propionate is converted directly to glucose within the liver to maintain blood glucose concentrations (Aschenbach et al., 2010).

The concentration of acetate and propionate is strongly correlated to the composition of the diet an animal is consuming. Cattle consuming diets that are high in rapidly fermentable feeds, such as starches and sugars in feedlot finishing rations, result in a greater propionate concentrations. In contrast, cattle that are grazing or being provided a high forage diet, result in a greater acetate concentrations (Church, 1988). In ruminants, the rapidly fermentable carbohydrates entering into the rumen provide little opportunity for glucose to be absorbed. Due to this occurrence, cattle are reliant on gluconeogenesis as the main source of glucose that is produced in the liver (Aschenbach et al., 2010).

In high concentrate diets, such as finishing rations, there is typically a prominent amount of starch from cereal grains present. Ingredients high in starch are commonly inclused to increase energy density of the ration. As starch levels increase in finishing diets, the passage rate of starch increases, allowing more starch to escape degradation in

the rumen. The starch escaping the rumen will travel to the small intestine where digestion occurs which causes the glucose concentration within the small intestine to increase (Church, 1988). Starch in the small intestine can either be absorbed in small intestine in the form of glucose, fermented in the large intestine, or removed via excretion in the feces (Church, 1988). High concentrations of glucose in the small intestine of finishing cattle is a common occurrence in rations that have high starch levels from high inclusion rates of corn or other cereal grains. A potential option to decrease the amount of starch being digested in the small intestine or excreted is to find an alternative commodity that can replace high starch feeds within a total mixed ration (TMR), such as whole cottonseed. Although the small intestine is more energetically efficient (~97%) when compared to the rumen (~80%) and large intestine (~40 to 45%), starch digestion is needed by the microbes within the rumen to form microbial protein (Harmon and McLeod, 2001; Huntington et al., 2006). If the location of starch digestion is to shift, the small intestine can be limited by factors such as particle size and digestive enzymes. If the starch were unable to be digested in the small intestine, the starch would be fermented in the less efficient large intestine resulting in a loss of microbial nitrogen (NASEM, 2016). Different types of concentrates, processing methods, and amounts of starch in the feed can cause these shifts in starch digestion (McLeod et al., 2006). According to NASEM (2016), whole cottonseed has a starch value of 2.20% compared to dry-rolled corn which has a value of 72.1 ± 3.18%.

Warner et al. (2020a) compared a feedlot ration containing WCS and gin trash to a control diet and analyzed plasma glucose concentrations. The authors reported no treatment × day interaction or treatment effect, but a day effect was present. Glucose concentrations remained around 96.0 mg/dL with the exception of a decrease on d 28 (86.9 mg/dL) and the final collection (84.9 mg/dL). Although there was a d effect, all glucose concentrations (86.9 to 96.7 mg/dL) were within the expected range of finishing cattle (65.2 to 101.1 mg/dL; Evans et al. 1975; Hancock et al. 1988; Kolath et al. 2006).

Another factor that can influence glucose concentrations within cattle is DMI. Foote et al. (2014) reported that DMI had a negative correlation with plasma glucose concentration in finishing beef cattle, which was supported by research conducted on lactating dairy cows (Quigley et al., 1991; Larsen et al., 2010). This negative association between DMI and glucose concentration is potentially due to the conversion of the absorbed propionate to glucose in the liver (Foote et al., 2014). Although there are many variables that can alter glucose concentrations in finishing beef cattle, the concentration of blood glucose is proportional to the utilization of glucose in the body (Bergman, 1973). Therefore, analyzing blood glucose concentration can serve as a good indication of overall glucose metabolism.

Blood Lactate

Blood lactate is formed from glucose during anaerobic glycolysis and is commonly used to assess the physiological and pathological phenomena which favors

anaerobic metabolism (Coghe et al., 2000). Situations such as shipping can induce stress and cause metabolic pathways within muscle to shift from an aerobic to anaerobic metabolism inducing glycolysis and causing an increase in lactate production (Williams et al. 2019). When lactate is produced, the lactate will be transported out of the muscle and diffuse into the blood, raising blood lactate concentrations. For cattle, blood lactate concentrations are commonly used to assess stressful time periods such as transportation and pre-slaughter handling (Melendez et al., 2021).

Another factor that may influence blood lactate levels in feedlot cattle is the sex of the animal. Williams et al. (2019) conducted an experiment evaluating the relationship between blood lactate measures and physiological biomarkers as a proxy for exit velocity. This experiment used feedlot steers (n = 87) and heifers (n = 109), and reported that heifers had a greater serum lactate concentrations (4.35 mM) compared to steers (3.45 mM). It was suggested that this difference was due to heifers being potentially more excitable than steers. Other research has been conducted to assess the correlation between plasma lactate and bovine respiratory disease (BRD). Montgomery et al. (2009) used blood collected from 665 crossbred heifers to analyzed plasma metabolites at initial processing and evaluates subsequent incidences of apparent BRD. Concentrations of blood lactate for cattle that were treated 0, 1, 2, or 3 times for apparent BRD ranged from the highest concentration being in those never treated (6.5 ± 0.28) to the lowest concentration being those treated 3 times(4.3 ± 0.48). The decrease in lactate

concentration after each treatment is suggested to be due to depleted glycogen stores from an extended period of fasting.

Warner et al. (2020a) compared a control diet to a diet containing cotton byproducts, and reported a day effect for plasma lactate concentrations. The peak lactate concertation was observed on d 0 which was suggested to be due to shipping, before gradually decreasing and remaining steady for the remainder of the experiment. The peak concentration on d 0 (0.373 g/L) after shipping was similar to the concentrations reported by Mitchell et al. (1988), who also reported the greatest lactate concentrations after transportation (0.40 ± 0.03 g/L). Extensive research indicates that blood lactate can be a reliable source of monitoring physiological and pathological phenomena in a feedlot setting, with the exception of potential influence of sex when comparing steers to heifers.

Non-esterified Fatty Acids

Non-esterified fatty acid (NEFA) levels within blood (plasma or serum) are used to assess energy status of cattle to determine is animals are in a positive or negative energy balance (Ndlovu et al., 2007; Adewuyi et a., 2005). Cattle fed in abundance have adapted to store excess nutrients in body as adipose tissue. If an animal experiences a negative energy balance or stress for an extended period of time, the fatty acids in adipose tissue are mobilized via lipolysis due to the actions of glucocorticoids, catecholamines, and cytokines, resulting in increased circulating NEFA (Adewuyi et al.,

2005). The circulating NEFA are then transported to the liver where NEFA are converted to acetyl-CoA, a usable form of energy (Adewuyi et al., 2005).

When analyzing NEFA concentrations in relation to energy balance, there is an inverse relationship. High NEFA concentrations are indicative of cattle in a negative energy balance and low NEFA concentrations are indicative of cattle in a positive energy balance (Ndlovu et al., 2007). There are no known consequences of cattle having low concentrations of NEFA. However, NEFA can become detramental to cattle at high levels resulting from a prolonged state of negative energy balance (Brown et al., 2012). Non-esterified fatty acids can undergo partial oxidation in the liver, eventually leading to ketosis and triglyceride formation causing the animal to develop a fatty liver (Brown et al., 2012). Analyzing NEFA concentrations can provide more precise approach to measuring energy balance compared to visual assessment or body condition scoring (Ndlovu et al., 2007).

Impact of whole cottonseed on rumen fluid pH, lactate, and VFA

VFA

The 3 most prominent VFA produced in ruminant animals are acetate, butyrate, and propionate. The 3 less prominent VFA produced in ruminant animals are valerate, isobutyrate, and isovalerate. The concentrations of the prominent VFA within the rumen are dependent on the composition of the diet. For feedlot cattle fully transitioned onto a high concentrate diet, VFA proportions of acetate:propionate:butyrate are approximately

50:40:10 (Li et al., 2011; NASEM, 2016). For grazing cattle or cattle fed a high forage diet, the expected ratio is around 70:20:10 to 65:25:10 (Owens and Goetsch, 1988; France and Siddons, 1993; Wolin et al., 1997). The addition of concentrate and reduction of roughage in feedlot rations causes a decrease in acetate, increase in propionate, and little to no change to butyrate proportions (Church, 1988). Volatile fatty acid concentrations will shift depending on the diet a ruminant is consuming, specifically when shifting from diets high in forage or high in concentrates.

The VFA are the main source of metabolizable energy for cattle. Most all VFA are produced and efficiently absorbed within the rumen, reticulum, and omasum (Church, 1988). Therefore, the best way to determine VFA concentrations is to collect rumen fluid via cannulation or by placing a tube down the animal's esophagus to extract the rumen fluid.

Horner et al. (1988) conducted a series of experiments on lactating Holstein cows, one of which analyzed in vitro rumen pH and VFA concentrations. The diets included whole cottonseed at 0, 5, 15, and 30% of total ration DM in a ration consisting of corn-soy concentrate, corn silage, and coastal Bermuda hay. The experiment reported greater acetic acid production in diets containing 15 and 30% whole cottonseed, but a reduction in overall VFA, propionate, butyrate, and isovaleric acid concentrations when increasing whole cottonseed inclusion rate from 0 to 30%. The greater acetate production was suggested to be a reflection of the lint fermentation, while the overall VFA concentration

reportedly decreased due to fewer soluble carbohydrates in the diet as whole cottonseed inclusion increased.

Warner et al. (2020b) conducted an experiment using 6 cannulated crossbred beef steers comparing a control treatment ration containing dry-rolled corn, prairie hay, Sweet Bran, and prairie hay to a cotton byproduct treatment containing whole cottonseed, gin trash, and dry-rolled corn. Neither a treatment × time interaction nor a time effect was present. However, a treatment effect was present for acetate:propionate ratio, acetate, and propionate proportions. The cotton byproduct treatment resulted in a greater acetate:propionate ratio and acetate proportion, while the control treatment had a greater propionate proportion. No differences were reported for total VFA concentrations or butyrate, isobutyrate, valerate, or isovalerate proportions. It was suggested that the results were due to the difference in physically effective neutral detergent fiber (peNDF), with the cotton byproduct treatment having greater peNDF. Increased acetate and decreased propionate with increased levels of peNDF is supported by previous studies conducted on dairy cattle (Beauchemin and Yang, 2005).

Rumen Fluid pH

The diet which cattle consume is highly correlated with rumen pH. Cattle consuming low fiber diets, like common finishing feedlot rations, typically have a rumen pH below 6, with a common range of 5.8-6.2 (Church, 1988; Schwartzkopf-Genswein et al., 2003). The composition of cattle finishing rations can further alter rumen pH,

occasionally dropping the pH below 5.8 causing the buffering capacity of the rumen fluid to be unable to keep up with VFA and lactic acid production resulting in a buildup of acid (Plaizier et al., 2008). By increasing the inclusion rate of cereal grains, such as corn, an influx of starch can be created within the rumen. This causes microbes within the rumen to favorably select for amylolitic bacteria, which are a common producer of the VFA, propionate (Church, 1988). If an animal's rumen pH drops to 5.8, cattle can experience decreased feed intake, diarrhea, laminitis, liver abscesses, and potential inflammation (Plaizier et al., 2008; NASEM, 2016). When analyzing rumen pH, it is suggested that the most acidic state will occur 4 to 8 h after being offered a fresh total mixed ration (Grünberg and Constable, 2009).

Acidosis is a digestive disorder that occurs within feedlot cattle when ruminal pH is less than 5.4 for 3 to 5 h per d (Cooper et al., 1997; AlZahal et al., 2007). Acidosis is commonly noticed in cattle consuming high concentrate rations that contain a low amount of roughage (diets containing less than 10% roughage; NASEM, 2016). The average rumen pH for cattle consuming high concentrate rations in a feedlot is between 5.6 and 6.2 (Schwartzkopf-Genswein et al., 2003). Acidosis is considered to be subcute at a pH of 5.5 (Garrett et al., 1999) and acute at a pH of 5.0 or less (Nagaraja and Titgemeyer, 2007). It is not common for cattle to become acidotic upon entry into the feedlot when fed receiving diets containing around 50% roughage. However, it is the transition period from a receiving ration to a finishing ration which is critical for maintaining an appropriate rumen environment as well as healthy rumen function. It is

recommended to use a 2-ration blending system or a step-up diet approach when transitioning cattle (Schwartskopf-Genswein et al., 2003). Other methods of preventing digestive disorders include delivering feed in a well-mixed state and at a consistent time, correctly processing grain, and offering multiple feedings per day.

Horner et al. (1988) conducted a series of experiments on lactating Holstein cows, one of which analyzed in vitro rumen pH and VFA concentration of diets that included whole cottonseed at 0, 5, 15, and 30% of total ration DM in a ration consisting of corn-soy concentrate, corn silage, and coastal Bermuda hay. Although the rumen pH decreased from before feeding to 4 h after feeding, the pH was reported to be more neutral as levels of whole cottonseed increased across time points. The increase in rumen fluid pH with increasing inclusion of whole cottonseed was suggested to be from the lint on the seed of whole cottonseed or the lower starch concentrations present when grain was replaced with whole cottonseed.

Warner et al. (2020b) reported neither a treatment × time interaction nor a treatment effect for rumen fluid pH in cattle fed a standard ration and a cotton byproduct finishing ration. However, there was a time effect present for rumen fluid pH where the most neutral pH occurred at h 2 and 24 post feeding, and the most acidic pH occurred at 12 h post feeding. It should be noted that the rumen fluid pH at each collection was within the expected range of cattle consuming high concentrate diets (5.6 to 6.2; Schwartzkopf-Genswein, 2003). The decrease in rumen fluid pH at h 12 is similar to that

of Robles et al. (2007), who reported the pH results of 4 rumaninally fistulated Holstein heifers fed a high concentrate ration once daily.

Rumen Fluid Lactate

High concentrate diets shift rumen VFA production away from acetate and towards propionate. Along with this VFA shift, a drop in rumen pH is common in cattle that are transitioning from high forage diets to high concentrate diets predominantly composed of easily digestible carbohydrates, such as starch and sugar. Although low ruminal pH is an indicator of ruminal acidosis, research suggests that rumen lactate concentrations may also be used to determine if an animal is experiencing acute ruminal acidosis. A low rumen pH can cause pyruvate to be reduced to lactate and propionate (Church, 1988). When this occurs, lactic acid would then exacerbate the decreasing rumen pH and CH_4 production.

An accumulation of lactic acid can occur within the rumen when the microbial population is unable to utilize lactate as rapidly as lactate is being produced (Dunlap, 1972). When an abrupt shift from a high roughage diet to a high concentrate diet occurs, the microbial species within the rumen are unable to adapt or repopulate in the rumen with a sufficient number of the microbial species needed to utilize the newly produced lactic acid. This causes a buildup of lactate, initiating a further drop in rumen pH (Dunlop and Hammond, 1965). Although the concentration of lactate is generally low within the rumen (Owens et al., 1998), research conducted by Dunlop (1972) reported cattle

experiencing acute ruminal acidosis had lactate concentrations that exceeded 50mM, but reported a less severe shift in lactate concentrations (< 10 mM) when cattle were experiencing subacute acidosis (Harmon et al., 1984).

According to Moller et al. (1997), when lactating dairy cattle were fed rations high in easily digestible concentrates, rumen fluid lactate concentrations could reach up to 80 mMol/L. Warner et al. (2020b) analyzed rumen fluid in cannulated crossbred beef steers fed a control finishing ration or a ration containing cotton byproducts and reported no treatment × time interaction, or main effects of treatment or time for rumen lactate concentrations. The results were expected as none of the steers had rumen pH indicative of acidosis.

The various studies suggest the inclusion of whole cottonseed in high concentrate rations does not present negative effects in rumen environment by decreasing rumen fluid pH or increasing lactate concentrations outside of expected ranges for feedlot cattle. However, the inclusion of whole cottonseed within rations can potentially shift rumen fluid VFA proportions to greater proportions of acetate due to the high fermentability of lint, or varying amounts of peNDF.

Impact of whole cottonseed on fecal evaluation

Fecal Evaluation

It is common in the dairy as well as feedlot industries to use visual observations of fecal matter to assess digestion and fermentation. These observations allow producers to alter practices if an animal is showing signs of digestive upset, such as acidosis (Owens et al., 1998). A common method of fecal assessment was developed by Ireland and Stalling (1998), using a scale of 1 through 4 where 1 = runny with a liquid consistency, splatters on impact, 2 = loose, may pile slightly, 3 = soft, piles but spreads slightly, and 4 = dry and hard, not distorted on impact. Fecal samples were collected via manual rectal evacuation and then dropped from a consistent height (1 m). Scores were then assigned via visual observation. Woolsoncroft et al. (2017) modified the method published by Ireland and Stalling (1998) for use within a feedlot setting. The modified method still required the fecal samples to be obtained via rectal palpation and appraised by both physical handling and visual appraisal, but did not require fecal samples to be dropped. This modified method uses a scoring system between 1 and 5: 1 = firm and hard, 2 = slightly firm, 3 = soft with high moisture, 4 = loose and runny, 5 = very loose and with a water consistency.

When evaluating fecal consistency, factors such as neutral detergent fiber (NDF), peNDF, type of non-fiber carbohydrates in the diet, and acid detergent fiber (ADF) influence the consistency and particle size within the manure (Hall, 2002; Ireland-Perry and Stalling, 1993). According to Ireland-Perry and Stalling (1993), when dietary ADF was included at 25% of the DM in a dairy TMR, the cattle fecal samples would be more firm than dairy cattle fed dietary ADF at 17% DM. In the case of peNDF, commodities

high in peNDF can slow passage rate and increase retention time in the rumen allowing time for further digestion.

Besides evaluating a fecal consistency score, a quantitative measure for evaluating feces is fecal pH. Feedlot cattle consuming a finishing ration commonly have a more acidic fecal pH than cattle consuming predominantly forage due to the higher starch levels included within the diet. A reduction in fecal pH can be due to an increase in hindgut fermentation producing a greater concentration of VFA (Depenbusch et al., 2008). Excess starch enters into the hindgut where it is fermented. The acid produced during the hindgut fermentation is then excreted in the feces, causing the pH of the feces to decrease (Wheeler et al., 1976).

Warner et al. (2020a) applied the Woolsoncroft et al. (2017) method when comparing a standard finishing ration to a cotton byproduct ration. While the standard diet had a predicted faster passage rate into the hindgut, the cotton byproduct treatment diet had a greater peNDF, and no difference in fecal score between the 2 treatments was reported. For fecal pH, there was a tendency for the cotton byproduct treatment to have a more neutral fecal pH on d 28, but no difference was present for any other collection day. Although fecal starch concentrations were not analyzed, this research supports the idea that fecal consistency score and fecal pH can be used as potential indicators as to the digestibility of starch and fiber in a non-invasive manner.

Summary of Literature Review

With the need for cotton fiber throughout the world, cotton byproducts, such as whole cottonseed, will continue to be a valuable commodity for livestock producers in the foreseeable future based on the unique nutrient composition of whole cottonseed. With states in the southern U.S. being large producers of both cotton and cattle, there has been an increased interest in the use of cotton byproducts within cattle rations. Although there are concerns from cattle feeders with the price and availability of these byproducts, the potential benefits and predicted availability in the future may lead to whole cottonseed becoming a more common ingredient in feedlot rations.

Although research suggests whole cottonseed can be fed to all classes of cattle, there are some limitations. In the feedlot and dairy cattle, whole cottonseed is recommend to be fed in total mixed rations at inclusion levels of 15% or less (Preston and Bartle, 1989). Feeding whole cottonseed at this inclusion level can be done without any negative effects on animal performance, carcass characteristics, or rumen health (Warner et al., 2020b; Cranston et al. 2006; Huerta-Leidenz et al., 1991).

There is published research on the effects of including whole cottonseed and other cotton byproducts within finishing feedlot rations. However, more research evaluating whole cottonseed in modern feedlot diets is necessary and there is limited research evaluating the potential of whole cottonseed to serve as the sole roughage source within finishing feedlot diets. Therefore, the objective of this series of experiments was to determine the effects of replacing prairie hay and dried distillers grains plus solubles with

whole cottonseed in diets balanced for peNDF on animal performance, carcass characteristics, plasma metabolites (glucose, lactate, PUN, NEFA), rumen pH, rumen VFA, and rumen lactate of feedlot cattle.

CHAPTER II

USING WHOLE COTTONSEED TO REPLACE DRIED DISTILLERS GRAINS PLUS SOLUBLES AND PRAIRIE HAY IN FINISHING BEEF CATTLE RATIONS BALANCED FOR PHYSICALLY EFFECTIVE NEUTRAL DETERGENT FIBER

K. N. Schneid*, A. P. Foote*, P. A. Beck*, and B. K. Wilson*

*Department of Animal and Food Sciences, Oklahoma State University, Stillwater 74078

Objective: The objective of this experiment was to determine the effects of replacing prairie hay and dried distillers grains plus solubles (DDGS) with whole cottonseed (WCS) in diets balanced for physically effective neutral detergent fiber (peNDF) on the growth, intake, feed efficiency, carcass characteristics, and plasma metabolites of finishing beef cattle.

Materials and Methods: Crossbred heifers (n = 103) and steers (n = 104) were blocked by bodyweight (BW) within sex and randomly allocated to pens within block (6 pens per treatment) with 17 (n = 10 pens) or 18 (n = 2 pens) animals per pen. Pens were randomly allocated to experimental treatment: either a control diet (CON; prairie hay, DDGS, dry-rolled corn, and liquid supplement), or a WCS diet (CTN; WCS, dry-rolled corn, and

molasses). A common vitamin and mineral supplement and urea were included in both diets at the same rate. Animals were harvested in 3 groups based on BW block.

Results and Discussion: Cattle fed the CTN treatment tended to have a greater final BW ($P = 0.10$) and had greater overall average daily gain (ADG) and gain to feed ratio (G:F; $P \leq 0.05$). There was no difference in overall DMI ($P = 0.23$). Fecal consistency scores (FCS) were greater for cattle fed the CON treatment on d 42, at the beginning of the beta-agonist feeding period, and at the final collection before harvest ($P \leq 0.03$). Cattle fed the CTN treatment had a more neutral fecal pH on d 140 and at the final collection ($P < 0.01$). No treatment × day interactions ($P \geq 0.70$) were detected for plasma glucose, lactate, urea nitrogen (PUN), or non-esterified fatty acid (NEFA) concentrations. Cattle fed the CON treatment had greater PUN concentrations ($P < 0.001$) and a tendency for a greater plasma lactate concentration ($P = 0.06$). A day effect was also observed for all plasma metabolites ($P < 0.001$).

Implications and Applications: This experiment suggests that feeding WCS improves the growth and feed efficiency of cattle when replacing the roughage and byproduct protein and fat sources within a finishing diet.

Key words: byproduct, feedlot, finishing diet, metabolites, performance

INTRODUCTION

Dried distillers grains plus solubles (DDGS) are used extensively in finishing diets being a readily available and competitively priced byproduct of ethanol production. The supply of DDGS varies due to changing demand for the primary production of ethanol. In recent years, the ongoing COVID-19 pandemic has resulted in a less reliable and simultaneously more expensive supply of DDGS with the concomitant decline in ethanol production (Irwin, 2020). While the effects of the ongoing pandemic have lessened, other regional, national, and global events will continue to affect the availability and price of commonly used byproducts. In addition to fluctuations in ethanol production, demand for DDGS from competing livestock industries has continued to increase creating more competition for the available supply of DDGS (Swiatkiewics et al., 2015).

With continually fluctuating commodity prices, there is an interest in finding alternative commodities to provide the needed protein and energy within feedlot diets in the Southern Plains. Because cotton is a popular crop in the southern US, cotton byproducts have the potential to be an effective source of protein, fat, and roughage within cattle finishing rations (Warner et al., 2020a).

Within feedlot diets, DDGS are commonly used as a source of both protein and energy in place of more expensive protein sources. In feedlot diets, DDGS are typically used as a primary or secondary byproduct by 38.6% consulting feedlot nutritionist (Samuelson et al., 2016). For both receiving and finishing rations, it is common for byproducts to be in included anywhere between 10% to 20% (Vasconcelos and Galyean,

2007; Samuelson et al., 2016). No more than 40% DDGS (DM) should be included in the diet and DDGS can be paired with low quality fibrous roughage to minimize ruminal acidosis in finishing feedlot rations (NASEM, 2016). Low to medium quality hay (hay that is fibrous, mature, or low in nutritive value) is commonly used as a roughage in feedlot diets to provide physically effective neutral detergent fiber (peNDF) to stimulate muscle contractions within the rumen for rumination. Research suggests that WCS is an effective source of protein, energy, and peNDF that can be mixed with less-nutrient dense ingredients and processed grain such as steam-flaked or dry-rolled corn to create a balanced feedlot ration (Cranston et al., 2013, Warner et al., 2020a).

With protein content of 22.9% ± 2.53, WCS contains less protein than DDGS (30.8% ± 2.67) but is still high in protein compared to many other commodities (NASEM, 2016). The energy derived from WCS is primarily from the oil content of the seed and the fiber is provided by the cottonseed hull and lint surrounding the seed (Rogers et al., 2002). When comparing peNDF, while prairie hay contains more peNDF than WCS (65.0% vs. 53.8%, respectively), WCS contains sufficient peNDF to serve as a roughage source in feedlot diets at the recommended 7 to 10% peNDF of dietary DM (Fox and Tedeschi, 2002; NASEM, 2016). As a result, WCS has the potential to be an effective roughage source for feedlot cattle by providing sufficient physical stimulation to allow for proper rumination. However, research is unclear as to if WCS is an as effective source of fiber as other common roughage sources. The objective of this experiment was to determine the effects of replacing prairie hay and DDGS with WCS in diets balanced for peNDF on the

growth, intake, feed efficiency, carcass characteristics, and plasma metabolites of finishing beef cattle.

MATERIALS AND METHODS

All procedures were approved by the Institutional Animal Care and Use Committee at Oklahoma State University (Animal Care and Use Protocol number: AG-19-8).

Cattle and Processing

Brangus crossbred heifers (*n* = 103) and steers (*n* = 104) used in this experiment were transported on the same day in 3 separate trucks approximately 1104 km from Wilson, LA to the Willard Sparks Beef Research Center (WSBRC) in Stillwater, OK in April of 2021. Upon arrival to the WSBRC (d -1), calves were immediately unloaded, individual body weights (BW) were recorded, and calves were administered individual identification tags prior to being sorted by sex. The calves were then placed in 2 separate holding pens (1 pen of heifers and 1 pen of steers) with ad libitum access to prairie hay (CP = 8.1%, NDF = 69.7%, ADF = 40.4%, and TDN = 57.0% DM) and water for approximately 10 h. The BW collected on d -1 were used to block cattle by BW within sex for allocation to experimental treatments.

On d 0, heifers, followed by steers, were randomly allocated within block based on d -1 BW within sex. After calves were allocated to pens (*n* = 12 pens; 6 pens of heifers, 6 pens of steers), calves were then ranked by BW within pen. The 6 calves

nearest to the median pen BW were selected to serve as a subset for intensive blood sampling. On d 0, all calves were individually weighed, implanted (steers = TE-IS, heifers = TE-IH; Elanco Animal Health, Greenfield, IL), vaccinated against clostridial (Vision 7 with SPUR, Merck Animal Health, Madison, NJ), viral and bacterial respiratory pathogens (Nuplura PH +3 and Titanium 5; Elanco Animal Health), administered a pour on insecticide (StandGuard; Elanco Animal Health), and an anthelmintic (Safe-guard; Merck Animal Health). In addition, fecal samples were collected to determine fecal consistency score (FCS; Ireland-Perry and Stalling, 1993; Woolsoncroft et al, 2017) and fecal pH. The subset of calves from each pen were bled via jugular venipuncture using 10 mL blood collection tubes containing dipotassium ethylenediaminetetraacetic acid (K_2EDTA BD Vacutainer; Franklin Lakes, NJ). After initial processing, the calves were housed in 31.0 m × 11. 9 m dry lot pens, which included a 4.30 m × 11.9 m concrete bunk pad with a shared concrete water tank between 2 adjacent pens (model J 360-F; Johnson Concrete, Hastings, NE) for the remainder of the experiment. Collection of BW, FCS, fecal pH and blood completed again on d 14, 28, 42, 56, 84, 112, 140, before feeding the beta-agonist and before shipping to harvest. During collections on d 112 all cattle were re-implanted (steers = TE-S, heifers = TE-H; Elanco Animal Health).

There were 12 experimental pens with 6 pens per treatment (3 pens of heifers and 3 pens of steers). All pens used 17 heifers or steers, with the exception of 2 pens which

housed 18 steers in 1 block. During the feeding period, cattle were monitored daily for health and well-being as described by Wilson et al. (2015).

If deemed necessary, cattle pulled from the home pen due to health concerns were treated following WSBRC standard protocols. By d 10, 7 steers and 3 heifers had been removed from various home pens and placed in a hospital pen based on treatment and sex due to hoof abscesses and/or severe lameness. On d 13, all cattle in the hospital pen were critically evaluated to determine eligibility to be returned to each animal's respective home pen. Upon evaluation, 7 of the 10 calves were permanently removed from the experiment due to the severity of injury and/or lameness. The remaining steer was returned to the home pen, but later removed from the experiment on d 67 again due to lameness complications and the inability to compete for bunk space within the home pen. The remaining 2 heifers were returned to in home pens and remained there for the duration of the experiment. The morning of d 56 collection, a heifer appeared to have labored breathing and later died the same day. Another heifer on d 90 appeared to have labored breathing and eventually became moribund. That heifer was euthanized later that same day. All animals in hospital pens were provided the respective treatment diet from the bunk of the respective home pen. This feed was recorded in the home pen feed delivery until the animal was either placed back in home pen or removed from the experiment. In total 10 animals, 3 heifers (1 consuming the CON diet and 2 consuming the CTN diet) and 7 steers (2 consuming the CON diet and 5 consuming the CTN diet), were removed from the experiment due to severe lameness or complications from hoof

abscesses resulting from cattle temperament or respiratory disease complications believed to be unrelated to experimental treatments.

Diets and Feed Management

Every morning at 0500 h, feed bunks were visually evaluated by trained personnel. The evaluation of the bunk was used to adjust the feed amount offered daily in attempt to allow 0.045 kg of feed or less to remain in the feed bunk (modified slick bunk approach). All cattle received a common receiving ration (RCV; Table 1) for 10 d after arrival consisting of Sweet Bran (Cargill Inc., Dalhart, TX), prairie hay, dry-rolled corn, and a dry vitamin and mineral supplement, followed by a 28-d transition period utilizing a step-up ration approach based on the final experimental diet composition (CON; Table 2 and CTN; Table 3) with 7 d per step.

On a dry matter (DM) basis, experimental dietary treatments consisted of the control diet (CON): hay, DDGS, dry-rolled corn, liquid supplement, and the WCS diet (CTN): WCS, dry-rolled corn, molasses (Table 4). Both diets contained dry vitamin and mineral supplement that contained all feed additives and urea. Due to the increased fat from WCS, the CTN diet included 6.00% molasses as a ration conditioner whereas the CON diet had 6.00% of liquid supplement that contained added fat as a conditioning agent. Thirty-one d prior to shipping to harvest, the beta-agonist ractopamine hydrochloride (Optaflexx 45; Elanco Animal Health) was added to both treatment

supplements at a calculated intake of 390 mg·animal^{-1}·d^{-1}. All feed was mixed and delivered using a trailer mounted 12B feed mixer (Roto-mix; Dodge City, KS).

Treatment diets were sampled twice weekly, immediately after feed was dispersed into the bunks. Samples were collected from 3 bunks (the first, middle, and last bunk for the respective treatment) with 3 samples from each bunk (beginning, middle, and end of bunk) to create the composite sample that was then dried in a forced air oven at 55°C for 48 h. Samples were composited monthly and stored in a freezer until further analysis could be completed. Feed refusals were collected and weighed on d 14, 28, 42, 56, 84, 112, 140, before feeding the beta agonist, before shipping to harvest, and as needed if excess orts remained in the bunk. Ort samples were dried following same procedures as diet samples to determine DM. Ort (DM) was subtracted from feed delivered (DM) before calculating pen dry matter intake (DMI).

Data Collection and Calculations

Individual BW were collected before the morning feeding at approximately 0430 h with no withdrawal from feed or water on d -1, 0, 14, 28, 42, 56, 84, 112, 140, before starting the beta-agonist feeding, and the morning of shipping for harvest. All BW were adjusted using a calculated 4% pencil shrink to accommodate for rumen fill since cattle were not withheld from feed before obtaining BW (BW × 0.96; NASEM, 2016). All individual BW were averaged within a pen and used to calculate other growth, intake, and efficiency measures. Pen average daily gain (ADG) was calculated by averaging the

individual ADG of animals within a pen for each period. Within pen, DMI (kg/d) was calculated by summing pen daily DM feed deliveries, subtracting feed refusals (DM), and dividing by number of animals in that pen. Within pen, DMI as a percentage of BW was calculated by dividing the pen average DMI for the period by the average of the beginning and ending BW (mean feeding BW) for that period. The gain to feed ratio (G:F) was calculated by dividing pen ADG (kg) by pen DMI (kg/d).

Due to intake being measured on a pen basis rather than individual animal basis, intake had to be corrected for the cattle removed (n = 10) from the experiment by subtracting the average individual DMI from the pen until animal in question ceased gaining BW. Once the animal ceased gaining BW, the NASEM (2016) equation was used to estimate the individual animal's energy intake at maintenance (NEm), NEm = 0.077 (shrunk BW)$^{0.75}$. This calculation and diet NEm concentration was then used to estimate animal DMI. The estimated individual animal's intake was then subtracted from the pen DM deliveries from the day the animal ceased gaining BW, until the animal was physically removed from the assigned pen (NASEM, 2016).

Blood and fecal samples were collected on 0, 14, 28, 42, 56, 84, 112, 140, before starting beta-agonist feeding, and the morning of shipping for harvest. Blood was collected via jugular venipuncture from the subset (6 animals per pen) using 10 mL blood collection tubes containing K_2EDTA (BD Vacutainer) and stored on ice until further processing. Blood samples were stored on ice for an average of 3 h before centrifuging at

3,000 × g for 20 min at 7°C. After centrifuging, plasma was collected and stored at –20°C until analysis for glucose, lactate, urea nitrogen (PUN), and non-esterified free fatty acids (NEFA) could be completed.

Fecal samples were collected via rectal palpation from all animals. Fecal pH was measured immediately after collection (Accumet AE150 benchtop pH meter; Thermo Fisher, Waltham, MA). Fecal samples were also visually appraised and assessed a FCS. This method uses a scale ranging from 1 to 5 characterized as following: 1 = firm and hard, 2 = slightly firm, 3 = soft with high moisture, 4 = loose and runny, 5 = very loose and with a water consistency (Woolsoncroft et al., 2018). The same evaluator collected the fecal samples and determined the FCS during each collection day. Fecal pH and FCS change were determined by subtracting the previous period value from later period value.

Due to varying BW across blocks, cattle were shipped to harvest in 3 different harvest groups based on visual appraisal of condition and BW. The heaviest blocks (n = 4 pens total; 2 pens per treatment; 1 pen of heifers and 1 pen of steers per treatment) were shipped approximately 120 km on d 177 to be processed on d 178 at a commercial abattoir in Arkansas City, KS. It should be noted that 1 heifer out of the heaviest block on CNT diet was rejected by the commercial abattoir in Arkansas City, KS, due to failure to meet hide color requirements. On d 178, the rejected heifer was transported back 120 km to WSBRC where the animal was held overnight before being shipped 61 km on d 179 to a different abattoir in Jennings, OK for processing that same day. Trained personnel from

Oklahoma State University (Stillwater, OK) collected carcass data for this specific heifer from the morning after harvest (d 180). Due to this issue, the remaining blocks of cattle were shipped approximately 435 km to a commercial abattoir in Dodge City, KS. The middle blocks (*n* = 4 pens total; 2 pens per treatment; 1 pen of heifers and 1 pen of steers per treatment) were shipped on d 205 to be processed on d 206, and the lightest blocks (*n* = 4 pens total; 2 pens per treatment; 1 pen of heifers and 1 pen of steers per treatment) were shipped on d 226 to be processed on d 227. Henceforth, the term " final " represents data collections the occurred the morning of shipping for harvest, depending on the harvest group (final = d 177, 205, or 226, respectively). The following carcass characteristics were measured for all harvested animals; hot carcass weight (HCW), fat thickness, and ribeye area (REA). The dressing percentage (DP), USDA Yield Grade (USDA YG), and marbling score were calculated or assigned by trained personnel from the abattoirs with the exception of the 1 heifer for which carcass data were collected by trained personnel from Oklahoma State University (Table 11).

Laboratory Analysis

Composited diet samples were shipped to a commercial laboratory for analysis of crude protein and minerals (Servi-Tech, Dodge City, KS). Whole cottonseed, prairie hay, and DDGS particle size was determined using a 3-sieve forage particle separator (18 mm, 8 mm, 4 mm sieves, and a bottom pan; Nasco; Fort Atkinson, WI). The 3-sieve particle separator was placed on a flat surface with the sample placed on the top sieve. The

particle separator was shaken 5 times, rotated 90° and repeated for a total of 40 shakes or 8 sets. The peNDF of WCS, DDGS, and prairie hay was calculated by multiplying the NDF of the specific commodity (DM basis) by the total percentage of the specific commodity retained in the top 3 sieves (sieves ≥ 4 mm; Table 5). To determine the amount of peNDF within the diets based on a desired inclusion rate of 15% WCS (DM), the peNDF of ingredients was multiplied by the percent inclusion rate within the diet. The peNDF was calculated within the CTN treatment based on WCS inclusion and then prairie hay was added to the CON treatment to create equal peNDF between the CTN and CON treatments. Entire treatment diets were not analyzed for peNDF due to possible inflation of peNDF from the pelleted supplement and other non-fibrous commodities within the diet that could be retained in the 4 mm sieve (NASEM, 2016).

Diet samples were dried in a 55˚C oven for 48 h before being ground through a 2-mm screen followed by a 1-mm screen (Puverisette 19, Fritsch, Pittsboro, NC). Proximate analysis was performed on the composited treatment diet samples. Laboratory DM percentages were calculated by subtracting the weights of samples after drying in 105˚C oven for 24 h from the weight of the sample prior to drying. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were analyzed according to manufacturer's instructions using ANKOM 2000 automated fiber analyzer (ANKOM Technology; Macedon, NY). Ether extract (EE) was analyzed by ANKOM XT15 extract (ANKOM Technology), and ash percentages were calculated by weight difference when samples were placed in furnace at 500°C for 12 h.

Plasma samples were thawed at room temperature and analyzed for glucose, lactate, and PUN. Plasma glucose and L - lactate were analyzed using an immobilized enzyme system (YSI Model 2950 D; YSI Inc., Yellow Springs, OH). Plasma urea nitrogen was analyzed using methods described by Marsh et al. (1965) with adaptations to a 96 well plate. Plasma NEFA were analyzed using a modified protocol of the NEFA-HR (2) kit (WAKO Pure Chemical Corporation, Osaka, Japan) based on the acyl-CoE synthetase-acyl-CoA oxidase method. Samples were analyzed in duplicates using a flat-bottom 96-well polystyrene plates on microplate reader (Biotek EPOCH, Biotek Instrument Inc., Winooski, VT) at 550 nm.

Statistical Analysis

This experiment used a randomized complete block design, with BW blocked within sex. There were 3 blocks based on BW (light, medium, and heavy). Data were analyzed using the MIXED procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). For all growth, intake, feed efficiency, fecal, and carcass data, treatment was the fixed effect, block was the random effect, and pen served as the experimental unit (n = 12). Plasma metabolite data were assessed for normality using UNIVARIATE procedures of SAS 9.4, and the Shaprio-Wilk test determined all data were normally distributed. The fixed effects of treatment, day and treatment × day with block as a random effect were used when analyzing plasma metabolite data. The analysis included day as a repeated measure using the appropriate covariance structure with pen as the subject. The appropriate

covariance structure was determined by comparing Akaike's Information Criteria (AIC). The covariance structure with the lowest AIC was used for metabolite analysis; plasma glucose and NEFA used heterogeneous compound symmetry, lactate used variance components, and PUN used heterogeneous autoregression 1. Data from heifers or steers that were removed or died during the experiment (n = 10) were excluded from all analysis. Significance was declared when $P \leq 0.05$ and tendencies were considered when $P > 0.05$ and $P \leq 0.10$.

RESULTS AND DISCUSSION

Experiment Diets

When creating the experimental diets, peNDF was determined for WCS, prairie hay, and DDGS using a 3-sieve forage particle separator (Table 2; Fort Atkinson, WI). Based on the desired fixed percentage of WCS and DDGS in the CTN and CON treatment diets, respectively, the percentage of prairie hay was adjusted in the CON diet to ensure equivalent peNDF (8.07%) between the experimental diets.

It was not possible to formulate the CON and CTN treatment diets to contain equivalent fat and protein. As such, the experimental objective was not to attempt to create treatments with equivalent fat and protein concentrations, but to determine if WCS could effectively replace both prairie hay and DDGS to supply the majority of the roughage, fat, and protein in the diet when diets were balanced for peNDF.

Net energy maintenance (NEm) and net energy gain (NEg) for the treatment diets were calculated using NASEM (2016) equations which resulted in similar energy values for both diets (Table 4). Based on the observed cattle growth, intake, and feed efficiency, the dietary NEm and NEg for the treatment diets were back calculated using shrunk BW at the beginning of finishing period (d 40), final shrunk BW, average DMI during finishing period, and shrunk ADG during finishing period. This resulted in a NEm of 1.83 Mcal/kg and NEg of 1.19 Mcal/kg for the CON diet and a NEm of 1.94 Mcal/kg and NEg of 1.29 Mcal/kg for the CTN diet.

Previous research by Warner et al. (2020a) and Cranston et al. (2006) has evaluated the inclusion of WCS in feedlot diets. The current experiment and Warner et al. (2020a) both included WCS at 15% of the diet and attempted to provide the majority of protein, fat, and roughage in the diet from either WCS alone or a combination WCS and cotton gin trash (sometimes referred to simply as 'gin trash,' 'cotton burrs,' or 'gin byproduct'). Cranston et al. (2006) evaluated the effects on cattle performance and carcass characteristics when replacing alfalfa hay, cottonseed meal, cottonseed hulls, and tallow with WCS in a finishing feedlot ration. Cranston et al. (2006) formulated treatment diets to provide similar amounts protein, fat, and NDF, whereas the current experiment formulated for equivalent peNDF between treatment diets.

Growth, Intake, and Feed Efficiency

While there was no difference in BW between cattle consuming the CON and cattle consuming the CTN treatment on d 0 (Table 6; $P = 0.32$), it is important to note that all 207 animals that arrived at the WSBRC (103 heifers and 104 steers) were randomly allocated within block to experimental treatments. This resulted in an average BW of 324 kg for cattle allocated to both the CON and the CTN experimental treatments on the day of allocation. However, due to multiple animals being removed from the experiment due to severe injury, lameness, or mortality and the data associated with those animals being removed from the analysis, there was a small numerical difference (~ 7 kg) in initial BW (Table 6; $P = 0.32$).

By d 56, cattle consuming the CTN treatment tended to be heavier ($P = 0.06$). It should be noted that by d 56, cattle had been completely transitioned to finishing diets and been consuming the experimental treatment diets for 18 d. By d 84 and until d 140, cattle consuming the CTN treatment had a greater BW compared to those consuming the CON treatment ($P \leq 0.03$). The BW of cattle consuming the CTN treatment at the beginning of the beta-agonist feeding period and final collection also tended to be greater compared to those consuming the CON treatment ($P = 0.10$). The increased BW observed in cattle consuming CTN treatment across those intervals was a result of increased ADG from d 15 to 28, d 43 to 56, and over the duration of the experiment (Table 6; $P \leq 0.03$). While numerical differences in BW were observed on d 0, the absolute difference in BW increased over the duration of the study, as indicated by detectable differences in ADG.

Cattle consuming the CON treatment had a greater DMI (kg/d) from d 0 to 14 (Table 7; $P = 0.03$). During this time cattle were fed the RCV diet (Table 1) for 10 d and Step 1 (Table 2 and 3), of the assigned treatment for 4 d. This difference in DMI then is not likely due to experimental treatments, unless there was some initial aversion to the CTN diet during the first 4 d of feeding Step 1. There were no other differences in DMI among cattle consuming either treatment for the remainder of the experiment ($P \geq 0.35$). When analyzing DMI as a percentage of BW, cattle receiving the CON treatment tended to have a greater DMI as a percentage of BW from d 0 to 14 ($P = 0.06$) and d 113 to 140 ($P = 0.08$), while having a greater DMI as a percentage of BW during the beta-agonist period ($P = 0.05$) and from d 140 to final ($P = 0.04$). The gain to feed ratio (G:F) was not different from d 0 to 14 (Table 7; $P = 0.42$). However, G:F was greater for cattle consuming the CTN treatment from d 15 to 28 ($P < 0.01$) and d 43 to 56 ($P = 0.02$). There were no differences in G:F from d 57 through d 140 ($P \geq 0.17$), but G:F was again greater for cattle consuming the CTN treatment during the beta-agonist feeding period ($P = 0.01$) and for the overall experiment (d 0 to final; $P = 0.05$).

Previous studies have reported inconsistent results when cattle fed WCS were compared to a more traditional ingredients in dry-rolled or steam-flaked corn-based diets. Cranston et el. (2006) reported no difference in ADG, an increase in DMI, and a decrease in G:F when steers were fed a diet containing WCS compared to a steam-flaked corn finishing ration containing a majority cottonseed meal, alfalfa hay, and cottonseed hulls.

Warner et al. (2020a) compared a diet containing WCS and cotton gin trash to a control diet containing dry-rolled corn, prairie hay, and Sweet Bran and reported similar results to the current experiment where cattle consuming the diet containing WCS had a tendency for greater final BW and overall greater ADG. However, Warner et al. (2020a) reported cattle consuming the treatment diet containing WCS and cotton gin trash had greater overall DMI and thus there was no difference in G:F in their experiment.

There are several possible explanations for lower intake of cattle fed the CTN diets during adaptation. One explanation for the greater DMI for cattle consuming the CON treatment from d 0 to 14 could potentially be a result of the animal's lack of previous exposure to WCS as a dietary ingredient. The RCV ration along with Step 1 of the CON step-up diets would potentially have been more recognizable to the calves than the potentially unfamiliar WCS in the CTN diet (Table 1, Table 2, and Table 4). Savell et al. (2007) compared WCS to soybean meal as a supplement to grazing backgrounding calves. The author reported that the calves being fed the WCS supplement consumed inadequate amounts of WCS, eventually leading to a decreased BW compared to the soybean meal control. It was speculated this was due to higher dietary fat inhibiting fiber digestion. The lack of difference in DMI for the remainder of the experiment is likely due to the treatment diets being balanced for peNDF. Galyean and Defoor (2003) suggested DMI for feedlot cattle is the result of metabolic factors such as chewing, rumination rates, and acid production rather than bulk fill. With eNDF and peNDF being

highly correlated with measuring particle size (NASEM, 2016); this previous research likely explains the similar DMI throughout the duration of the experiment.

Fecal Characteristics

The characteristics of feces can be an indicator of what is occurring within the digestive tract (Owens et al. 1998). When evaluating feces, the consistency can indicate site and extent of digestion along with potential digestive upsets (Church, 1988; Monteiro and Faciola, 2020). By evaluating the fecal consistency and assigning a score based on the Ireland-Perry and Stalling (1993) method adapted by Woolsoncroft et al. (2017), an animal's digestive health can be evaluated. An increase in ruminal passage rate corresponding to an increase in hindgut fermentation, as well as increased fat intake, can cause the fecal consistency to appear more "loose" or watery (Hall, 2007; Kononoff, 2002). A loose fecal consistency can also be a sign of digestive upset, potentially due to insufficient peNDF within the diet (Yang and Beauchemin, 2009). With both treatments being balanced for peNDF, it is assumed that differences in nutrient composition, fermentation, and passage rate potentially produced the changes observed in the FCS of the cattle.

Upon arrival to the feedlot, cattle had the lowest overall FCS compared to all other periods (CON, FCS = 2.94; CTN, FCS = 3.01). This was not unexpected due to cattle grazing forage prior to arrival. Between d 0 and 28, there was no difference in FCS for cattle consuming either treatment (Table 8; $P \geq 0.67$). This was expected as cattle

were receiving the same RCV diet for 10 d and respective treatment Step 1 and 2 for a total of 14 d. However, there was a difference in FCS on d 42 with cattle consuming the CON treatment having a higher FCS ($P = 0.03$). It should be noted that all cattle were transitioned to the final experimental treatment diets by d 38, 4 d prior to d 42 collection. Between d 56 and 140, no differences in FCS were detected ($P \geq 0.12$). The FCS at the beginning of beta-agonist feeding and prior to shipping were greater ($P < 0.01$) in cattle fed the CON treatment. Although a difference in FCS was present between cattle fed the CON and the CTN treatments during the beta-agonist feeding period and prior to shipping, the difference may be of limited biological significance given the sensitivity of the scale used (Table 8) and a lack of observed differences in rumen health indicators such as incidence of acidosis or low rumen pH . The overall FCS change was greatest for cattle consuming the CON treatment with an overall change of 0.69 (Table 8; $P = 0.06$). Cattle consuming the CON treatment also tended to have a greater FCS change from d 43 to 56 ($P = 0.09$). These results are similar to Warner et al. (2020a) where cattle fed the cotton byproduct diet had a numerically higher FCS until d 28 and cattle fed the control diet had a higher or numerically higher FCS for the remainder of the experiment.

Although peNDF was balanced between roughage and byproduct sources within the treatment diets, potential correlation between ingredient particle size and FCS when feeding a total mixed ration (TMR) could help explain the overall greater FCS for cattle consuming the CON treatment (Melendez and Roy, 2016). When determining peNDF, prairie hay had the greatest particle percentage collect on the 18.0 mm sieve and DDGS

had the greatest particle percentage collect on the 4.0 mm sieve, while WCS had the overall greatest particle percentage of any sieve collected on the 8.00 mm sieve (Table 5). While prairie hay and WCS are both viable sources of peNDF based on the accepted definition of peNDF, there is still a difference in absolute particle size present between these 2 ingredients. The CTN treatment contained higher levels of dry-rolled corn and had only WCS to serve as a roughage source. With WCS having a smaller particle size than prairie hay and the roughage portion of WCS being associated with the seed itself, the differences in FCS are likely not strictly a function of peNDF, but potentially also the result of differences in roughage composition and site and extent of digestion. Reveneau et al. (2005) compared WCS processing methods and determined that decreasing the particle size of WCS through processing increased animal productivity potentially due to increasing the rate of passage. This could explain a lower FCS resulting from a slower passage rate of the unprocessed WCS within the CTN treatment compared to ingredients in the CON diet. Future research is needed to determine if processing WCS to decrease particle size could alter site and extend of digestion.

There was no difference in fecal pH between cattle consuming the CON and CTN treatments on d 0, 28, or 42 (Table 9; $P \geq 0.54$) as the cattle were being transitioned to experimental finishing diet treatments. However, cattle fed the CON treatment tended to have a more neutral fecal pH on d 14 ($P = 0.08$). Since all cattle were on the same RCV diet for 10 d, this difference in fecal pH is not likely due to experimental treatments, unless this was a result of the intake difference observed during the first 14 d. On d 56

and 84, cattle fed the CTN treatment tended to have a more neutral fecal pH ($P \geq 0.06$). Similarly, on d 140 and at the final collection, cattle fed the CTN treatment had a more neutral fecal pH ($P < 0.01$). Fecal pH change differed from d 15 to 28 ($P = 0.02$) and tended to differ from d 113 to 140 ($P = 0.08$) with cattle consuming the CON treatment have a greater fecal pH change. Fecal pH change differed again during the beta-agonist feeding period ($P = 0.02$) with cattle consuming the CTN treatment having a greater change towards a more neutral fecal pH. Warner et al. (2020a) reported no difference in fecal pH throughout the duration of the experiment but reported cattle consuming the diet containing WCS consistently had a numerically more neutral fecal pH.

The more acidic fecal pH in cattle fed the CON diet is interesting due to CTN treatment having an assumed higher intake of starch due to the greater inclusion of dry-rolled corn. Wheeler et al. (1976) reported that a decrease in fecal pH was associated with increased levels of starch within the feces where lower levels of starch indicate a further extent of starch digestion. Although treatments were not analyzed for starch levels, the CTN treatment contained more dry-rolled corn (72.1% ± 3.18 starch; NASEM, 2016) compared to the CON treatment (Table 4). The more acidic fecal pH for cattle consuming the CON treatment suggests that fecal pH may not strictly be a function of starch digestion (Gentry et al., 2016) but potentially a result of increased passage rate of the smaller particles within the diet, thus leading to increased hindgut fermentation and lower fecal pH.

Plasma Metabolites

No treatment × day interaction ($P \geq 0.70$) was detected for plasma glucose, lactate No treatment × day interaction ($P \geq 0.70$) was detected for plasma glucose, lactate, PUN, or NEFA concentrations (Table 10). Cattle consuming the CON treatment had greater PUN concentrations ($P < 0.001$) and tended to have greater plasma lactate concentrations ($P = 0.06$). No treatment effect was observed for plasma glucose or NEFA ($P \geq 0.24$). A day effect was observed for all analyzed metabolites ($P < 0.001$). The greatest plasma glucose concentrations were observed on d 14 (99.6 mg/dL*)*, before gradually decreasing until d 84 when the glucose concentrations began to increase through the final collection. Plasma lactate was greatest on d 14 (0.54 g/L) but fluctuated in concentration for the remainder of the experiment. The concentration of PUN was lowest on d 0 (0.75 mmol/L) and increased in concentration until d 84. The NEFA concentrations were greatest on d 0 (671.6 μEq/L) and decreased until d 28 with subsequent increase on d 56.

According to Cao et al (2021), increasing amounts of peNDF can potentially increase plasma glucose concentrations. This may help explain the results of the current experiment where no difference in plasma glucose was observed between treatments when diets were balanced for peNDF. Warner et al. (2020a) also reported no difference in plasma glucose or lactate when cattle fed a control diet were compared to cattle fed a diet containing cotton byproducts during finishing. However, Warner et al. (2020a) did report a treatment × day interaction for PUN where cattle fed the control treatment had a higher

PUN concentration on d 28 and 56. Low concentrations of PUN on d 0 could be a result of low feed intake prior to and during shipping. Cattle fed the CON treatment having greater concentrations of PUN may be due to observed differences in carcass composition (Table 11).

Elevated NEFA concentrations are commonly a result of fat mobilization in response to stress or a negative energy balance (Drackley, 2000; Kang et al., 2017). As a result, it would be expected that the highest NEFA concentrations would occur on d 0 after transportation, feed restriction, and feeding a low-quality forage upon arrival. After a decrease in NEFA concentration from d 0 and 28. The NEFA concentrations increased on d 42 and again on d 84 and 140, with the greatest NEFA concentration increase occurring from d 84 to 112 (Table 10). With no difference in glucose and NEFA concentrations between cattle fed the treatment diets, it is presumed that both diets supplied sufficient energetic nutrients to result in sufficient body reserve turnover (van Knegsel et al., 2007).

Carcass Traits

Consistent with the tendency observed in greater final live BW (Table 6; P= 0.10), cattle fed the CTN treatment also had greater HCW (Table 11; P= 0.02). While cattle consuming both treatments had similar DP (P = 0.88), cattle fed the CTN treatment had greater fat thickness (P = 0.05), and final calculated USDA YG (P = 0.001). There

was no difference in REA or marbling score between cattle fed either treatment ($P \geq 0.67$).

Results from the carcass data are in contrast to the results of Cranston (2003), who reported no difference in HCW, fat thickness, or USDA YG, but a difference in DP and marbling score when comparing cattle fed a diet containing WCS to cattle fed a more typical feedlot diet balanced for NDF and fat. The carcass results in the current experiment are in agreement with Huerta-Leidenz et al. (1990) who reported that cattle fed a finishing diet containing 15% WCS had a greater USDA YG compared to cattle fed a control diet. The results from the current experiment are also in agreement with the results of Warner et al. (2020a) where the inclusion of WCS and cotton gin trash compared to a control diet resulted in cattle having no difference in REA or marbling score but greater HCW, fat thickness, and a tendency for a greater DP.

The similarity in the BW, ADG, HCW, and fat thickness results from the current experiment and Warner et al. (2020a) is most likely due to the difference in fat content or other aspects of WCS in the experimental treatment diets of both experiments. Within each experiment, the treatment diets were similar in overall energy content based on NASEM (2016) calculations. However, the diet containing WCS in each experiment contained a greater overall fat content. It is possible that these NASEM (2016) energy calculations or those energy calculations used by commercial laboratories potentially undervalue the fat content or other nutritional aspects of WCS in these energy

calculations. In an experiment evaluating the ruminal degradability and metabolism of feedlot diets with or without cotton byproducts, Warner et al. (2020b) reported increased ruminal acetate proportions in steers consuming a diet containing cotton byproducts compared to a control diet. Warner et al. (2020b) speculated that this difference in acetate production resulted in an increase in subcutaneous fat accretion in cattle fed WCS. According to Rhoades et al. (2007), acetate primarily increases the deposition of subcutaneous fat compared with intramuscular fat, which supports the differences reported by Warner et al. (2020a) and observed in the current experiment. This increase in acetate production and a subsequent increase in fat thickness could explain why cattle consuming the CTN treatment had greater fat thickness (0.14 cm greater; $P = 0.05$) with no difference in REA or DP ($P \geq 0.67$), in the current experiment. In addition, with cattle being fed the CTN treatment having more subcutaneous fat but no difference in marbling score it appears that cattle fed the CTN treatment also shifted more fat deposition to subcutaneous and perhaps intermuscular depots instead of into intramuscular fat. This increased carcass fat resulted in a 17 kg increase in HCW (Table 11) for cattle consuming the CTN treatment which accounted for over 80% of the difference observed in final BW (21 kg; Table 6). This repartitioning of the retained energy as subcutaneous fat suggests that cattle potentially retained more energy from the CTN treatment, and that excess energy was preferentially stored as subcutaneous fat.

APPLICATIONS

The objective of this experiment was to determine the effects of replacing prairie hay and DDGS with WCS in diets balanced for peNDF on growth, intake, feed efficiency, carcass characteristics, and plasma metabolites of finishing cattle. Animals receiving the CTN treatment had improved performance compared to animals receiving the CON treatment, with greater ADG and no difference in DMI, resulting in overall greater G:F. The FCS were greater and fecal pH were more acidic for cattle fed the CON treatment after animals were fully transitioned onto experimental treatment diets. Cattle fed the CON treatment had greater PUN concentrations and a tendency for greater plasma lactate concentrations, suggesting the potential for greater glucose metabolism and amino acid catabolism in cattle fed the CON treatment. There was no difference in REA, DP, or marbling score between treatments, but cattle fed the CTN treatment had a greater HCW, fat thickness, and USDA YG.

This experiment suggests that WCS can effectively replace the roughage supplied by prairie hay and the protein and fat supplied by DDGS within finishing feedlot diets while simultaneously resulting in increased growth and feed efficiency. With constant price fluctuations and variability in availability of commodities, these results provide an alternative feeding strategy for finishing cattle with the replacement of 2 commonly used commodities with a single commodity while maintaining or increasing animal performance in the feedlot.

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Table 1. Receiving diet ingredients and analyzed nutrient composition for cattle upon arrival to feedlot

	Diet
Ingredient, % of DM	RCV[1]
Dry-rolled corn	15.00
Prairie hay	28.44
Sweet Bran[2]	51.36
Dry supplement[3]	5.20
Nutrient composition, DM	
Dry matter, %	70.4
Crude protein, %	17.2
Acid detergent fiber, %	25.1
Total Digestible Nutrients, %	69.8
Net Energy Maintenance, Mcal/kg	0.74
Net Energy Gain, Mcal/kg	0.46
Calcium, %	0.72
Phosphorus, %	0.68
Magnesium, %	0.33
Potassium, %	1.32

[1]Recieving diet; common receiving diet for all cattle upon arrival. Diet was analyzed by Servi-Tech Laboratories, Dodge City, KS

[2]Sweet Bran (Cargill Inc., Dalhart, TX)

[3]Dry supplement was formulated to contain (% DM basis) 40.0% ground corn, 29.6% limestone, 20.0% wheat middlings, 7.0% urea, 1.0% salt, 0.53% magnesium oxide, 0.51% zinc sulfate, 0.17% manganese oxide, 0.13% copper sulfate, 0.08% selenium premix (0.6%), 0.0037% cobalt carbonate, 0.32% vitamin A (30,000 IU/g), 0.20% tylosin (Tylan-40, Elanco Animal Health, Greenfield IN) and 0.33% monensin (Rumensin-90; Elanco Animal Health)

Table 2. Control treatment (CON) step-up ingredient inclusion percentages for feedlot steers and heifers

	CON step-up diets[4]				
Ingredient, % of DM	Step 1	Step 2	Step 3	Step 4	CON treatment
Prairie hay	24.30	20.16	16.01	11.87	7.73
Dried distillers grains	3.00	6.00	9.00	12.00	15.00
Dry-rolled corn	25.10	35.21	45.31	55.42	65.52
Sweet Bran[1]	41.09	30.81	20.55	10.27	6.00
Liquid supplement[2]	1.20	2.40	3.60	4.80	0.00
Dry supplement[3]	5.16	5.12	5.08	5.04	5.00
Urea	0.15	0.30	0.45	0.60	0.75

[1]Cargill Inc., Dalhart, TX

[2]Liquid supplement was formulated to contain (% DM basis) 45.86% corn steep, 36.17% cane molasses, 6.00% hydrolyzed vegetable oil, 5.46% 80/20 vegetable oil blend, 5.20% water, 1.23% urea (55% solution), and 0.10% xanthan gum

[3]Dry supplement was formulated to contain (% DM basis) 40.0% ground corn, 29.6% limestone, 20.0% wheat middlings, 7.0% urea, 1.0% salt, 0.53% magnesium oxide, 0.51% zinc sulfate, 0.17% manganese oxide, 0.13% copper sulfate, 0.08% selenium premix (0.6%), 0.0037% cobalt carbonate, 0.32% vitamin A (30,000 IU/g), 0.20% tylosin (Tylan-40, Elanco Animal Health, Greenfield IN) and 0.33% monensin (Rumensin-90; Elanco Animal Health)

[4]Cattle were placed on a RCV for 10 d followed by steps 1-4, with 7 d per step before starting the finishing ration for the remainder of the experiment

Table 3. Whole cottonseed treatment (CTN) step-up ingredient inclusion percentages for feedlot steers and heifers

Ingredient, % of DM	CTN Step-up Diets[4]				
	Step 1	Step 2	Step 3	Step 4	CTN treatment
Prairie hay	22.75	17.06	11.38	5.69	0.00
Whole cottonseed	3.00	6.00	9.00	12.00	15.00
Dry-rolled corn	26.65	38.30	49.95	61.60	73.25
Sweet Bran[1]	41.09	30.82	20.54	10.27	0.00
Molasses	1.20	2.40	3.60	4.80	6.00
Dry supplement[2]	5.16	5.12	5.08	5.04	5.00
Urea	0.15	0.30	0.45	0.60	0.75

[1]Cargill Inc., Dalhart, TX

[2]Dry supplement was formulated to contain (% DM basis) 40.0% ground corn, 29.6% limestone, 20.0% wheat middlings, 7.0% urea, 1.0% salt, 0.53% magnesium oxide, 0.51% zinc sulfate, 0.17% manganese oxide, 0.13% copper sulfate, 0.08% selenium premix (0.6%), 0.0037% cobalt carbonate, 0.32% vitamin A (30,000 IU/g), 0.20% tylosin (Tylan-40, Elanco Animal Health, Greenfield IN) and 0.33% monensin (Rumensin-90; Elanco Animal Health)

[4]Cattle were placed on a RCV ration for 10 d followed by steps 1-4, with 7 d per step before starting the CTN treatment finishing ration for the remainder of the experiment

Table 4. Ingredients analyzed nutrient composition of experimental treatment finishing diets

	Diet	
Ingredient, % of DM	CON[1]	CTN[2]
Dry-rolled corn	65.52	73.25
Dried distillers grains	15.00	-[3]
Prairie hay	7.73	-
Whole cottonseed	-	15.00
Liquid supplement[4]	6.00	-
Dry supplement[5]	5.00	5.00
Molasses	-	6.00
Urea	0.75	0.75
Nutrient composition, DM basis		
Dry matter, %	81.48	83.98
Crude protein[6], %	15.45	15.65
Neutral detergent fiber, %	21.20	17.75
Acid detergent fiber, %	7.55	13.15
peNDF[7], %	8.07	8.07
Total digestible nutrients[8], %	77.63	76.93
Fat, %	2.66	3.46
Net energy maintenence[9], Mcal/kg	1.67	1.65
Net energy gain[9], Mcal/kg	1.06	1.04
Calcium, %	0.60	0.49
Phosphorus, %	0.48	0.42
Magnesium, %	0.21	0.23
Potassium, %	0.88	0.86

[1]Contol diet (CON); representative of a typical feedlot diet
[2]Whole cottonseed diet (CTN); whole cottonseed is used as the primary fiber source in the diet
[3]A missing value under ingredient indicate there was 0.00% of that ingredient included
[4]Liquid supplement is formulated to contain (% DM basis) 45.86% corn steep, 36.17% cane molasses, 6.00% hydrolyzed vegetable oil, 5.46% 80/20 vegetable oil blend, 5.20% water, 1.23% urea (55% solution), and 0.10% xanthan gum
[5]Dry supplement is formulated to contain (% DM basis) 40.0% ground corn, 29.6% limestone, 20.0% wheat middlings, 7.0% urea, 1.0% salt, 0.53% magnesium oxide, 0.51% zinc sulfate, 0.17% manganese oxide, 0.13% copper sulfate, 0.08% selenium premix (0.6%), 0.0037% cobalt carbonate, 0.32% vitamin A (30,000 IU/g), 0.20% tylosin (Tylan-40, Elanco Animal Health, Greenfield IN) and 0.33% monensin (Rumensin-90; Elanco Animal Health)
[6]Analyzed by ServiTech Laboratories, Dodge City, KS

[7]Physically effective neutral detergent fiber provided by the roughage and byproducts in the diet
[8]Calculated according to Weiss et al. (1992)
[9]Calculated according to NASEM (2016)

Table 5. Particle separation and estimated physically effective neutral detergent fiber (peNDF) of treatment diet ingredients

	Ingredients[1]		
Item	PH	DDGS	WCS
Neutral detergent fiber, % DM	69.7	34.3	54.0
Sieve screen size, mm	Retained[3], %		
18.0	57.3	0.00	1.62
8.0	18.1	0.47	93.4
4.0	17.9	58.7	4.66
Less than 4mm	6.70	40.8	0.30
Greater than 4 mm	93.3	59.2	99.7
Estimated peNDF[2], % DM	65.0	20.3	53.8

[1]PH = prairie hay, DDGS = dry distillers grains plus solubles, WCS = whole cottonseed

[2]Physically effective NDF (peNDF) percentage was estimated by multiplying the NDF as a decimal by the percent of particles greater than 4 mm

[3]Percentage of the commodity that remained on that respective sieve

Table 6. Influence of using whole cottonseed in place of dried distillers grains plus solubles and prairie hay in finishing rations balanced for physically effective neutral detergent fiber on growth of feedlot heifers and steers

	Treatment[1]			
Item	CON	CTN	SEM[2]	*P*-value
BW[3], kg				
d 0	332	339	15.0	0.32
d 14	339	345	14.4	0.32
d 28	378	389	15.9	0.15
d 42	407	418	16.5	0.20
d 56	429	443	16.6	0.06
d 84	466	484	16.4	0.03
d 112	488	507	16.9	0.01
d 140	533	550	17.1	0.03
Beta-agonist[4]	571	584	10.5	0.10
Final[5]	615	636	14.9	0.10
ADG[6], kg				
d 0 to 14	0.44	0.49	0.140	0.67
d 15 to 28	2.83	3.17	0.156	0.02
d 29 to 42	2.09	2.00	0.089	0.47
d 43 to 56	1.49	1.84	0.077	0.01
d 57 to 84	1.35	1.46	0.048	0.13
d 85 to 112	0.73	0.84	0.059	0.17
d 113 to 140	3.32	3.54	0.154	0.27
Beta-agonist to final	1.39	1.56	0.188	0.24
d 140 to final	1.34	1.48	0.130	0.35
d 0 to final	1.40	1.53	0.048	0.03

[1]Treatments included (DM basis): CON = 7.73% hay, 15.00% dry distillers grains plus solubles, 65.52% dry-rolled corn, 6.00% liquid supplement, or CTN = 15.00% whole cottonseed, 73.25% dry-rolled corn, 6.00% molasses. Both diets contained 5.00% dry supplement and 0.75% urea

[2]*n* = 6 pens, per treatment; 3 pens of heifers and 3 pens of steers per treatment

[3]Body weight (BW) was adjusted using a calculated 4% pencil shrink

[4]Cattle were harvested in 3 groups; d 178 (*n* = 4 pens total; 2 pens per treatment; 1 pen heifers and 1 pen steers per treatment), d 206 (*n* = 4 pens total; 2 pens per treatment; 1 pen heifers and 1 pen steers per treatment), and d 227 (*n* = 4 pens total; 2 pens per treatment; 1 pen heifers and 1 pen steers per treatment). Beta-agonist BW was obtained

the day the pens started Ractopamine hydrochloride (Optaflexx 45; Elanco Animal Health, Greenfield, IL; 31 d prior to harvest

[5]Final BW were taken the day of shipping for harvest

[6]Pen average daily gain (ADG) were calculated from individual shrunk BW gain in kg, divided by days on feed for each period

Table 7. Influence of using whole cottonseed in place of dried distillers grains plus solubles and prairie hay in finishing rations balanced for physically effective neutral detergent fiber on feed intake and efficiency of feedlot heifers and steers

	Treatment[1]			
Item	CON	CTN	SEM[2]	*P*-value
DMI[3], kg/d				
d 0 to 14	6.1	5.8	0.12	0.03
d 15 to 28	11.2	11.1	0.25	0.62
d 29 to 42	12.0	11.7	0.35	0.37
d 43 to 56	14.0	12.3	1.18	0.35
d 57 to 84	11.1	10.3	1.03	0.58
d 85 to 112	10.2	10.3	0.33	0.89
d 113 to 140	10.3	10.1	0.29	0.35
Beta-agonist to final	11.1	10.9	0.40	0.68
d 140 to final	11.1	10.9	0.30	0.56
d 0 to final	10.8	10.4	0.36	0.49
DMI[4], % of BW				
d 0 to 14	1.84	1.73	0.094	0.06
d 15 to 28	3.14	3.05	0.143	0.32
d 29 to 42	3.07	2.92	0.105	0.20
d 43 to 56	3.32	2.89	0.249	0.25
d 57 to 84	2.48	2.26	0.229	0.45
d 85 to 112	2.15	2.09	0.078	0.31
d 113 to 140	2.02	1.92	0.070	0.08
Beta-agonist to final	1.87	1.79	0.056	0.05
d 140 to final	1.94	1.85	0.054	0.04
d 0 to final	2.37	2.24	0.090	0.23
G:F[5]				
d 0 to 14	0.073	0.086	0.0236	0.42
d 15 to 28	0.253	0.286	0.0124	<0.01
d 29 to 42	0.175	0.171	0.0073	0.76
d 43 to 56	0.112	0.151	0.0103	0.02
d 57 to 84	0.122	0.172	0.0330	0.30
d 85 to 112	0.071	0.082	0.0055	0.17
d 113 to 140	0.324	0.353	0.0185	0.24
Beta-agonist to final	0.125	0.143	0.0164	0.01
d 140 to final	0.121	0.135	0.0106	0.19
d 0 to final	0.130	0.148	0.0063	0.05

[1]Treatments included (DM basis): CON = 7.73% hay, 15.00% dry distillers grains plus solubles, 65.52% dry-rolled corn, 6.00% liquid supplement, or CTN = 15.00% whole cottonseed, 73.25% dry-rolled corn, 6.00% molasses. Both diets contained 5.00% dry supplement and 0.75% urea

[2]*n* = 6 pens, per treatment; 3 pens of heifers and 3 pens of steers per treatment

[3]Pen dry matter intake (DMI) were calculated from pen as fed intake for by period multiplied by the treatment diet DM percentage

[4]Dry matter intake as a percent of BW was calculated by dividing the pen average DMI for the period by the average of the beginning and ending BW (mean feeding BW) for that period

[5]Gain to feed ratio was calculated by dividing pen ADG by pen daily DMI for each period

Table 8. Influence of using whole cottonseed in place of dried distillers grains plus solubles and prairie hay in finishing rations balanced for physically effective neutral detergent fiber on fecal scores of feedlot heifers and steers

	Treatment[1]			
Item	CON	CTN	SEM[2]	*P*-value
Fecal score[3]				
d 0	2.94	3.01	0.112	0.69
d 14	3.45	3.43	0.048	0.67
d 28	3.49	3.52	0.123	0.88
d 42	3.33	3.12	0.065	0.03
d 56	3.31	3.25	0.036	0.24
d 84	3.36	3.21	0.086	0.12
d 112	3.32	3.19	0.077	0.23
d 140	3.35	3.29	0.134	0.70
Beta-agonist[4]	3.45	3.21	0.090	<0.01
Final[5]	3.56	3.32	0.055	<0.01
Fecal score change[6]				
d 0 to 14	0.504	0.420	0.130	0.66
d 15 to 28	0.049	0.094	0.139	0.82
d 29 to 42	-0.168	-0.399	0.124	0.22
d 43 to 56	-0.021	0.123	0.060	0.09
d 57 to 84	0.056	-0.035	0.077	0.41
d 85 to 112	-0.040	-0.025	0.099	0.92
d 113 to 140	0.025	0.105	0.153	0.68
Beta-agonist to final	0.118	0.114	0.112	0.93
d 140 to final	0.179	0.032	0.135	0.10
d 0 to final	0.622	0.315	0.125	0.11

[1]Treatments included (DM basis): CON = 7.73% hay, 15.00% dry distillers grains plus solubles, 65.52% dry-rolled corn, 6.00% liquid supplement, or CTN = 15.00% whole cottonseed, 73.25% dry-rolled corn, 6.00% molasses. Both diets contained 5.00% dry supplement and 0.75% urea

[2]*n* = 6 pens, per treatment; 3 pens of heifers and 3 pens of steers per treatment

[3]Fecal score on a scale from 1 to 5, with a score of 5 indicating looser fecal consistency and a score of 1 representing a cow on a dry hay

[4]Cattle were harvested in 3 groups; d 178 (*n* = 4 pens total; 2 pens per treatment; 1 pen heifers and 1 pen steers per treatment), d 206 (*n* = 4 pens total; 2 pens per treatment; 1 pen heifers and 1 pen steers per treatment), and d 227 (*n* = 4 pens total; 2 pens per

treatment; 1 pen heifers and 1 pen steers per treatment). Beta-agonist fecal scores were obtained the day the pens started Ractopamine hydrochloride (Optaflexx 45; Elanco Animal Health, Greenfield, IL; 31 d prior to harvest)

[5]Final fecal scores were taken the day of shipping for harvest

[6]Change in collection is the difference between collection periods; subtract a later collection period from an earlier collection period

[6]Change in collection is the difference between collection periods; subtract a later collection period from an earlier collection period

Table 9. Influence of using whole cottonseed in place of dried distillers grains plus solubles and prairie hay in finishing rations balanced for physically effective neutral detergent fiber on fecal pH of feedlot heifers and steers

	Treatment[1]			
Item	CON	CTN	SEM[2]	*P*-value
Fecal pH				
d 0	6.98	7.03	0.072	0.54
d 14	6.77	6.71	0.030	0.08
d 28	6.27	6.29	0.035	0.67
d 42	6.27	6.30	0.052	0.69
d 56	6.13	6.29	0.059	0.07
d 84	6.10	6.24	0.047	0.06
d 112	6.45	6.50	0.054	0.53
d 140	6.15	6.37	0.038	<0.01
Beta-agonist[3]	6.40	6.47	0.045	0.09
Final[4]	6.45	6.63	0.026	<0.01
Fecal pH change[5]				
d 0 to 14	0.211	0.326	0.087	0.17
d 15 to 28	0.500	0.416	0.035	0.02
d 29 to 42	-0.001	-0.013	0.065	0.90
d 43 to 56	0.140	0.019	0.057	0.16
d 57 to 84	0.033	0.043	0.061	0.86
d 85 to 112	-0.351	-0.254	0.058	0.27
d 113 to 140	0.299	0.125	0.067	0.08
Beta-agonist to final	-0.050	-0.158	0.061	0.02
d 140 to final	-0.298	-0.254	0.050	0.49
d 0 to final	0.533	0.408	0.084	0.15

[1]Treatments included (DM basis): CON = 7.73% hay, 15.00% dry distillers grains plus solubles, 65.52% dry-rolled corn, 6.00% liquid supplement, or CTN = 15.00% whole cottonseed, 73.25% dry-rolled corn, 6.00% molasses. Both diets contained 5.00% dry supplement and 0.75% urea

[2]*n* = 6 pens, per treatment; 3 pens of heifers and 3 pens of steers per treatment

[3]Cattle were harvested in 3 groups; d 178 (*n* = 4 pens total; 2 pens per treatment; 1 pen heifers and 1 pen steers per treatment), d 206 (*n* = 4 pens total; 2 pens per treatment; 1 pen heifers and 1 pen steers per treatment), and d 227 (*n* = 4 pens total; 2 pens per treatment; 1 pen heifers and 1 pen steers per treatment). Fecal pH were obtained the day the pens started Ractopamine hydrochloride (Optaflexx 45; Elanco Animal Health, Greenfield, IL; 31 d prior to harvest)

[4]Final fecal pH were taken the day of shipping for harvest
[5]Change in collection is the difference between collection periods; subtract a later collection period from an earlier collection period

Table 10. Effects of using whole cottonseed in place of dried distillers grains plus solubles and prairie hay in finishing rations balanced for physically effective neutral detergent fiber on plasma metabolite concentrations of feedlot heifers and steers

Variables	Treatment[1]		SEM[2]	*P*-Value	Days on feed											
	CON	CTN			0	14	28	42	56	84	112	140	Beta-agonist[3]	Final[4]	SEM[2]	*P*-Value
Glucose, mg/dL	92.7	86.1	4.72	0.24	91.5^{b}	99.6^{a}	97.8^{a}	87.1^{bc}	82.1^{c}	82.8^{c}	84.1^{c}	87.3^{bc}	90.5^{b}	91.1^{b}	7.12	<0.0001
Lactate, g/L	0.47	0.35	0.049	0.06	0.49^{ac}	0.54^{a}	0.43^{bcd}	0.34^{ef}	0.31^{f}	0.38^{de}	0.43^{bd}	0.35^{ef}	0.49^{ab}	0.37^{def}	0.06	<0.0001
Plasma urea nitrogen, mmol/L	1.46	1.24	0.036	<0.001	0.75^{d}	1.05^{c}	1.04^{c}	1.09^{c}	1.82^{a}	2.03^{a}	1.32^{b}	1.53^{b}	1.42^{b}	1.45^{b}	0.10	<0.0001
Non-esterified fatty acids, µEq/L	223.9	215.5	16.7	0.72	671.6^{a}	183.7^{cd}	140.7^{ef}	155.6^{de}	129.5^{f}	130.2^{f}	245.3^{b}	180.0^{c}	186.3^{c}	174.4^{cd}	38.0	<0.0001

[1]Treatments included (DM basis); CON = 7.73% hay, 15.00% dry distillers grains plus solubles, 65.52% dry-rolled corn, 6.00% liquid supplement, or CTN = 15.00% whole cottonseed, 73.25% dry-rolled corn, 6.00% molasses. Both rations contained 5.00% dry supplement and 0.75% urea

[2]*n* = 6 pens per treatment; 3 pens of heifers and 3 pens of steers per treatment

[3]Beta-agonist plasma was obtained the day the pens started Ractopamine hydrochloride (Optaflexx 45; Elanco Animal Health, Greenfield, IL; 31 d prior to harvest)

[4]Cattle were harvested in 3 groups; d 178 (*n* = 4 pens total; 2 pens per treatment; 1 pen heifers and 1 pen steers per treatment), d 206 (*n* = 4 pens total; 2 pens per treatment; 1 pen heifers and 1 pen steers per treatment), and d 227 (*n* = 4 pens total; 2 pens per treatment; 1 pen heifers and 1 pen steers per treatment)

[a, b, c, d, e, f] Values within row with unlike subscripts differ ($P \leq 0.05$)

Table 11. Influence of using whole cottonseed in place of dried distillers grains plus solubles and prairie hay in finishing rations balanced for physically effective neutral detergent fiber on carcass characteristics of feedlot heifers and steers

	Treatment[1]			
Item	CON	CTN	SEM[2]	*P*-Value
Hot carcass weight, kg	399	416	12.2	0.02
Ribeye area, cm^2	91.6	90.7	2.28	0.67
Fat thickness[3], cm	1.77	1.91	0.108	0.05
Dressing percentage	64.6	64.6	0.49	0.88
Calculated USDA Yield Grade	3.51	3.83	0.218	0.001
Marbling score[4]	480	477	20.1	0.84

[1]Treatments included (DM basis); CON = 7.73% hay, 15.00% dry distillers grains plus solubles, 65.52% dry-rolled corn, 6.00% liquid supplement, or CTN = 15.00% whole cottonseed, 73.25% dry-rolled corn, 6.00% molasses. Both rations contained 5.00% dry supplement and 0.75% urea

[2]*n* = 6 pens per treatment; 3 pens of heifers and 3 pens of steers per treatment

[3]Fat measurement taken between the 12^{th} and 13^{th} ribs

[4]$Small^{00}$ = 400; $Modest^{00}$ = 500; $Moderate^{00}$ = 600

CHAPTER III

SHORT COMMUNICATION: EFFECT OF WHOLE COTTONSEED INCLUSION IN FINISHING CATTLE DIETS BALANCED FOR PHYSICALLY EFFECTIVE NEUTRAL DETERGENT FIBER ON RUMINAL METABOLISM

K. N. Schneid*, A. P. Foote*, P. A. Beck*, and B. K. Wilson*

*Department of Animal and Food Sciences, Oklahoma State University, Stillwater 74078

ABSTRACT

Objective: The objective of this experiment was to determine the effects of replacing dried distillers grains plus solubles (DDGS) and prairie with whole cottonseed (WCS) in diets balanced for physically effective neutral detergent fiber (peNDF) on rumen fluid pH, lactate, and volatile fatty acid (VFA) concentrations and proportions.

Materials and Methods: Four ruminally cannulated Holstein steers were randomly assigned to 1 of 2 experimental treatments. Treatments included a control diet (CON; prairie hay, DDGS, dry-rolled corn, and liquid supplement) and a whole cottonseed diet (CTN; WCS, dry-rolled corn, and molasses). A vitamin and mineral supplement and urea were included in both diets at the same concentration. After 25 d on the treatment diets, rumen fluid was collected during a 12 h time period with collections

occurring every 2 h. Rumen fluid samples were immediately analyzed for pH before being frozen in 2 mL aliquots at -20°C for later analysis of rumen fluid lactate and VFA concentrations and proportions.

Results and Discussion: A treatment × time interaction was present for rumen fluid lactate ($P < 0.001$), with steers on the CON treatment having a greater concentration at h 2 post feeding. No treatment × time interactions ($P \geq 0.22$) were present for rumen fluid pH or any VFA proportions. Rumen fluid pH was effected by time ($P = 0.02$), but not treatment ($P = 0.98$). The most neutral pH was reported at h 2 post feeding and the most acidic pH was reported at h 8 post feeding. Acetate:propionate, butyrate, and valerate proportions were greater ($P \leq 0.04$) and acetate proportions tended to be greater ($P = 0.06$) for steers fed the CON treatment. Steers fed the CTN treatment had greater propionate proportions ($P = 0.03$). No treatment effect was reported for isobutyrate or isovalerate ($P \geq 0.35$). No time effect was present for any of the VFA proportions ($P \geq 0.12$).

Implications and Applications: This experiment suggests that WCS can replace the roughage and byproduct protein and fat source within a finishing diet while maintaining an acceptable rumen pH and lactate concentrations as well as creating a more efficient ruminal environment through shifts in VFA proportions in cattle fed a finishing ration balanced for peNDF.

Key words: byproducts, cotton, feedlot, rumen fluid, volatile fatty acids

INTRODUCTION

Supplies of dried distillers grains plus solubles (DDGS) vary over time due to changing demand for the primary production of ethanol. With varying prices and availability of DDGS, whole cottonseed (WCS) could potentially be a viable alternative to DDGS as well as other commonly used byproducts and roughages in finishing rations in the southern United States. Cotton production is predicted to result in 3.6 million tonnes of WCS being available to livestock producers in the United State in 2022 (Meyer, 2022; Cotton Incorporated, 2022). The ability of WCS to provide protein, fat, and fiber within cattle diets has resulted in increased interest in the commodity from cattle feeders.

Recently Schneid et al. (2022) reported that WCS could replace both the roughage (prairie hay) and byproduct energy and protein source (DDGS) in finishing rations balanced for physically effective neutral detergent fiber (peNDF) while increasing overall ADG and G:F. The authors reported that steers fed the WCS diet also had greater hot carcass weight (HCW) and fat thickness, resulting in a greater USDA YG. However, it is unclear how the replacement of prairie hay and DDGS with WCS would impact rumen pH, lactate, and volatile fatty acid (VFA) concentrations and proportions.

Determining the ruminal characteristics when using WCS as the principle roughage source within a finishing feedlot diet could help explain the results from previous animal performance experiments. Therefore, the objective of this experiment was to determine the effect of using WCS to replace prairie hay and DDGS in finishing rations balanced for peNDF had on rumen fluid pH, lactate, and volatile fatty acid (VFA) concentrations and proportions.

MATERIALS AND METHODS

All procedures were approved by the Institutional Animal Care and Use Committee at Oklahoma State University (Animal Care and Use Protocol Number: AG-19-77).

Cattle and Diets

Four ruminally cannulated Holstein steers were housed at the Oklahoma State University Willard Sparks Beef Research Center (WSBRC) located in Stillwater, OK. Steers were housed in two 6.10 × 10.9 m partially covered dry lot pens with a shared 76-L concrete water tank between the 2 adjacent pens (model J 360-F; Johnson Concrete, Hastings, NE).

Steers were randomly allocated to 1 of 2 experimental treatments. Treatments consisted of a control diet (CON): prairie hay, DDGS, dry-rolled corn, liquid supplement, and a WCS diet (CTN): WCS, dry-rolled corn, molasses (Table 1). Both diets contained a dry vitamin and mineral supplement that contained all feed additives and urea at the same concentration. Feeding occurred once daily at 0800 h. Daily evaluations of the bunk were used to maintain ad libitum access (targeting orts ≥ 4.54 kg) to feed throughout the experiment.

Steers were transitioned to experimental diets over 10 d using a 2-ration blending method with a 10% diet transition per d. Due to smaller amount of experimental diet initially being offered, the treatment diets were top-dressed on to the common ration and then hand mixed in until d 5. After d 5, the common ration would then be top-dressed on the treatment diets and then hand mixed in until d 10. This process was the same for both

treatments. After fully transitioning onto the respective dietary treatment the cattle remained on treatment diets for 25 d before rumen fluid collections occurred.

Collection

Rumen fluid collections occurred for 12 h. The steers were haltered and tied at 0645 h. Sampling began at 0700 h (h 0) and continued until 1900 h (h 12) with collection occurring every 2 h (0, 2, 4, 6, 8, 10, and 12 h). Following the h 0 rumen fluid collection, the respective treatment diets were offered to the steers within the designated bunks. After each collection, steers were unhaltered and allowed free movement with access to the pen and bunk. Before each subsequent collection, steers were re-haltered and tied approximately 15 min prior to the start of the collection.

Rumen fluid was collected using a 0.297 mm screen (Rumen Fluid Sampler Tube; Bar Diamond, Parma ID) attached to a 101 cm extension set and a 60 mL syringe. All rumen fluid samples were taken from the cranial or ventral sacs within the rumen. A total of 50 mL of rumen fluid was collected at each sampling period. After the rumen fluid was extracted rumen pH was immediately analyzed using Accumet AE150 benchtop pH meter (Thermo Fisher; Waltham, MA) before being separated into 4 micro-centrifuge tubes and frozen at -20°C for subsequent analysis of rumen fluid lactate and VFA.

Rumen fluid lactate concentrations were analyzed by centrifuging samples at 21,000 × g for 15 min at 4˚C (Sorvall Legend Microcentrifuge; Thermo Scientific, Hampton, NH) before the supernatant was analyzed (immobilized enzyme system; YSI Model 2950 D; YSI Inc., Yellowspring, OH). Rumen fluid VFA concentrations and proportions were analyzed by gas chromatography mass spectrometry using dimethyl

carbonate extraction as described by Foote (2022). Briefly, rumen fluid acidified using potassium bisulfate (Acros Organics from Fisher Scientific; Chicago, IL) and dimethyl carbonate was used as the organic solvent (99%; Acros Organics). Samples were then analyzed using an Agilent 5977B gas chromatography mass spectrometry (Agilent Technology, Inc; Santa Clara, CA) system with a liquid sampling system and single quadrupole mass spectrometry detector.

Statistical Analysis

Rumen fluid pH, lactate, and VFA were analyzed using a MIXED procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). The fixed effects within the model were treatment, time, and the interaction (treatment × time), and individual animal was the subject. The appropriate covariance structure was determined by comparing Akaike's Information Criteria (AIC). The compound symmetry covariance structure provided the best fit for rumen pH data, while the variance components covariance structure was determined to be the best fit for rumen VFA data, and the heterogenous autoregression 1 was determined to be the best fit for lactate. Significance was declared when $P \leq 0.05$ and tendencies were considered when $P > 0.05$ and $P \leq 0.10$.

RESULTS AND DISCUSSION

Rumen Fluid pH

There was no treatment × time interaction (Table 2; $P = 0.22$) or treatment effect ($P = 0.98$) present for rumen fluid pH, but there was a time effect ($P = 0.02$). The most neutral rumen pH (pH = 5.98) was collected at h 4 post feeding, while the most acidic rumen pH (pH = 5.61) was collected at h 8 post feeding. During the 12 h collection

period, at no point did the rumen pH become low enough to be considered in an acidotic state (pH ≤ 5.5; Garrett et al., 1999). Over the course of the collection period, rumen pH ranged between 5.61 and 5.98 which was within the expected range of pH of 5.6 to 6.2 for feedlot cattle consuming a high concentrate diet (Schwartskopf-Genswein, 2003).

Warner et al. (2020b) conducted an experiment using 6 cannulated crossbred beef steers and compared a standard finishing diet containing dry-rolled corn, Sweet Bran, and prairie hay to a cotton byproduct treatment containing dry-rolled corn, whole cottonseed, and gin trash. Warner et al. (2020b) observed similar fluctuations in rumen pH to the current experiment with an increase at h 4 (pH = 5.94) post feeding followed by a decrease at h 6 (pH = 5.87), and again on h 12 (pH = 5.82; Table 2). Robles et al. (2007) also reported lower rumen pH at h 12 post feeding heifers on a high concentrate diet. Although h 12 was not the lowest value reported in the current experiment, the pH at h 12 post feeding was the second lowest overall and lower than the initial rumen pH at h 0. While there were some differences among h, it should again be noted the pH for each h remained within the normal range for feedlot cattle reported by Schwartzkopf-Genswein et al. (2003).

Rumen Fluid Lactate

A treatment × time interaction was present for rumen fluid lactate (Figure 1; $P < 0.001$). Rumen fluid lactate concentrations are correlated to feed intake as well as diet fermentability (Counotte and Prins, 1981). The increase in ruminal lactate concentrations for the cattle fed the CON treatment from h 0 to h 2 is therefore expected as cattle were initially offered feed after h 0 collection. Generally, lactate concentrations for both diets increased from h 0 to h 2, however the cattle fed the CON treatment increased in

concentrations at a much greater rate. After h 2 post feeding, lactate concentration for the cattle fed the CON treatment continued to decrease until h 8, before gradually increasing until h 12, whereas the CTN treatment gradually increased from h 4 until h 12.

Rumen Fluid VFA Proportions

There was not a treatment × time interaction present for any VFA ($P \geq 0.81$), nor was there a time effect for any VFA ($P \geq 0.12$). Treatment effects were observed for acetate:propionate, butyrate, and valerate (Table 3), where the cattle fed the CON treatment had greater proportions of each ($P \leq 0.04$) and had a tendency for a greater proportion of acetate ($P = 0.06$). The cattle fed the CTN treatment had a greater proportion of propionate ($P = 0.03$). No treatment effects were observed for total VFA concentrations, isobutyrate proportions, or isovalerate proportions ($P \geq 0.35$).

The lack of a time effect for VFA is likely due to animals being fed ad libitum prior to the start of collections and after h 0 collection. Total VFA concentrations were 99.6 mM for the cattle fed the CON treatment and 98.8 mM for the cattle fed the CTN treatment, which were within the expected range for cattle consuming a high concentrate ration (70 to 130 mM; NASEM, 2016). The increased propionate proportion observed in the cattle consuming the CTN treatment would be at the expense of acetate and could potentially be due to the CTN diet having a greater level of starch from the greater inclusion of dry-rolled corn and decreased neutral detergent fiber (NDF; Rumsey et al., 1970). As the CTN treatment diet contained potentially more starch and less NDF than the CON treatment, the acetate:propionate or acetate and propionate proportions in the cattle fed the CTN treatment were not unexpected (Rumsey et al., 1970). Warner et al. (2020b) reported that cattle consuming a cotton byproduct finishing ration had increased

acetate:propionate and acetate proportions and decreased propionate and butyrate proportions. The authors suggested that the shift in VFA was due to the cotton byproduct treatment having a greater peNDF. However, the cotton byproduct treatment also was reported to have a greater NDF in their experiment. With the current experimental treatments balancing the roughage and byproducts ingredients for peNDF, and the CON treatment having greater NDF, the shifts in acetate and propionate are most likely due to the greater percentage of NDF rather than peNDF (Arieli, 1997). Warner et al. (2020b) and the current experiment both reported cattle fed WCS having a decreased proportion of butyrate. The decrease in butyrate and valerate proportions when feeding WCS was likely due to decreased number of protozoa caused by the increased levels of protected lipids in WCS (Keele et al. 1989).

Although the shifts in acetate and propionate proportions were not unexpected due to the nutrient components of the treatment diets, when comparing the results of the VFA proportions from the current experiment to the animal performance results of previous finishing trials feeding the same or similar diets, the results conflict somewhat with the reported carcass characteristics. With butyrate and acetate being positively correlated with fat thickness (Bulumulla et al., 2018), the decreased proportion of butyrate and tendency for a decreased proportion of acetate for cattle fed the CTN treatment does not support the carcass results reported by Schneid et al. (2022) or Warner et al. (2020a). Both Schneid et al. (2022) and Warner et al. (2020a) reported a greater fat thickness for animals fed a finishing ration containing WCS. Although the butyrate and acetate proportions do not support the reported fat thickness observed in these previous trials, the decreased proportions of acetate, butyrate, and valerate, and a greater

proportion of propionate in the cattle fed the CTN treatment could help explain the greater ADG and G:F reported by Schneid et al. (2022) in finishing cattle consuming the same diets.

APPLICATION

The objective of this experiment was to determine the effects of replacing DDGS and prairie hay with WCS in diets balanced for peNDF on rumen fluid pH and lactate concentrations, as well as ruminal VFA proportions. Animals consuming the CTN treatment maintained normal rumen fluid pH and lactate concentrations, and had greater propionate proportions but had decreased acetate:propionate, butyrate, valerate proportions and a tendency for decreased acetate proportions. Overall, these results suggest that WCS can serve as an effective replacement for DDGS and prairie hay in finishing diets balanced for peNDF as the sole roughage, byproduct protein, and major fat source while maintaining an acceptable rumen environment and potentially creating a more efficient utilization of energy through increased propionate proportions.

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Table 1. Ingredients analyzed nutrient composition of experimental treatment finishing diets

	Diet	
Ingredient, % of DM	CON[1]	CTN[2]
Dry-rolled corn	65.52	73.25
Dried distillers grains	15.00	-[3]
Prairie hay	7.73	-
Whole cottonseed	-	15.00
Liquid supplement[4]	6.00	-
Dry supplement[5]	5.00	5.00
Molasses	-	6.00
Urea	0.75	0.75
Nutrient composition, DM basis		
Dry matter, %	81.48	83.98
Crude protein[6], %	15.45	15.65
Neutral detergent fiber, %	21.20	17.75
Acid detergent fiber, %	7.55	13.15
peNDF[7], %	8.07	8.07
TDN[8], %	77.63	76.93
Fat, %	2.66	3.46
NEm[9], Mcal/kg	1.67	1.65
NEg[9], Mcal/kg	1.06	1.04
Ca[6], %	0.60	0.49
P[6], %	0.48	0.42
Mg[6], %	0.21	0.23
K[6], %	0.88	0.86

[1]Contol diet (CON); representative of a typical feedlot diet

[2]Whole Cottonseed diet (CTN); whole cottonseed is used as the primary fiber source in the diet

[3]A missing value under ingredient indicate there was 0.00% of that ingredient included in that step

[4]Liquid supplement is formulated to contain (% DM basis) 45.86% corn steep, 36.17% cane molasses, 6.00% hydrolyzed vegetable oil, 5.46% 80/20 vegetable oil blend, 5.20% water, 1.23% urea (55% solution), and 0.10% xanthan gum

[5]Dry supplement is formulated to contain (% DM basis) 40.0% ground corn, 29.6% limestone, 20.0% wheat middlings, 7.0% urea, 1.0% salt, 0.53% magnesium oxide, 0.51% zinc sulfate, 0.17% manganese oxide, 0.13% copper sulfate, 0.08% selenium premix (0.6%), 0.0037% cobalt carbonate, 0.32% vitamin A (30,000 IU/g), 0.20% tylosin (Tylan-40, Elanco Animal Health, Greenfield IN) and 0.33% monensin (Rumensin-90; Elanco Animal Health)

[6]Analyzed by ServiTech Laboratories, Dodge City, KS

[7]Physically effective neutral detergent fiber provided by the roughage and byproducts in the diet

[8]Calculated according to Weiss et al. (1992).

[9]Calculated according to NASEM (2016).

Table 2. Effects of using whole cottonseed in place of dried distillers grains plus solubles and prairie hay in finishing rations balanced for physically effective neutral detergent fiber on rumen pH of cannulated Holstein steers

	Treatments[1]				Time[3]								
Variable	CON	CTN	SEM[2]	*P*-value	0	2	4	6	8	10	12	SEM[2]	*P*-value
pH	5.80	5.81	0.223	0.98	5.81^{abc}	5.91^{a}	5.98^{a}	5.85^{ab}	5.61^{c}	5.82^{abc}	5.67^{bc}	0.169	0.02

[1]Treatments included (DM basis); CON = 7.73% hay, 15.00% dry distillers grains plus solubles, 65.52% dry-rolled corn, 6.00% liquid supplement, or CTN = 15.00% whole cottonseed, 73.25% dry-rolled corn, 6.00% molasses. Both rations contained 5.00% dry supplement and 0.75% urea

[2]n = 2 animals per treatment

[3]Time refers to h post-feeding

[a, b, c] Values within row with unlike subscripts differ ($P \leq 0.05$)

Table 3. Effects of using whole cottonseed in place of dried distillers grains plus solubles and prairie hay in finishing rations balanced for physically effective neutral detergent fiber on rumen volatile fatty acid (VFA) total concentrations and molar proportions of cannulated Holstein steers

	Treatments[1]			
VFA	CON	CTN	SEM[2]	*P*-value
Total, mM	99.5	98.8	7.31	0.94
Proportion, mol/100 mol				
Acetate:Propionate	2.63	1.57	0.328	0.04
Acetate	0.560	0.489	0.0253	0.06
Propionate	0.241	0.358	0.0344	0.03
Butyrate	0.166	0.126	0.0098	0.01
Isobutyrate	0.0067	0.0075	0.00057	0.35
Valerate	0.0188	0.0141	0.00089	0.002
Isovalerate	0.0070	0.0069	0.00057	0.95

[1]Treatments included (DM basis); CON = 7.73% hay, 15.00% dry distillers grains plus solubles, 65.52% dry-rolled corn, 6.00% liquid supplement, or CTN = 15.00% whole cottonseed, 73.25% dry-rolled corn, 6.00% molasses. Both rations contained 5.00% dry supplement and 0.75% urea

[2]No treatment × time interaction was observed for any VFA ($P \geq 0.81$)

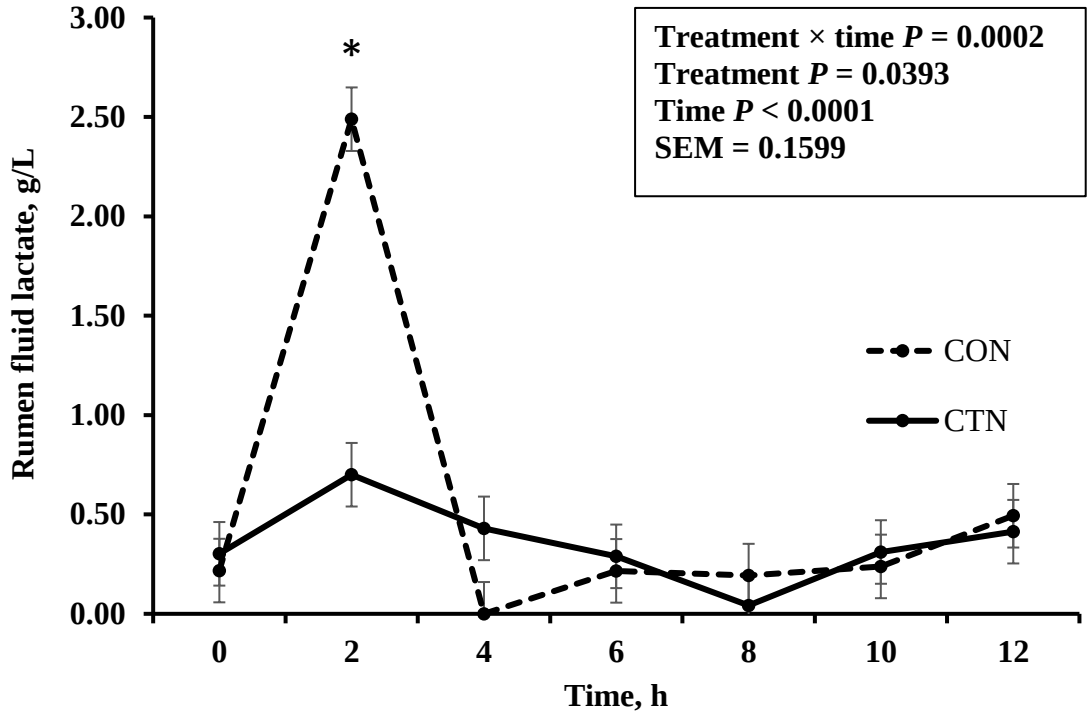

Figure 1: Concentration of rumen fluid lactate in rumen cannulated holstein steers consuming a CON treatment (7.73% hay, 15.00% dry distillers grains plus solubles, 65.52% dry-rolled corn, 6.00% liquid supplement) or CTN treatment (15.00% whole cottonseed, 73.25% dry-rolled corn, 6.00% molasses). A * represents a significant difference between treatments at $P \leq 0.05$.

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VITA

Kasi Nicole Schneid

Candidate for the Degree of

Master of Science

Thesis: USING WHOLE COTTONSEED TO REPLACE DRIED DISTILLERS GRAINS PLUS SOLUBLES AND PRAIRIE HAY IN FINISHING BEEF CATTLE RATIONS BALANCED FOR PHYSICALLY EFFECTIVE NEUTRAL DETERGENT FIBER

Major Field: Animal Science

Biographical:

Education:

Completed the requirements for the Master of Science in Animal Science at Oklahoma State University, Stillwater, Oklahoma in July, 2022.

Completed the requirements for the Master of Science in Safety, Security and Emergency Management at Eastern Kentucky University, Richmond, Kentucky in March, 2022.

Completed the requirements for the Bachelor of Science in Agriculture Pre-Veterinary at Eastern Kentucky University, Richmond, Kentucky in 2020.

Experience:

Graduate Research and Teaching Assistant at Oklahoma State University (August 2020 – May 2022)

Professional Memberships:

American Society of Animal Science, Southern Section of American Society of Animal Science, The Plains Nutrition Council