UTILIZATION OF COTTON BYPRODUCTS IN CATTLE FINISHING DIETS: IMPACTS ON PERFORMANCE, CARCASS TRAITS, AND RUMINAL DEGRADABILITY OF DIET COMPONENTS

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Abstract: Two experiments were conducted to evaluate the inclusion of cotton byproducts in feedlot finishing diets on the performance and carcass traits of steers and to evaluate the in situ ruminal degradability of the individual diet components and treatment diets. In experiment 1, crossbred beef steers (n = 64; BW = 318 ± 12.3 kg) were assigned to 1 of 2 experimental treatments in a randomized complete block design (8 pens/treatment; 4 steers/pen). Treatments included a control diet (CON; prairie hay (PH), Sweet Bran, dry-rolled corn, and a liquid fat supplement), and a cotton byproduct diet (CTN; cotton gin trash (CGT), whole cottonseed, dry-rolled corn, and water). Both contained urea and a vitamin and mineral supplement. Over the entire feeding period, DMI (P = 0.04), and ADG (P = 0.08) was greater for CTN steers than CON steers with no difference in G:F (P = 0.86). The CTN steers tended to have heavier final BW (P = 0.09) and had a heavier hot carcass weight (P = 0.02), and greater fat thickness (P = 0.03) than CON steers. The CON steers tended to have a lower USDA Yield Grade (P = 0.07), less KPH (P = 0.09), and decreased dressing percentage (P = 0.10) than CTN steers. In experiment 2, six ruminally cannulated steers were used in a crossover design. In-situ bags containing individual ingredients and whole diet samples were incubated in the rumen for up to 96 h in steers consuming the same diets as experiment 1. The A, B, and C fractions, Kd and effective degradability of DM and OM were not different between CON and CTN substrates ($P \geq 0.25$). No differences ($P \geq 0.37$) were detected for the % NDF disappearance at 48 h between CON and CTN substrates. When the CON substrate was incubated in steers consuming the CON diet, effective degradability of starch was not different (P = 0.84) from when the CTN diet was incubated in steers consuming the CTN diet. These experiments suggests that cotton byproducts can be utilized in finishing diets of beef cattle with no adverse effects on performance or digestibility.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

CHAPTER I

REVIEW OF LITERATURE

Introduction

While cotton production has always been predominant in the Southwestern United States, production has been steadily increasing in the region in recent years (USDA, 2018). It is estimated that the United States is currently producing approximately 24.7 million bales of cotton (Meyer, 2020), and production is continuing to increase as the acres of cotton planted in the Southwest in 2020 increased by 4% compared to the acres of cotton planted in 2019 (Meyer, 2020). While the primary product of cotton ginning is the fiber itself, the process also yields a variety of byproducts including whole cottonseed, cotton gin trash, cottonseed meal, cottonseed hulls, and cottonseed oil. In addition to producing over 45% of the United States cotton crop (USDA, 2019), the Southern Great Plains region of Texas and Oklahoma contain a large number of cattle feedlots. The various byproducts produced from cotton ginning have nutritive value and therefore the potential to be included in cattle diets as alternative sources of protein, fat, and fiber (Rogers et al., 2002). There is also potential for cotton byproducts to be less expensive than traditional sources of protein, fat, and fiber in finishing diets if producers are in proximity to a gin. As a waste product, cotton gin trash is often of no cost to

purchase aside from the costs associated with transportation and hauling (Meyer, 2007).

Although cotton byproducts have the potential to provide protein, fat, and fiber to cattle diets, there are a few limitations associated with the use of cotton byproducts. Because gin trash can be bulky, transportation costs often limit the use to producers in a cotton growing region unless pelleted or cubed (Lalor et al., 1975). While gin trash is often economical, whole cottonseed can be expensive compared to other protein byproducts and may have competition as a feedstuff with the dairy industry as more dairy operations move into the Southwestern region of the United States. However, the financial concerns relating to whole cottonseed may be offset by the increased nutritional value compared to other traditional ingredients.

Feeding Value of Cotton Byproducts

Gin trash has a nutritive value that is comparable to other commonly used roughage sources in feedlot diets. The reported nutrient values for gin trash are 90.9% dry matter (DM), 12.1% ash, 48.5% total digestible nutrients (TDN), 3.6% fat, 60.9% neutral detergent fiber (NDF), and 8.7% crude protein (CP; NASEM, 2016). Although NASEM (2016) provides average nutrient values for gin trash, it is important that producers who plan to utilize gin trash analyze the specific batch of gin trash to be fed prior to formulating rations. The composition of gin trash can be highly variable in protein and ash content depending on the region in which it is grown and how it is harvested (Kennedy and Rankins, 2008). A review by Rogers et al. (2002) reported that protein content of gin trash can range from 7.4 to 16.6% and ash content can range from 5.9 to 20.9%. The protein content of gin trash varies depending upon how much immature cottonseed is left in the gin trash relative to other components lower in protein content

such as soil and stems (Lalor et al., 1975). Additionally, the weather conditions during growing and harvesting season can affect the CP content (Lalor et al., 1975). Although the nutritive value of gin trash is considered to be of low to moderate quality, gin trash is of greater fat and protein content than that of native prairie hay (88.0% DM, 10.3% ash, 48.4% TDN, 1.8% fat, 66.6% NDF, and 6.8% CP; NASEM 2016), which is commonly used as a low to medium quality roughage in feedlot diets. When fed at a rate of less than 10% of DM in a finishing diet, the low nutritive value of gin trash is of minimal concern, as the other 90% of ingredients can satisfy nutrient requirements (Lalor et al., 1975).

In feedlot diets, roughage is included in small amounts to maintain rumen health and function. The term physically effective fiber (peNDF) specifically relates to the particle size of the feed and the ability of a feed to stimulate chewing activity (Mertens, 1997). Large forage particles are important to increase chewing time during eating and rumination which increases saliva production and rumen pH, which aides in preventing disorders such as acidosis (Mertens, 1997). Fiber sources with a larger particle sizes help to maintain a fiber mat in the rumen which allows feed retention time to increase, ultimately increasing digestion of feed in the rumen (Parish, 2008). In addition to rumen health, Galyean and Hubert (2014) reported that increasing peNDF in high-grain diets can increase dry matter intake (DMI). Gin trash has similar peNDF values to native prairie hay (58.5% vs 56.3% of DM, respectively; Warner et al., 2020) and therefore has the potential to serve as the primary source of roughage in a feedlot diet.

Whole cottonseed is a unique feedstuff, as whole cottonseed is high in fat and protein, but also provides a considerable amount of fiber to the diet. The composition of whole cottonseed is 92.6% DM, 4.1% ash, 93.0% TDN, 19.5% fat, 47.8% NDF, and

22.9% CP (NASEM, 2016). Although whole cottonseed is similar in protein content compared to a corn byproduct such as wet corn gluten feed (23.8%; NASEM, 2016), whole cottonseed has a greater peNDF value than Sweet Bran, a branded wet corn gluten feed product (39.2 vs 31.5% of DM; Warner et al., 2020) and may decrease the need for traditional roughages in a finishing diet. While whole cottonseed can contribute significant amounts of protein, fat, and fiber to a diet, research has suggested that whole cottonseed is not be included at more than 15% of the dietary DM in a feedlot diet (Preston and Bartle, 1989). Including whole cottonseed above the maximum recommended levels could increase fat levels in the diet to a level that results in a reduction in fiber digestion (Stewart and Rossi, 2010). Moore et al. (1986) included whole cottonseed at 30% of diet DM in a predominantly wheat straw diet and reported that digestion of acid detergent fiber was depressed by approximately 5% while dry matter intake (DMI) was reduced by 16.5 g per kg of body weight (BW) compared to steers fed a diet consisting of wheat straw, cottonseed hulls, and cottonseed meal. In addition, including fat at increased levels in the diet can depress feed intake, resulting in decreased growth performance of cattle. Feedlot steers consuming diets containing tallow at the rate of 3, 6, and 9 % of diet DM linearly decreased DMI, ADG, and F:G (Zinn and Plascencia, 2004).

Impacts of Cotton Byproducts on Production and Carcass Traits

Production

In a series of experiments, Cranston et al. (2006) determined the effects of feeding whole cottonseed and cottonseed meal on the performance of finishing beef cattle. The first experiment in this series replaced a portion of steam flaked corn and all of the

cottonseed meal in a control diet with whole cottonseed (15.1% of diet DM). Although final BW was not affected, steers consuming the diet containing whole cottonseed consumed more feed over the duration of the study (8.70 vs 8.11 kg/d) compared to the control. Cranston et al. (2006) suggested that these observed differences were a function of the variation between the NDF and energy concentration between the diets, as the NDF in the whole cottonseed diet was approximately 12% greater than the NDF in the control diet. This suggestion is based on the work of Galyean and Defoor (2003) which concluded that the amounts of NDF and effective NDF provided by the roughage can influence the DMI of cattle consuming finishing diets. While DMI was increased for steers consuming the whole cottonseed diet, Cranston et al. (2006) reported that ADG was similar between diets. As a result of increased DMI and similar ADG for steers consuming the cotton diet, the observed gain:feed was greater for steers consuming the control diet.

In experiment 2, Cranston et al. (2006) replaced cottonseed meal, alfalfa hay, cottonseed hulls, and tallow in the control diet with whole cottonseed (15.36% of diet DM). The diet containing whole cottonseed was formulated to contain a similar amount of NDF as the control diet in this experiment. Similar to experiment 1, final BW and ADG were not affected by diet. In contrast with experiment 1, steers consuming the control diet consumed more feed that those fed the cottonseed diet (8.46 vs 8.00 kg/d), which was likely a function of the similar NDF between diets combined with the decreased energy content of the control diet.

When considering gin trash as a roughage source for finishing beef cattle, Erwin and Roubieck (1958), reported that gin trash can be included with hegari sorghum silage

at up to a 60:40 ratio with no adverse effects on ADG. However, when gin trash was included as 80 or 100% of the roughage in a finishing diet, steers had decreased ADG compared to steers consuming a maximum of 60% of the roughage as gin trash. Jones et al. (1957) also evaluated gin trash as a roughage source for finishing steers comparing equal parts gin trash and ground alfalfa hay to equal parts cottonseed hulls and ground alfalfa hay as the roughage component in a ground sorghum-based concentrate diet. The steers consuming the cottonseed hulls and ground alfalfa hay treatment had small advantages in ADG and hot carcass weight (HCW) compared to those consuming gin trash and ground alfalfa hay (Jones et al., 1957). However, these slight differences could be offset if the cost of gin trash was less than the cost of cottonseed hulls (Jones et al., 1957).

Gin trash has also been evaluated as a supplement for beef cows and stocker cattle. Hill et al. (2000) fed gin trash ad libitum to dry lot beef cows with or without 1.4 kg of corn supplement per day. After an adaptation period for cows to adjust to the palatability of gin trash, cows consumed an average of 14.5 kg of gin trash per day. However, cows consuming only gin trash lost weight over the course of the experiment, while corn-supplemented cows maintained condition (Hill et al., 2000). Kennedy and Rankins (2008) included either peanut hulls or gin trash at 45% of the total supplement with 55% cracked corn to stocker cattle consuming bermudagrass hay. Steers consuming the gin trash supplement had an increased DMI of 3.4 kg per day and gained approximately 0.25 kg per day more than steers consuming the peanut hull supplement (Kennedy and Rankins, 2008).

Carcass Traits

Conflicting results have been reported on the effects of including cotton byproducts in the finishing diet of beef cattle on carcass traits. Cranston et al. (2006) reported no differences in HCW or rib eye area (REA) between steers consuming the cottonseed diet and steers consuming the control diet in the first experiment. However, it was reported that steers fed the control diet had an increased dressing percentage compared to those fed the cottonseed diet. Additionally, Cranston et al. (2006) reported that steers fed the control diet had fatter carcasses than those consuming the cotton diet, as demonstrated by a greater marbling score and numerically greater kidney, pelvic, and heart fat. In experiment 2, Cranston et al. (2006) reported that no differences were observed for any measured carcass traits when finishing cattle were fed diets that contained whole cottonseed.

Huerta-Leidenz et al. (1990) conducted an experiment in which whole cottonseed was fed at a rate of 15% of diet DM in the diet, to replace a small amount of corn, cottonseed meal, and cottonseed hulls in the diet. When whole cottonseed was included in the diet at 15%, no differences in carcass traits were reported when compared to the carcasses of steers consuming the control diet. However, when whole cottonseed was increased to 30% of diet DM, HCW, and REA decreased while yield grade increased compared to the control (Huerta-Leidenz et al., 1991). Preston and Bartle (1989) also reported that HCW decreased when whole cottonseed was fed above 15% of DM. However, the authors reported no differences in dressing percentage or quality grade factors (Preston and Bartle,1989).

Similar results have been reported in growing and finishing lambs consuming cotton byproducts. Kandylis et al. (1998) conducted an experiment to determine the

effects of feeding whole cottonseed between 5% and 30% of diet DM in a corn-based diet on carcass composition of finishing lambs. Results suggested that there were no differences in harvest weights, HCW, or dressing percentage between lambs fed a control diet (0% whole cottonseed), and those fed any level of whole cottonseed between 5% and 30% of diet DM. Corte et al. (2016) fed whole cottonseed at 0, 10, or 20% of diet DM to finishing lambs. The authors reported that REA had a tendency to increase with increasing amounts of whole cottonseed in the diet. However, no differences were reported among treatments for HCW, dressing percentage, or fat thickness (Corte et al., 2016).

Digestibility of Cotton Byproducts

Unprocessed gin trash is reported to have an in vitro DM digestibility (IVDMD) of approximately 34% (Thomasson, 1990). Gin trash has a decreased IVDMD compared to other crop residues such as corn stalks, which have average IVDMD of 59% (Roth et al., 1987). Gin trash can be variable in digestibility depending upon the method in which it is harvested. For example, stripper harvesting of cotton increases the amount of burrs and stems present in the gin trash, which results in decreased digestibility compared to spindle-harvested cotton (37.8 vs 58.5% IVDMD; Pordesimo et al., 2005). In the year 2000, it was reported that approximately 67% of the gin trash was produced from cotton that was harvested using the stripper method (Holt et al., 2000).

When ground through a 1 mm screen, Arieli et al. (1989) reported that whole cottonseed had an in situ DM disappearance of 67.5% and CP disappearance of 89.7% when incubated for 48 h. Although there are different varieties of whole cottonseed, such as short staple, and pima, the digestibility between types appears to be less variable than

the differences observed in gin trash. Sullivan et al. (1993) reported that pima cotton had a decreased ether extract digestibility compared to short staple cotton (71.6 vs 78.8%). However, when pima cotton was processed by methods such as cracking or grinding, ether extract apparent digestibility was similar to that of the short staple cotton (Sullivan et al, 1993). The DM, CP, NDF, and acid detergent fiber (ADF) apparent digestibility did not differ among cottonseed varieties in dairy cattle consuming whole cottonseed at 15% of dietary DM (Sullivan et al., 1993).

Methods for Altering Digestibility

Gin trash has an increased lignin value (15.9%) compared to other common low to medium quality roughage sources including bermudagrass hay (5.4%) and native prairie hay (2.1%; NASEM, 2016). Lignin and digestibility have an inverse relationship where as lignin increases, digestibility decreases (Mowat et al., 1968). Low quality feedstuffs that have increased amounts of lignin are often physically processed or chemically treated to improve digestibility. Grinding is the primary method of physical processing, which is effective in increasing the surface area of the product so that rumen microbes have a greater opportunity to attach to and digest the material. Chemical processing aides in pre-digesting a fraction of the lignocellulosic material (Pordesimo et al., 2005). The most widely used chemical treatments to improve digestibility of low quality forage are sodium hydroxide and anhydrous ammonia (Conner and Richardson, 1987). The application of chemical solutions to low quality forages improves the digestibility by solubilizing the hemicellulose, and increasing the rate and extent of cellulose and hemicellulose digestion (Klopfenstein, 1978).

To test the effects of physical and chemical processing on IVDMD, Pordesimo et al. (2005) treated gin trash ground to a 0.5, 1.0, or 2.0 mm particle size with either 4% or 6% sodium hydroxide. Results indicated that the gin trash ground to 0.5 mm was 47.8% digestible while the gin trash ground to 2.0 mm was only 33.8 % digestible. The difference in digestibility observed among particle sizes was attributed to increasing the total surface area of the gin trash exposed to the rumen environment when ground to a finer particle size (Pordesimo et al., 2005). When testing the effects of chemical treatment on digestibility, pre-treatment of gin trash with sodium hydroxide resulted in increased digestibility. However, the 6% sodium hydroxide was more effective in increasing the digestibility compared to the 4% sodium hydroxide for all types of gin trash (70.5% vs 60.6% IVDMD, respectively). The most effective method for increasing digestibility was determined to be a combination of grinding the gin trash to 0.5 mm and treating the gin trash with 6% sodium hydroxide at room temperature for 4 h (Pordesimo et al., 2005). Similarly, Arndt et al. (1980) reported that treating ground gin trash with a 25% sodium hydroxide solution increased DM digestibility of the total diet (70% gin trash, 19.5% sorghum grain, 8% soybean meal, 0.7% urea, and 1.8% mineral) by 35% compared to the diet containing untreated gin trash.

The existing literature suggests that chemical processing of cotton gin trash does not have an effect on the growth performance of steers. When gin trash (untreated or treated with 4% sodium hydroxide) was fed ad libitum to feedlot steers and top dressed with a corn and soybean meal supplement, ADG and average daily feed intake was not affected by the treatment of gin trash (Arndt and Richardson, 1982). However, in feedlot lambs, Arndt and Richardson (1982) reported that lambs consuming untreated cotton gin

trash as a roughage source had a decreased ADG, similar DMI, and increased F:G compared to lambs consuming cotton gin trash treated with sodium hydroxide.

In summary, the physical or chemical treatment of low-quality roughages such as gin trash can improve the digestibility. However, it is important to factor in the expense of chemically treating low quality roughages, as the total cost after treatment of low quality byproducts may be comparable to the cost of a higher quality roughage. This could be especially of concern when considering the cost of equipment for physical or chemical processing on a small scale operation. In past economic analyses, it was reported that the cost of 1 ton of NaOH treated wheat straw was $45 per ton, while a 10% CP hay was $60 per ton (Males, 1987).

Heat treatment of whole cottonseed has been thought to decrease CP degradation in the rumen, resulting in an increase in the amount of CP that reaches the small intestine (Arieli et al., 1989). Reducing the amount of CP degraded in the rumen would eliminate the production of excess ammonia and the cost of urea excretion (Arieli et al., 1989). This concept is primarily of focus in dairy cattle, as increasing rumen undegradable protein may increase milk production. Arieli et al. (1989) reported that heating whole cottonseed at 180°C for 2 h effectively decreased the disappearance of DM and CP in the rumen for up to 48 h of incubation. However, Smith and Vosloo, (1994) reported that a lower temperature of 155°C for 20 min was sufficient to result in minimal ruminal protein and fat digestion in wether lambs. While heat treatment of whole cottonseed in feedlot diets is likely of minimal interest, heat treatment is a method of altering protein digestibility that producers can utilize to increase ruminally undegradable protein, if necessary.

Fecal Evaluation as a Predictor of Digestibility

In addition to conducting lab analyses, or in situ and total fecal collection experiments to measure digestibility, simple fecal evaluation methods are available to provide researchers and producers with a method to assess the site and extent of feed digestion and fermentation in cattle (Hall, 2002). Factors such as the adequacy of peNDF and the types of non-fiber carbohydrates in a diet can affect texture and particle size of manure (Hall, 2002). Additionally, the adequacy of peNDF and the types of non-fiber carbohydrates in a diet can also affect the rate of passage, which can extend or depress fermentation of feeds (Hall, 2002). Site and extent of starch digestion in ruminants can be influenced by various factors including, but not limited to: source of dietary starch, dietary composition, amount of feed consumed in a given time period, chemical alterations, and adaptation of the rumen environment to the diet (Huntington, 1995).

A fecal scoring system intended for use in dairy cattle was created by Ireland-Perry and Stallings (1993), which evaluated fecal samples collected via rectal palpation by dropping them onto a clean floor from approximately 1 m of height. Depending upon how much the fecal sample spread and splattered upon impact, fecal samples were assigned a number between 1 and 4; 1 = runny consistency that splatters on impact, 4 = dry and hard consistency that does not distort upon impact. This system was created based on the idea that digestion of nutrients may be more complete when feces have a greater moisture content (Ireland-Perry and Stallings, 1993). The amount of fiber in a diet may also impact fecal consistency scores; when dietary ADF was 25% of the DM in a dairy cattle ration, fecal scores were significantly firmer than when dietary ADF was 17% of the DM (Ireland-Perry and Stallings, 1993). Additionally, cows consuming diets with

decreased fiber had a reduced fecal pH and an increased fecal starch content (Ireland-Perry and Stallings, 1993), supporting the concept presented by Wheeler et al. (1976).

The fecal scoring system from Ireland-Perry and Stallings, (1993) was slightly altered and adapted for use in feedlot cattle (Woolsoncroft et al., 2017). Using this method, fecal samples are obtained and evaluated by both physically handling and visually appraising the sample without dropping it. Fecal scores using this method range from 1 to 5; 1 = firm, hard, dry appearance such as a cow on dry hay, 3 = soft and moist, but not runny, 5 = very thin and watery, cannot be caught in an open hand. The optimal fecal score is considered to be a 3 for feedlot cattle (Woolsoncroft et al., 2017). A looser fecal consistency can be associated with an inadequate amount of effective fiber in the diet and a shorter retention time in the rumen (Woolsoncroft, 2017). As a result, specific feedstuffs included in a diet may alter fecal consistency scores. For example, due to the amount of increased peNDF in whole cottonseed, the inclusion of whole cottonseed in a finishing diet may increase retention time in the rumen, resulting in an increased fecal pH and firmer fecal samples than a diet containing Sweet Bran. It is unlikely that utilizing gin trash instead of prairie hay would alter fecal pH or fecal consistency scores, as both roughages have similar peNDF values (56.3 vs 58.2 % of DM, respectively; Warner et al., 2020).

Another simple method to assess starch digestion in ruminants is to obtain a measurement of fecal pH. It has been reported that a decreased fecal pH is associated with an increased amount of starch in the feces (Wheeler et al., 1976). The reduction in pH is attributed to the increase in volatile fatty acid (VFA) production due to increased fermentation in the hindgut (Depenbusch et al., 2008). Additionally, an increase in

hindgut fermentation may result in a less firm fecal consistency. When an increased amount of VFA are present in the hindgut, an influx of water into the hindgut from the blood due occurs due to an increase in osmolality in the digestive tract (Ishler and Varga, 2001). When these measurements are taken together, fecal consistency scores and fecal pH can provide basic insight on the digestibility of starch and fiber in the diets of ruminants in a non-invasive manner.

Ruminal pH of Cattle Consuming High Concentrate Diets

Rumen pH is critical in maintaining the digestive function and health of ruminant animals and is controlled by a variety of behavioral (González et al., 2012) and physiological mechanisms (Aschenbach et al., 2011). The composition of the diet has an influence on ruminal pH; as starch in the diet increases, the rumen environment adapts and shifts to favor amylolytic bacteria which predominantly produce the VFA, propionate (Church, 1988). Lactic acid and VFA can accumulate if the buffers in the rumen cannot keep up with acid production, and ruminal pH decreases as a result (Plaizier et al., 2008). When ruminal pH has been consistently depressed for long bouts of time throughout the day symptoms such as feed intake depression, reduced fiber digestion, diarrhea, laminitis, liver abscesses, and inflammation can occur (Plaizier et al., 2008; NASEM, 2016).

Acidosis is a common digestive disorder in ruminants, characterized by a ruminal pH of less than 5.6 (Cooper et al., 1997) for 3 to 5 h/d (AlZahal et al., 2007). Acidosis commonly occurs in feedlot cattle consuming a diet abundant in rapidly fermentable nonstructural carbohydrates. The chance of acidosis increases when more than 90% of the diet DM consists of nonforage ingredients (NASEM, 2016). Acidosis is considered to be subacute when the pH of the rumen is below 5.5 (Garrett et al., 1999) and acute when

the rumen pH is less than 5.0 (Nagaraja and Titgemeyer, 2007). The average ruminal pH of feedlot cattle consuming high concentrate diets is between 5.6 and 6.2 (Schwartzkopf-Genswein et al., 2003); however, ruminal pH commonly fluctuates throughout the day. Ruminal pH is generally increased immediately prior to feeding, then decreases shortly after feeding due to an increase in carbohydrate fermentation. Approximately 11 to 13 h post-feeding, the lowest daily pH is observed which is primarily influenced by the rate of ruminal feed digestion (Schwartzkopf-Genswein et al., 2003). Prevention of acidosis can be achieved through a variety of feed management strategies including: implementing step up diets or a 2-ration blending system when increasing the amount of rapidly fermentable carbohydrates in a diet, including ionophores in the diet, delivering feed at a uniform time, offering feed multiple times per day, and correctly processing grain (Schwartzkopf-Genswein et al., 2003).

Volatile Fatty Acids

In addition to carbon dioxide, methane, and microbial cells, the anaerobic microorganisms in the rumen produce VFA as an end-product of fermentation (Wolin et al., 1997). The most predominant VFA are acetate, propionate, and butyrate. All VFA provide energy to the ruminant; however, acetate and propionate are utilized more efficiently than butyrate. The composition of the diet influences the type of microorganisms present in the rumen, which produce different proportions of VFA. Diets that contain large amounts of rapidly fermentable carbohydrates shift the microbial population of the rumen to a population that is mostly amylolytic, which produce increased propionate compared to cellulolytic microorganisms (Church, 1988). Cattle consuming predominantly roughage based diets commonly have an

acetate:propionate:butyrate ratio of approximately 65:25:10, while cattle consuming predominantly concentrate based diets commonly have an acetate:propionate:butyrate ratio of approximately 50:40:10 (Church, 1988).

Although it is well known that the proportions of forage and concentrate in a diet can influence the type and amount of VFA produced in the rumen, other factors such as the inclusion of ionophores and grain source in the diet may also influence the composition of ruminal VFA. For example, monensin has the potential to alter VFA concentrations, as the main function of monensin is to alter rumen microorganism composition and fermentation. Boling et al. (1977) concluded that molar percentages of both acetate and butyrate decreased while propionate increased as monensin inclusion increased in the diet from 0 mg to 300 mg. The type of grain included in the diet may also influence VFA production, as Franks et al. (1972) reported that feeding barley at the rate of 80% of the total diet increased butyric acid while decreasing propionic acid when compared to oats, sorghum, or corn fed at the same rate. However, grain source did not alter the acetate to propionate ratio or the total concentration of VFA (Franks et al., 1972).

Additionally, research has shown that altering VFA concentrations can have effects on performance and carcass traits. Average daily gain was negatively affected when the finishing diet had an increased acetate to propionate ratio (Weiss et al., 1967), supporting the fact that propionate provides more energy to the animal than acetate or butyrate. The acetate to propionate ratio also accounted for 56% of the variance in fat composition and 58% of the variance in protein composition of beef × dairy steer carcasses (Weiss et al., 1967). An increased acetate to propionate ratio was associated

with increasing fat and decreasing protein composition of the carcasses, suggesting that acetate is more effective for lipogenesis (Weiss et al., 1967). In contrast to Weiss et al. (1967), Bulumulla et al. (2018) concluded that adipose fat thickness was positively correlated with propionate. However, it has also been reported that acetate and butyrate positively correlated with adipose fat thickness (Bulumulla et al., 2018).

Blood Metabolites

In addition to measuring metabolites in the rumen of cattle, measuring intermediary metabolites in the blood can also provide insight into the effects of imposed dietary treatments on nutrient metabolism. A few commonly measured blood metabolites to assess nutritional status include blood urea nitrogen, glucose, and lactate. Blood urea nitrogen is used as an indicator of protein nutritional status in cattle. Concentrations of urea nitrogen in whole blood (BUN) or blood plasma (PUN)can be used to assess protein metabolism in animals, or used to fine-tune diets to minimize protein excretion (Kohn et al., 2005). Blood glucose is associated with the energy intake of cattle (Lee et al., 1978) and is measured to identify potential alterations in carbohydrate metabolism. In blood, L-Lactate concentrations can be used to evaluate stress (Mitchell et al., 1998), and status of anaerobic metabolism (Figueiredo et al., 2008) while D –Lactate blood concentrations can be closely associated with acute ruminal acidosis (Nagaraja and Titgemeyer, 2006).

Urea Nitrogen

In ruminants, digestible protein is either degraded in the rumen to be used for microbial protein synthesis or degraded in the small intestine and absorbed into the portal blood system (Hammond, 1996). If an excessive amount of nitrogen is supplied to the rumen, ruminal ammonia increases (Kang-Meznarich and Broderick, 1981). Additionally,

ammonia is produced from the deamination of amino acids that are digested post-ruminally; in both cases, ammonia is detoxified in the liver by converting the ammonia to urea, which then circulates back into the blood (Hutton, 1972). Excess urea can be excreted in the urine by the kidneys, or eventually return to the rumen via diffusion from the blood or as a component of saliva through urea recycling (Hammond, 1996). Because of the known physiological mechanisms associated with the production of urea and the relationship to nitrogen intake, urea is often measured in the blood or milk of ruminants to monitor protein status and nitrogen utilization in livestock. An increase in urea nitrogen can be a result of increased CP in the diet, increased muscle protein degradation, decreased protein accretion (Gleghorn et al., 2004), or inefficient utilization of dietary CP (Broderick and Clayton, 1996).

While concentrations of urea nitrogen can be attributed to numerous factors, the level of CP and amount of ruminally degradable protein in a diet appear to influence urea nitrogen concentration. Gleghorn et al. (2004) reported that serum urea nitrogen was increased across the entire finishing period in cattle consuming a diet with 14.5% CP, compared to cattle consuming a diet with 11.5% CP, indicating a direct relationship between increased levels of CP and increased levels of serum urea nitrogen. To correlate PUN with protein level and ruminal degradability Huntington et al. (2001) completed an experiment in growing Angus steers fed either soybean meal or a 2:1 ratio of corn gluten meal to blood meal in the daily supplement to provide 100, 200, 300, or 400 g of protein. The remainder of the 800 g of total supplement contained ground corn, monensin sodium, vitamins, and minerals. The supplement was offered in addition to corn silage. Compared to a control supplement, PUN concentrations increased with any amount of protein

supplementation increased regardless of the source of protein. Additionally, steers consuming the soybean meal supplement had greater PUN levels overall that increased more rapidly in response to an increasing amount of protein compared to steers consuming the corn gluten meal and blood meal supplement (Huntington et al., 2001). For comparison, soybean meal has a ruminally degradable protein (RDP) value of 70.4% of CP while corn gluten meal and blood meal have RDP values of 30.0% and 25.2% of CP, respectively (NASEM, 2016) suggesting that increasing RDP in the diet can increase PUN concentrations. In contrast to Huntington et al. (2001), a second experiment completed by Gleghorn et al. (2004) comparing sources of protein using urea, cottonseed meal, and a combination of both, reported that serum urea nitrogen was affected more consistently by the concentration of CP in the diet, than by the source of protein.

Utilizing cotton byproducts as a protein source in a finishing diet may alter the observed PUN concentrations in finishing feedlot steers compared to steers consuming other commonly used protein sources. According to Samuelson et al. (2016), the most commonly used protein sources for feedlot receiving and finishing diets are corn byproducts including wet corn gluten feed and corn distillers grains. Wet corn gluten feed has a CP content of 23.8% with 65.7% of the CP considered RDP, while whole cottonseed has a CP content of 22.9% (NASEM, 2016) with 73.0% of the CP considered RDP (NRC, 2000). Although there is only a RDP difference of approximately 7%, whole cottonseed could have the potential to increase PUN concentrations in ruminants compared to wet corn gluten feed depending on the dietary inclusion rate. However, based on the conclusion made by Gleghorn et al. (2004), the CP content of whole cottonseed and wet corn gluten feed may not differ enough to alter PUN concentrations.

Because of conflicting results seen in the literature, further research is necessary to validate these results.

Utilizing cotton gin trash as a roughage source in finishing diets compared to prairie hay would not likely influence the PUN concentration on the basis of RDP content in the roughage. While prairie hay has an estimated RDP (6.8% CP; NASEM, 2016, 70% RDP, % of CP; Beef Magazine) almost double of cotton gin trash (12.3% CP; 35.6% RDP, % of CP, NASEM, 2016), the estimated protein content of cotton gin trash is almost double the estimated CP content of prairie hay, thus both theoretically should contribute an almost equal amount of RDP to the diet. Aside from differences in CP and RDP, roughage sources are only included at small percentages in finishing diets (6 – 12% of diet DM; Samuelson et al., 2016). Because of the low inclusion rate of roughages in finishing diets, it is likely of more interest to consider the CP and RDP values of the byproduct and grain sources in the diet when evaluating potential differences in nitrogen metabolism and protein utilization.

In addition to providing insight to protein utilization in an animal, results from urea nitrogen analysis can assist in altering and improving diets (Kohn et al., 2005). Altering livestock diets to decrease excess nitrogen can be a financial benefit for producers, as protein is an expensive nutrient to supplement. Once all rumen degradable and metabolizable protein requirements are met, nitrogen excretion increases, particularity in the urine (Vasconselos et al., 2009). Aside from increasing input costs, excess nitrogen excretion in the urine and feces also creates environmental challenges. To minimize protein waste and maximize animal performance, the optimal concentration of

CP in a finishing diet is between 12 and 13% on a DM basis for cattle in feedlot settings (Thomson et al, 1995).

Glucose

Glucose is the primary source of energy for various tissues in the body including the nervous system, mammary gland, fetal tissue, adipose tissue, and muscle (Bergman, 1973). Synthesis of glucose occurs primarily in the liver using precursors that are absorbed as a result of digestion and fermentation of the diet (Reynolds, 2005). In ruminants, the primary precursors of glucose include propionate (Leng and Annison, 1962) and amino acids (Bergman, 1973). It is estimated that between 45 and 65% of carbon used for the synthesis of glucose arises from propionate, and that 32% of propionate is directly converted into glucose (Leng et al., 1967).

Because propionate is a primary contributor to glucose production, diet composition can influence the concentration of glucose. Diets that have increased amounts of rapidly fermentable carbohydrates promote the production of propionate at the expense of acetate. Evans et al. (1975) reported that sheep consuming a diet of approximately 62% corn had increased plasma glucose, insulin, and propionate and decreased plasma acetate compared to sheep consuming a diet consisting of 11.8% corn and 88.2% legume hay. Similar results were reported in dairy cows where cows consuming a diet comprised of 60% corn, 20% legume hay, and 20% ground soybeans had increased plasma glucose, propionate, and isobutyrate concentrations and decreased plasma acetate concentrations compared to cows consuming a diet comprised of 67% legume hay, 20% corn, and 13% ground soybeans (Evans et al., 1975).

As starch concentration in the diet increases, a greater amount of starch escapes degradation the rumen and is digested in the small intestine, resulting in a substantial amount of glucose being absorbed in the small intestine (Church, 1988). Inclusion of cotton byproducts in the diet could potentially decrease the total amount of starch in a total mixed ration, depending on the rate of inclusion. For comparison, whole cottonseed has a starch value of only 2.2% of DM while wet corn gluten feed has a starch value of 15.2% of DM (NASEM, 2016). Other commonly used cotton byproducts such as cottonseed meal and cottonseed hulls are also low in starch (1.7 and 1.1% of DM, respectively). Although starch content among common byproducts differs, finishing diets are often primarily comprised of a single grain source and therefore starch content of the total diet is likely not impacted by the inclusion of various byproducts.

Aside from diet composition, the amount of glucose in the body can be altered by the DMI of the diet. It has been reported that DMI is negatively correlated with plasma glucose concentrations in finishing beef cattle (Foote et al., 2014). It is speculated that the relationship between plasma glucose and DMI could be related to the conversion of absorbed propionate to glucose by the liver (Foote et al., 2014). The concentration of glucose in the blood is attributed to the combined effects of production and utilization (Huntington, 1997). While it is difficult to identify the cause of the increase or decrease in production or utilization, the concentration of glucose in the blood is proportional to glucose utilization in the body, within limits (Bergman, 1973) and can therefore serve as a valuable indicator of glucose metabolism.

Lactate

Glycerol, proteins, and carbohydrates are all ultimately catabolized via metabolic pathways into the compound pyruvate (VanSoest, 1994; Ungerfield and Kohn, 2006). Pyruvate can then be converted into other intermediates such as acetyl co-A and lactate. Increased values of lactic acid in the blood and rumen fluid can be an indicator of acidosis (Dunlop, 1972). Although ruminal acidosis is defined by a decreased rumen pH, some researchers have also identified alterations in lactate concentrations related to acute ruminal acidosis. Concentrations of lactate in the rumen are generally low (Owens et al., 1998); however, when steers experience acute ruminal acidosis (defined by a pH between 3.9 and 4.5), lactate concentrations can exceed 50mM (Dunlop, 1972). During subacute acidosis, concentrations of ruminal lactate were less inflated (< 10 mM; Harmon et al., 1984) when steers were abruptly fed a 70% concentrate diet.

The amount and rate of lactic acid accumulation in the rumen are largely dependent upon the ability of the microbial population to utilize the lactate being produced more rapidly than the lactate accumulates (Dunlop, 1972). When high concentrate diets are fed abruptly, lactate utilizing microbial species are not able to populate the rumen in sufficient numbers to utilize the increased amounts of lactic acid produced by lactate-producing microbial species which causes a depression in ruminal pH (Dunlop and Hammond, 1965). Because excess lactate can be absorbed into the blood stream, analyzing blood samples can be a reliable method to assess lactate concentrations in the body and provide insight to lactic acid utilization in the rumen, should direct rumen fluid sampling not be an option.

In addition to a ruminal acidosis occurrence, lactate in the blood can be increased when cattle are exposed to stress. Stress responses generally cause an increase in the

hormones epinephrine and cortisol, which increase gluconeogenesis and proteolysis pathways (Boles et al., 2012). Such responses can subsequently increase anaerobic metabolic processes such as muscle depletion which results in an increased concentration of lactic acid in the blood (Boles et al., 2012). According to Sako et al. (2007), the average lactate concentration in the plasma of beef cattle is approximately 2.69 mM. Following transportation, Mitchell et al. (1998) reported lactate concentrations of 4.7 mM and 7.4 mM after slaughter. In contrast, Boles et al. (2012) reported that when handled through a chute, average blood lactate concentrations of cattle were less elevated with values between 2.5 and 3.0 mM. Due to the variation in reported experiments, associating specific blood lactate levels with stress may require additional research to determine how intense a stress event must be before these anabolic processes begin in the body.

Summary of Literature Review

Cotton production is predicted to continue to increase in the Southwestern United States, resulting in a subsequent increase in the availability in cotton byproducts. Since the Southwestern United States is an important region for the production of both cotton and cattle, byproducts such as cotton gin trash and whole cottonseed have the potential to be incorporated in to cattle diets as sources of protein, fat, and fiber. The cost of transportation and the potential for price competition for whole cottonseed with the dairy industry may result in some financial limitations regarding the use of cotton byproducts. However, the benefits from cotton byproducts may offset the financial concerns. For example, whole cottonseed has greater nutrient values for protein, fat, and fiber, which may decrease the amount of protein or fat supplements required in the diet and decrease the need for traditional roughages. Additionally, while cotton gin trash can be bulky and

expensive to transport (Lalor et al., 1975), the purchase price of the cotton gin trash may offset transportation costs if a cattle feeder is located in close proximity to a cotton gin.

The current literature suggests that cotton byproducts can successfully be fed to all classes of cattle. When paired with an energy supplement, gin trash can be fed to wintering beef cows without the loss of body condition score (Hill et al., 2000). Similarly, it is reported that feeding a combination of gin trash and corn to stocker cattle can increase overall DMI (Kennedy and Rankins, 2008). In feedlot and dairy cattle, gin trash is most commonly used as a source of physically effective fiber to stimulate rumination. It is also a common practice to include whole cottonseed in total mixed rations for dairy cattle (Kellog, 2001). The inclusion of cotton byproducts does not appear to have negative effects on performance or carcass characteristics in beef cattle when fed at recommended amounts (Huerta-Leidenz et al., 1991; Cranston et al., 2006). Whole cottonseed is recommended to be fed at 15% or less of diet DM (Preston and Bartle, 1989), and when used as a roughage source, cotton gin trash is suggested to be fed at a rate of 10% of diet DM or less in a finishing diet (Lalor et al., 1975). Although the digestibility of low-quality roughages is often a concern, it has been suggested that digestibility of cotton gin trash can be improved through physical or chemical processing (Conner and Richardson, 1987; Pordesimo et al., 2005).

Previous research has been conducted to investigate the inclusion of various cotton byproducts in feedlot diets. However, there is a lack of research on using cotton byproducts as the primary sources of protein, fat, and fiber in finishing diets for beef cattle. The need for such research exists as cotton production continues to increase in the Southwestern United States, making cotton byproducts more economical and readily

available to be included in cattle diets. Cotton byproducts such as whole cottonseed and gin trash have a great potential to be included in finishing cattle diets as the primary sources of protein, fat, and fiber, however, more research is necessary to support this suggestion.to livestock diets as less expensive sources of protein, fat, and fiber compared to common ingredients such as low to medium quality roughages or corn byproducts.

CHAPTER II

EFFECTS OF UTILIZING COTTON BYPRODUCTS IN A FINISHING DIET ON BEEF CATTLE PERFORMANCE, CARCASS TRAITS, FECAL CAHRACTERISTICS, AND PLASMA METABOLITES

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ABSTRACT: Increased cotton production in the Southwestern U.S. has increased the availability of cotton byproducts for use in cattle diets. The objective of this experiment was to evaluate the inclusion of cotton byproducts in feedlot finishing diets on the performance, carcass traits, fecal characteristics, and plasma metabolites of steers. Crossbred beef steers (n = 64; BW = 318 ± 12.3 kg) were assigned to 1 of 2 experimental treatments in a randomized complete block design (8 pens/treatment; 4 steers/pen). Treatments included a control (CON) diet which included prairie hay, Sweet Bran, rolled corn, and a corn steep and molasses based liquid fat supplement and a cotton byproduct (CTN) diet which included cotton gin trash, whole cottonseed, rolled corn, and water. Both diets contained urea and dry supplement. Over the entire feeding period, dry matter

intake (P = 0.04) was greater for CTN steers than CON steers with no difference in the gain to feed ratio (P = 0.86) between treatments. The CTN steers tended to have heavier final BW (P = 0.09) and greater overall average daily gain (P = 0.08). The CTN steers had heavier heavier hot carcass weight (P = 0.02) and greater fat thickness (P = 0.03) than CON steers, but marbling score and rib eye area were not different between treatments (P ≥ 0.64). Steers fed the CON diet tended to have a lower yield grade (P = 0.07), less kidney, pelvic and heart fat (P = 0.09), and decreased dressing percentage (P = 0.10) than CTN steers. Liver scores did not differ (P ≥ 0.17) between treatments. Fecal consistency scores were decreased for CTN steers on d 56 (P = 0.03) and fecal pH tended to be greater for the CTN steers on d 28 (P = 0.09) compared to CON steers, but neither differed during other periods (P ≥ 0.18). A treatment × day interaction (P = 0.04) was detected for plasma urea nitrogen (PUN) concentration, where PUN concentrations differed between treatments only on d 28 and 56. On both d 28 and 56, CTN steers had lower PUN concentrations (P = 0.03, P = 0.002, respectively). No treatment × day interaction was detected for plasma glucose or lactate concentrations. A day effect was observed for both metabolites (P < 0.01). Results from this experiment suggest that cotton byproducts can be effectively used as a source of fiber, fat, and protein in feedlot rations without adverse effects on performance or carcass characteristics.
Key words: cotton byproducts, cotton gin trash, feedlot, finishing diet, whole cottonseed

INTRODUCTION

When considering economic inputs for beef cattle production, feed costs account for the majority of expenses (Ahola and Hill, 2012). Since 2015, cotton production has

steadily increased in the Southwestern U.S. The United States Department of Agriculture (USDA) predicts that cotton production will continue to increase in 2019-2020, producing approximately 4 million additional bales than 2018-2019 (Dohlman et al., 2019). This increase in cotton production has resulted in greater availability of byproducts such as cotton gin trash (CGT) and whole cottonseed (WCS) for use in beef cattle diets.

In feedlots, low to medium quality hay is commonly used as the primary roughage source in finishing diets; however, hay can be expensive when compared to other available low-quality plant byproducts. Cotton gin trash is a low-quality byproduct that consists of stems, burrs, lint, leaves, immature cottonseed, and dirt. Although CGT is low in protein and energy content, CGT is a source of effective fiber and has the potential to be a more economical option for producers than traditional roughages. Aside from the costs associated with hauling and transportation, CGT is often of no cost to purchase (Meyer, 2007). Since CGT is a waste product, CGT is readily available, and has minimal competition as a feed commodity with other livestock species. It has been reported that when CGT is fed as part of the roughage in a diet, average daily gains were similar to steers fed silage (Erwin and Roubicek, 1985).

Whole cottonseed provides additional fiber to the diet and can also be used as a good source of fat and protein. Because WCS is a common ingredient in dairy diets (Kellogg, 2001), there is a potential for price fluctuation and competition as more dairy operations move into the Southwestern region of the country. Based on current average prices reported by the Agricultural Marketing Service-USDA, corn byproducts such as wet corn gluten feed are less expensive than WCS. However, WCS still has potential to

be included in feedlot diets because of the unique nutrient composition, as WCS may reduce the need for traditional roughages as well as additional protein and fat supplementation. It has been suggested that WCS can be added to finishing diets with little to no adverse effects on animal performance or carcass characteristics (Cranston et al. 2006).

A limited number of studies have been completed in the feedlot in which cotton byproducts have served as the major sources of roughage, protein, and fat source in the diet. Therefore, the objective of this study was to determine the effects of including cotton byproducts in a finishing diet on the performance, carcass traits, fecal characteristics, and plasma metabolites of crossbred beef steers.

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-17-13).

Cattle and Processing

Sixty-four crossbred steers (initial BW = 318 ± 12.3 kg) were transported approximately 589 km from the University of Arkansas Livestock and Forestry Research Station (Batesville, AR) to the Willard Sparks Beef Research Center (WSBRC) in Stillwater, Oklahoma. Upon arrival (d -1), steers were individually weighed and held in feedlot pens overnight with ad libitum access to prairie hay and water.

On d 0, steers were individually weighed, implanted (Revalor 200; Merck Animal Health, Madison, NJ), vaccinated against clostridial (Vision with SPUR; Merck Animal Health, Madison, NJ) and viral and bacterial respiratory (Titanium 5 + PH-M; Elanco

Animal Health, Greenfield, IL) pathogens, administered an anthelmintic (Safeguard; Merck Animal Health, Madison, NJ), and a pour-on insecticide (StandGuard; Elanco Animal Health, Greenfield, IL). Steers were blocked by (BW) at arrival and randomly allocated to pens within block. Steers were housed in sixteen 4.57 × 13.24 m partially covered feedlot pens with a shared 76-L concrete water tank between 2 adjacent pens (model J 360-F; Johnson Concrete, Hastings, NE).

Steers were monitored daily for health status as described by Wilson et al. (2015) and were treated according to standard WSBRC protocol, if necessary. Only 1 steer was treated for bovine respiratory disease symptoms with tildipirosin (Zuprevo; Merck Animal Health, Madison, NJ) according to label directions. Two steers, both consuming the cotton byproduct based (CTN) diet, were removed from the experiment due to animal well-being concerns not associated with the experimental treatments. One steer was removed due to a severe bone infection and the other was removed due to complications associated with coccidiosis.

Diets and Feed Management

Within block, 4 cattle were randomly assigned to each pen and treatment was randomly assigned to pens within block. A total of 16 pens were used for this experiment, with 8 pens per treatment. All steers were fed a common receiving diet (RCV; Table 1) for 8 d to allow steers to acclimate to the feedlot environment and stabilize feed intake before providing experimental diets. Steers were then transitioned to respective finishing diets over a 22 d period by increasing the amount of finishing diet delivered by 4 to 5 percent each day until each treatment received 100 percent of the respective finishing diet.

On a dry matter (DM) basis, treatment diets included a control (CON) diet (Table 1; 7% hay, 15% Sweet Bran, 67.25% rolled corn, 5% corn steep and molasses based liquid fat supplement) or a cotton byproduct based (CTN) diet (7% CGT, 15% WCS, 72.25% rolled corn, 5% water). Both diets contained 0.75% urea and 5% dry mineral supplement. Water was added to the CTN diet to reduce dust, act as a binder, and to improve palatability; no liquid supplement was included in the CTN due to the high fat content compared to the CON diet. Urea was weighed by hand separately from other ingredients, added to the mixer, and mixed into the complete ration. Ractopamine hydrochloride (Optaflexx 45; Elanco Animal Health, Greenfield, IL) was included in the diet (actual average ractopamine hydrochloride intake = 390 mg·steer-1·d-1) for 28 d before harvest.

At 0500 h each morning, feed bunks were visually evaluated to determine the amount of feed remaining from the previous day. The amount of feed to be delivered that day was adjusted based on this evaluation so that cattle left no more than 0.045 kg of feed in the bunk. Cattle were fed once daily at 1000 h. Feed was mixed and delivered using a trailer mounted feed mixer (274-12B feed mixer; Roto-mix; Dodge City, KS).

Diet samples were collected twice weekly and DM was calculated after samples were dried in a forced air oven at 60°C for 48 h. A monthly composite was created after DM was calculated and stored in a freezer until nutrient analysis could be completed. Feed refusals were weighed back before feeding on d 0, 14, 28, 56, 84, 112, 140, and 168 or if excessive orts remained in the bunk. Refusal samples were dried to determine DM content and were subtracted from DM delivered in order to calculate dry matter intake (DMI).

Data Collection and Calculations

Individual BW was recorded for all steers on d 0, 14, 28, 56, 84, 112 and before shipping for harvest. The BW was measured before morning feeding at approximately 0500 h with no withdrawal from feed or water. All BW were adjusted using a 4% pencil shrink (BW × 0.96). Steer BW was averaged within pen and used to calculate the following variables. Individual average daily gain (ADG) was calculated by dividing individual shrunk body weight gain in kg by days on feed for each period. Pen ADG was calculated as the average of the individual ADG for each steer in the pen for that period. Dry matter intake was calculated from total DMI for the pen for that period divided by the number of steers and the days on feed in that period. Gain to feed ratio (G:F) was calculated by dividing the ADG for the pen by the average daily DMI for the pen for each respective period.

The data from the 2 steers removed from the experiment were excluded from all analyses (deads out data). Since feed intake was not measured on an individual animal basis, intake data were corrected by removing the average daily DMI for each steer removed from the pen until the respective steer ceased gaining BW. From the time the steer ceased gaining BW until the steer was physically removed from the pen and the experiment, DMI data were estimated and removed using the NASEM (2016) equation where NEm = 0.077 (SBW)0.75.

A fecal grab sample was obtained via rectal palpation on d 0, 14, 28, 56, 84, 112 and before shipping for harvest. The pH of the fecal sample was recorded using a portable pH meter (pH 6+ Meter; Oakton Instruments, Vernon Hills, IL). Fecal samples were also scored for consistency using the method adapted from Ireland-Perry and

Stallings (1993) and Woolsoncroft et al. (2017). This method uses a 1-5 scale characterized by the following: 1 = firm, hard, and dry, 2 = slightly less firm and hard, 3 = relatively soft and moist, but not runny, 4 = loose, very moist and runny; consistency of pancake batter, 5 = very thin and watery, cannot be caught in hand. Samples were handled and visually appraised by the same evaluator at each collection. Changes in fecal score and fecal pH were calculated by subtracting the earlier date value from the later date value for each steer, then an average change for the pen was determined.

Additionally, on d 0, 14, 28, 56, 84, 112 and before shipping to harvest, a 10 mL blood sample was collected via jugular venipuncture into a tube containing sodium heparin (BD Vacutainer; Franklin Lakes, NJ) and stored on ice. Blood was allowed to clot for an average of 1.5 h before centrifuging. Blood tubes were centrifuged at 1,294 × g for 10 min at 4 °C (Sorvall RC6; Thermo Scientific, Waltham, MA), and plasma was collected and stored in a -80 °C freezer until analysis for plasma urea nitrogen (PUN), lactate, and glucose concentrations.

Cattle were shipped approximately 522 km to Tyson Fresh Meats (Amarillo, TX) for harvest in 2 groups. The 4 heaviest blocks (8 pens) were shipped on d 140 of the experiment and the 4 lightest blocks (8 pens) were shipped on d 168. In further discussion, “final” will be representative of the data collected before shipping to harvest; which is either d 140 or d 168, depending on harvest group. Carcass data were collected by trained personnel from the West Texas A & M University Beef Carcass Research Center (Canyon, TX) at harvest.

Laboratory Analysis

For all rations, a single 400 g sample from the middle of the feed batch was collected from the mixer twice weekly. Within each month, the twice weekly samples were composited and stored until analysis. The composited receiving diet samples were sent to a commercial laboratory for analysis (Table 1; Servi-Tech; Dodge City, KS). To conduct proximate analysis on both treatment diets, samples of diets were composited, dried in a 60°C oven for 48 h, then ground through a 2mm screen (Pulverisette 19, Fritsch; Pittsboro, NC). Laboratory DM was calculated by weight difference when samples were dried at 105°C for 12 h. Acid detergent fiber (ADF) and neutral detergent fiber (NDF) were analyzed using an ANKOM 2000 automated fiber analyzer (ANKOM Technology; Macedon, NY) according to manufacturer's instructions. Particle size of prairie hay, Sweet Bran, WCS, and CGT was determined with a 3.8 L sample using a 3-sieve forage particle separator (Table 2; Nasco; Fort Atkinson, WI). The sieves were shaken in one direction 5 times, rotated one-quarter turn and repeated for a total of 8 sets or 40 shakes. The physically effective neutral detergent fiber (peNDF) for prairie hay, Sweet bran, WCS, and CGT was estimated by calculating the percent of the sample remaining in the top 3 sieves (all $\geq$ 4 mm) and multiplying by the NDF (DM basis) content of the feedstuff (NASEM, 2016). To determine the peNDF from the roughage and byproducts of each diet, the peNDF of each contributing ingredient was multiplied by the percent inclusion in the diet. The respective roughage and byproduct peNDF values were then added to create a total peNDF for the diet. The whole diets were not analyzed for peNDF, as rations containing whole grains and supplements can have particles become trapped on the 4mm sieve, falsely inflating the physical effectiveness factor of the ration (NASEM, 2016). This was avoided by only calculating dietary peNDF values

for whole ingredients that provided the greatest amount of effective fiber and omitting manufactured ingredients (NASEM, 2016).

Percent N was determined using dry combustion analysis in a crude nitrogen analyzer (TruSpec CN, LECO; St. Joseph, MI). Crude protein was calculated by multiplying % N × 6.25. Fat was analyzed using an automated ether extractor (XT 15 Extractor, ANKOM; Macedon, NY) according to manufacturer's instructions, with petroleum ether. Minerals were analyzed by the Soil, Water, and Forage Analytical Laboratory (Stillwater, OK) using wet digestion and an inductively coupled plasma spectrometer.

Plasma samples were thawed at room temperature immediately before PUN, glucose, and lactate analysis. Plasma urea nitrogen was analyzed according to the methods described by Marsh et al. (1965) adapted for a 96 well plate. Plasma glucose and L – lactate were analyzed using an immobilized enzyme system (YSI Model 2950 D; YSI Inc., Yellow Springs, OH).

Statistical Analysis

This experiment was organized in a randomized complete block design. For all data measurements, pen served as the experimental unit (n = 16). All data were analyzed using the MIXED procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). Treatment was included as the fixed effect and block as a random effect for performance and fecal characteristics. Plasma metabolite data were assessed for normality using the UNIVARIATE procedure of SAS 9.4. Based on results from the Shaprio-Wilk test, all data were normally distributed. Covariance structures (CS) within the model were compared. The autoregressive CS was the CS that best fit the data (the CS with the

lowest Akaike information criterion) in the current experiment. The fixed effects of treatment, day, and treatment × day and block as a random effect were used in the model to analyze plasma metabolite data. Day was included as a repeated measure using autoregressive covariance structure with pen as the subject. All data from steers removed from the experiment were excluded from analysis. Significance was determined when $P \leq 0.05$ and tendencies were considered when $P > 0.05$ and $P \leq 0.10$.

RESULTS AND DISCUSSION

Experimental Diets

When creating the experimental diets, it was not possible to balance the diets for equivalent NDF, ADF, or fat with the ingredients available (Table 1). Therefore, the objective of the experiment was not to create diets that had equivalent fat or fiber levels, but rather to determine if cotton byproducts could be used successfully to supply a majority of the protein, fat, and fiber (roughage) within a finishing diet. Thus, the primary sources of protein (Sweet Bran vs WCS) and fiber (prairie hay vs CGT) were included at equal percentages in both diets (DM basis) and diets were balanced to contain similar amounts of crude protein and calculated energy according to Weiss (1992). Sweet Bran and the liquid supplement served as the primary sources of protein and fat respectively in the CON diet, while WCS served as the primary source of both protein and fat in CTN diet. An additional 5% corn (67.25% vs 72.25% of diet DM for CON and CTN, respectively) was included in the CTN diet. It was decided not to include additional WCS in the CTN diet (i.e. 20% diet DM) as then the experimental diets would have even greater differences in fat content. Urea was included at the same rate in both diets to ensure adequate degradable protein concentration.

Again, it is important to note that the objective was not to substitute one specific ingredient for another (ie. WCS for Sweet Bran), but rather to provide the majority of the macro nutrients in the finishing diet via cotton byproducts or the common ingredients at the facility. It should also be noted that some ingredients (i.e. Sweet Bran) may not have been fed at levels to promote optimal DMI and performance. For example, it has been suggested that wet corn gluten feed be included at a rate of 20% to 30% of diet DM to optimize cattle performance (Bremer et al. 2008; Loza et al. 2010).

Performance

As expected, no differences in BW were observed between treatment groups on d 0 (Table 3; $P = 0.49$). However, d 84 and final BW tended to be heavier for the CTN fed steers ($P \leq 0.09$). The tendency towards a heavier final BW is a result of the tendency for CTN steers to have a greater ADG ($P \leq 0.08$) from d 28 to final and over the course of the entire experiment. The tendency for greater overall ADG of the CTN steers (1.95 vs 2.09 kg/d) was likely a result to the greater DMI of the CTN steers over the entire feeding period ($P = 0.04$).

Although CTN steers tended to have a greater ADG and DMI during the finishing period and overall, the steers fed the CON ration had a numerically greater ADG during the transition period (d 0 to 28) of 0.13 kg/d ($P = 0.43$). This numerical difference in ADG during the transition period is also likely a result of the differences observed in DMI between treatments during this period, as the CON steers tended to have greater DMI from d 14 to 28 ($P = 0.09$). The numerically greater DMI (0.2 kg/d) by CON steers during the 28-d transition period may be attributed to palatability differences and ingredient recognition of the experimental diets. The steers had previously been

consuming mature Bermuda grass pasture, and perhaps recognized and accepted diets containing prairie hay more readily compared to the unfamiliar (WCS) and less palatable (CGT) ingredients in the CTN diet. Intakes possibly remained lower throughout the transition period until steers were fully acclimated to the CTN diet. No differences in G:F were found during any period of the experiment ($P \geq 0.16$).

The ADG results from d 28 to final in the current experiment are similar to those described by Huerta-Leidenz et al. (1991) who reported a numerically greater ADG (1.15 vs 0.95 kg/d) when WCS was included in a finishing diet at 15% compared to a control diet that consisted of corn, cottonseed meal, cottonseed hulls, and molasses. In contrast, the ADG results presented in the current experiment differ from a study completed by Cranston et al. (2006), who reported that final BW and ADG were not affected by the inclusion of 15.4 % WCS when fed in combination with steam-flaked corn in a finishing diet compared to a control diet that consisted of steam-flaked corn, cottonseed meal, cottonseed hulls, tallow, and alfalfa hay as the primary protein, fat, and fiber sources.

The difference in results between the current experiment and those reported by Cranston et al. (2006) could simply be due to a difference in the composition of the experimental diets. For example, the control diet used by Cranston et al. (2006) supplied fiber and protein in the form of cotton byproducts and alfalfa hay, whereas the control diet in the current experiment did not contain any cotton byproducts and utilized prairie hay and corn byproducts as the major fiber and protein sources. Additionally, diets in the Cranston et al. (2006) experiment were formulated contain similar amounts of protein, fat, and NDF supplied by the roughage, while the diets in the current experiment were formulated to contain similar amounts of crude protein and energy only.

The difference in overall DMI observed between treatments in this experiment may be related to the amount of physically effective fiber in the treatment diets. According to a review by Galyean and Defoor (2002), DMI = 1.858 + 0.0290 × eNDF % from roughage. Although eNDF was not directly measured in this experiment, eNDF and peNDF are highly correlated (NASEM, 2016). Given the correlation between eNDF and peNDF, the difference in DMI detected in the current experiment may be partially explained by the 11.6% more peNDF supplied by roughage and byproducts in the CTN diet compared to the CON diet.

Diets in this experiment were not balanced for peNDF, but rather formulated to include the primary roughage sources at the same rate between treatments. Prairie hay and CGT contributed similar amounts of peNDF to each diet, with 88.2 vs 85.7% of the NDF classified as peNDF, respectively. However, it is also important to note that while WCS is a considered a concentrate, WCS also provides a substantial amount of fiber and peNDF that may reduce the amount of traditional roughage needed in the diet. The WCS in the CTN diet contained 98.0% of the NDF as peNDF, while the Sweet Bran in the CON diet contained 88.2% of the NDF as peNDF. The difference between the peNDF content of WCS and Sweet Bran in the diets was the primary source of the variation in overall peNDF between the diets. The inclusion of fibrous byproducts greatly increased the peNDF of the experimental diets, therefore it may be important to consider fiber content from both the roughage and fibrous byproducts when using equations to predict differences in DMI.

Carcass Traits

The higher final BW was reflected in hot carcass weight (HCW), where the CTN steers had a 14 kg heavier HCW on average than CON steers (Table 4; $P = 0.02$). Additionally, the CTN carcasses had greater fat content as demonstrated by a greater back fat thickness of 0.13 cm ($P = 0.03$), and a tendency to have a greater kidney, pelvic, heart fat (KPH) percentage ($P = 0.09$), and yield grade (YG; $P = 0.07$). Dressing percentage (DP) also tended to be higher for the CTN steers than the CON steers, (62.7 and 62.2, respectively; $P = 0.10$). A similar result was reported by Huerta-Leidenz et al. (1991) who reported that YG was numerically greater (2.3 vs 2.7) when 15 % WCS was included in finishing diets compared to the control.

In contrast to our findings, Cranston et al. (2006) reported no differences in carcass characteristics when comparing finishing steers fed a diet containing 15% WCS to a control diet. The difference in fat thickness, KPH, and YG results between studies could be attributed the fact that diets used by Cranston et al. 2006 were formulated to contain equal percentages of fat, and diets in this current experiment were not. Increases in YG are not desirable and beef carcasses with a YG of 4 or 5 are often severely discounted. Although the CTN steers in this study had higher YG than CON, the average CTN YG was 2.83 and therefore discounts for YG 4 and 5 carcasses are likely of minimal concern when considering the inclusion of WCS at 15% in a finishing diet.

Cotton gin trash can have a highly variable nutrient composition depending on the region CGT is produced in (Meyer, 2007), which could be a source of variation in the results between this experiment and previous results reported. While the energy values from the 2 diets in the current experiment were similar, the sources of energy varied between the 2 diets, thus the CTN steers could have had greater carcass fat composition

due to differences in metabolism of fat or other macro nutrients. Interestingly, there were no differences in marbling score between treatments, despite the greater back fat thickness, KPH, DP and YG observed in the CTN steers. There were also no differences in rib eye area (REA), further supporting the idea that the CTN cattle were gaining weight mostly as fat instead of lean tissue at the end of the finishing period. Liver scores were also assessed, and no differences were observed between treatments (Table 4; $P \leq 0.17$).

Fecal Characteristics

Fecal grab samples were evaluated for consistency to estimate the extent of digestion of experimental diets. Although fecal consistency can be altered by various functions and factors, fecal consistency is thought to be indicative of the site and extent of digestion of feed. When hindgut fermentation increases as a result of an increased passage rate, fecal consistency can appear more "loose" (Hall, 2007; Kononoff, 2002). Additionally, a loose fecal consistency can be a sign of less effective fiber in the diet (Woolsoncroft, 2018). Fecal scores were lowest, or more firm, on d 0 and increased after beginning the transition to the finishing rations. This was expected, as the steers had previously been consuming only mature Bermuda grass pasture and were transitioned to a high concentrate, low fiber diet, starting on d 8 of the experiment.

On d 56, CTN steers had lower fecal scores (2.93 vs. 3.19; $P = 0.03$) than CON steers, although this is likely of low biological significance. No differences in fecal scores were detected for any other period; however, steers consuming CTN diet were scored numerically lower during every collection period once consuming the finishing diet. This numerical difference in fecal consistency from d 28 to final possibly suggests that the

CON diet resulted in a faster passage rate and greater extent of hindgut digestion than the CTN diet. Since the CTN diet contained more peNDF, mostly due to the inclusion of WCS, a lower fecal score was not surprising. There were no differences in fecal score change for either treatment within any collection period, therefore fecal scores did not change more dramatically for one treatment compared to the other between periods ($P >$ 0.21).

Fecal pH was also taken as an indicator of site and extent of digestion. A decrease in fecal pH may suggest a decrease in extent of rumen fermentation and a subsequent increase in hindgut fermentation (Yang and Beauchemin, 2006). Although digestibility was not directly measured in this study, previous literature suggests that a higher fecal pH might be attributed to less starch present in the feces, indicating a further extent of starch digestion (Wheeler and Noller, 1977). Greater amounts of starch in the feces may be reflective of pH being too low for optimal amylase activity in the small intestine (Turgeon et al., 1981). Fecal pH was highest on d 0, which was reflective of the cattle consuming mature Bermuda grass pasture before arrival to the feedlot.

As expected, fecal pH decreased as concentrate levels increased through transition period. On d 28, fecal pH tended to be higher in the CTN steers ($P = 0.09$) but no differences in fecal pH were observed between treatments on any other collection day (Table 5). However, similar to fecal consistency scores, fecal pH was often numerically greater for the CTN steers compared to the CON steers. This numerical difference may support the suggestion that the CTN diet had further extent of digestion in the rumen, possibly due to a slower passage rate, which could result in less starch present in the feces. Since digestibility and fecal starch content were not directly measured in this

experiment, further research is required to validate these suggestions. There were no differences in fecal pH change at any period in the study, therefore fecal pH did not change more dramatically for one treatment compared to the other between periods ($P \geq 0.10$).

Plasma Metabolites

A treatment × day interaction was observed for PUN concentrations (Figure 1; $P = 0.04$). Although both treatments decreased in PUN concentration from d 14 to 28, the CTN steers had a greater decrease than the CON steers ($P = 0.03$). From d 28 to 56, PUN concentrations increased, however the increase was greater in the CON steers than the CTN steers ($P = 0.002$). Although the reason for these differences is unclear, we speculate that amino acid catabolism might have been decreased in the CTN steers, ultimately resulting in lower PUN concentrations on d 28 and 56. The CTN fed steers had numerically lower PUN levels on every collection day aside from the final measurement, at which CTN fed steers had numerically greater levels of PUN ($P \geq 0.05$).

Generally speaking, both treatments had the maximum PUN level on d 0, decreased through the receiving and transition period, and steadily increased from d 28 to harvest. This can be attributed to the fact that DMI was increasing in both treatments from d 28 to harvest, resulting in higher total protein consumption. Van Bibber-Krueger et al. (2017) reported PUN levels between 3.33 and 4.51 mMol/L in finishing heifers supplemented with ractopamine hydrochloride and Zn. These values are similar to results seen in this experiment, which on average ranged from 3.80 to 3.99 mMol/L from d 112 to the end of the finishing period.

No treatment × day interaction was detected for plasma glucose or lactate concentrations (Table 6). A day effect ($P < 0.0001$) was observed for plasma glucose concentrations, however there was no main effect ($P = 0.67$) of treatment. The day effect was observed on d 28 and final, when the lowest plasma glucose concentrations were detected for both treatments. Glucose values observed at any period averaged between 84.1 and 98.5 (± 3.1) mg/dL. These concentrations are within expected normal ranges; previous studies have reported plasma glucose levels ranging from 65.2 to 101.1 mg/dL in finishing feedlot steers (Evans et al. 1975; Hancock et al. 1988; Kolath et al. 2006). A day effect ($P < 0.001$) was also detected for plasma lactate concentrations, but no treatment effect ($P = 0.91$) was detected. Peak plasma lactate concentrations were observed on d 0 for both treatment groups, which is likely due to the stressors associated with shipping. Mitchell et al. (1988) also reported higher levels of plasma lactate in ruminants after transportation, with values averaging 0.42 ± 0.15 g/L, which are similar to d 0 results in the current experiment, 0.40 ± 0.03 g/L. After arrival, lactate concentrations decreased and remained steady regardless of treatment from d 14 to d 112, and were similar to those reported by Sako et al. (2007).

At the final collection, lactate concentrations had further decreased. Because lactate is a product of glucose metabolism, the decrease in lactate at the final collection is likely related to the decrease in glucose concentration at the same time. When examined in combination, the minimal differences in plasma metabolite data between the 2 treatments indicate that observed differences in growth rates are not likely due to substantial alterations in glucose or protein metabolism. Additional metabolite

measurements are needed to further support this conclusion, as only a small portion of overall metabolism was measured in this experiment.

CONCLUSION

This experiment suggests that WCS and CGT can be effectively used as protein, fat, and fiber sources in a finishing feedlot diet without compromising performance or carcass characteristics. Including cotton byproducts in the diet improved ADG and DMI without impacting G:F. Carcasses of steers fed the CTN diet were heavier with a greater dressing percentage, back fat, yield grades, and KPH fat. The fecal consistency and pH data from this experiment combined with the limited research available investigating the digestibility of cotton byproducts warrants further investigation. A subsequent experiment will be conducted to evaluate the in situ digestibility of these diets and the individual ingredients. Overall, this experiment has implications for feedlots in the Southwestern U.S. to utilize cotton byproducts in finishing diets if cotton byproducts are available at an economical cost compared to other protein, fat, and fiber sources.

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Table 2.1: Ingredient and nutrient composition of diets

	Diet		
Ingredient, % of DM	RCV[1]	CON[2]	CTN[3]
Rolled corn	12.7	67.25	72.25
Prairie hay	22.5	7.0	-
Cotton gin trash	-	-	7.0
Whole cottonseed	-	-	15.0
Sweet Bran[4]	60.7	15.0	-
Liquid supplement[5]	-	5.0	-
Dry supplement[6]	4.1	5.0	5.0
Urea	-	0.75	0.75
Nutrient composition, DM basis			
Dry matter, %	70.10	80.70	84.34
Crude protein, %	16.70	14.16	14.13
Neutral detergent fiber, %	- [7]	25.15	27.33
Acid detergent fiber, %	23.90	8.59	15.28
peNDF[8], %	-	8.80	9.82
TDN, %	68.90	79.30[9]	78.20[9]
Fat, %	-	3.25	5.82
NE_m, Mcal/kg	1.00	1.72[10]	1.69[10]
NE_g, Mcal/kg	0.69	1.10[10]	1.07[10]
Ca[11], %	0.53	0.62	0.85
P, %	0.53	0.57	0.46
K, %	0.93	1.00	0.84
S, %	-	0.22	0.19
Na, %	-	0.11	0.05
Mg, %	-	0.29	0.28
Cu, mg/L	-	20.00	24.60
Fe, mg/L	-	144.57	165.93
Zn, mg/L	-	161.03	145.97
Mn, mg/L	-	58.32	57.86

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

[2] Control diet (CON); representative of a typical finishing diet

[3] Cotton diet (CTN); cotton byproducts used as the primary protein, fat, and fiber source in the diet

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

[5] Liquid supplement was formulated to contain (% DM basis) 45.86% corn steep, 36.17% cane molasses, 6% hydrolyzed vegetable oil, 5.46% 80/20 vegetable oil blend, 5.2 % water, 1.23% urea (55% solution), and 0.10% xanthan gum.

[6] 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), 0.10% vitamin E (500 IU/g), 0.009% vitamin D (30,000 IU/g), 0.20 % tylosin (Tylan-40,

Elanco Animal Health, Greenfield IN) and 0.33% monensin (Rumensin- 90; Elanco Animal Health)

[7] A – symbol under nutrient composition indicates nutrient not analyzed in the receiving ration

[8] Physically effective fiber provided by the roughage and byproducts in the diet

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

[10] Calculated according to NASEM (2016)

[11] Minerals analyzed by the Soil, Water and Forage Analytical Laboratory (Stillwater, OK)

Table 2.2: Particle separation and estimated physically effective fiber of diet ingredients

	Ingredient[1]			
Item	PH	SB	WCS	CGT
NDF[2], % DM	66.0	35.7	40.0	65.7
Sieve Screen size, mm	Retained/screen %			
19.0	30.3	0	1.8	29.8
8.0	25.1	3.4	89.3	32.7
4.0	32.8	84.8	6.9	23.3
Particles less than 4mm	11.8	11.8	2.0	14.3
Particles greater than 4mm	88.2	88.2	98.0	85.7
Estimated peNDF[3], % DM	58.2	31.5	39.2	56.3

[1] PH = prairie hay, SB = Sweet Bran, WCS = whole cottonseed, CGT = cotton gin trash

[2] Neutral detergent fiber

[3]Percent of physically effective NDF was estimated by multiplying the percentage of sample larger than 4 mm in particle size by the percent NDF (as a decimal) of the ingredient before separation

Table 2.3: Effect of including cotton byproducts in a finishing ration on growth performance and feed efficiency of crossbred steers

	Treatment[1]			
Item	CON	CTN	SEM[2]	*P*-value
BW,[3]kg				
d 0	312	313	11.8	0.49
d 14	349	350	11.5	0.87
d 28	382	380	11.9	0.54
d 56	446	453	14.4	0.18
d 84	496	509	17.4	0.07
d 112	542	559	17.6	0.50
Final[4]	614	632	11.7	0.09
ADG[5], kg				
d 0 to 14	2.69	2.68	0.203	0.98
d 14 to 28	2.36	2.12	0.115	0.14
d 28 to 56	2.28	2.61	0.161	0.15
d 56 to 84	1.78	2.02	0.132	0.10
d 84 to 112	1.63	1.79	0.063	0.04
d 112 to final	1.73	1.80	0.060	0.29
d 0 to 28	2.53	2.40	0.107	0.43
d 28 to final	1.84	2.03	0.085	0.06
d 0 to final	1.95	2.09	0.080	0.08
DMI[6], kg/d				
d 0 to 14	7.0	7.1	0.16	0.49
d 14 to 28	11.2	10.3	0.36	0.09
d 28 to 56	11.3	11.8	0.55	0.41
d 56 to 84	12.3	13.3	0.57	0.07
d 84 to 112	12.5	13.4	0.45	0.03
d 112 to final	13.0	13.9	1.05	0.09
d 0 to 28	9.1	8.9	0.18	0.42
d 28 to final	12.3	13.2	0.46	0.07
d 0 to final	11.7	12.4	0.35	0.04
G:F[7]				
d 0 to 14	0.391	0.379	0.0314	0.74
d 14 to 28	0.210	0.208	0.0091	0.83
d 28 to 56	0.204	0.220	0.0077	0.16
d 56 to 84	0.145	0.151	0.0060	0.40
d 84 to 112	0.131	0.135	0.0065	0.39
d 112 to final	0.134	0.130	0.0032	0.30
d 0 to 28	0.279	0.272	0.0121	0.68
d 28 to final	0.150	0.153	0.0029	0.32
d 0 to final	0.167	0.167	0.0036	0.86

[1] Treatments included (DM basis): (CON) = 7% hay, 15% Sweet Bran, 67.25% rolled corn, 5% liquid supplement, or (CTN) = 7% cotton gin trash, 15% whole cottonseed, 72.75% rolled corn. Both rations contained 5% dry supplement and 0.75% urea

[2] n = 8 pens per treatment

[3] Body weight adjusted by a 4% calculated pencil shrink

[4] Cattle were harvested in 2 groups; d 140 (n = 4 pens per treatment) and d 168 (n = 4 pens per treatment)

[5] Pen average daily gain ADG calculated from individual shrunk body weight gain, kg divided by days on feed for each period

[6] Pen dry matter intake calculated from total DMI for the pen for each period divided by the total steers and days on feed in each period

[7] Gain to feed calculated by dividing the ADG for the pen by the average daily DMI for the pen for each respective period.

Table 2.4: Effect of including cotton byproducts in a finishing ration on the carcass characteristics of crossbred feedlot steers

	Treatment [1]			
Item	CON	CTN	SEM[2]	*P*-value
Hot carcass weight, kg	382	396	7.0	0.02
Rib eye area, cm^2	96.0	95.1	1.93	0.64
Fat thickness[3], cm^2	1.24	1.37	0.064	0.03
KPH[4], %	1.81	1.91	0.063	0.09
Dressing percentage	62.2	62.7	0.28	0.10
Calculated yield grade	2.51	2.83	0.109	0.07
Marbling score[5]	508	499	14.3	0.64
Liver score[6], % of pen				
O	90.6	83.3	4.8	0.18
A -	3.13	9.38	3.917	0.17
Contamination	6.25	7.29	4.480	0.86

[1] Treatments included (DM basis); (CON) = 7% hay, 15% Sweet Bran, 67.25% rolled corn, 5% liquid supplement, or (CTN) = 7% cotton gin trash, 15% whole cottonseed, 72.25% rolled corn. Both rations contained 5% dry supplement and 0.75% urea

[2] n = 8 pens per treatment

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

[4] Kidney, pelvic, and heart fat

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

[6] Liver scores at harvest: O = normal, healthy liver, free of abscesses. A- = livers that displayed less than 2 abscesses which are generally less than 2.54 cm in diameter. Contaminated = contaminated with fecal material during harvest

Table 2.5: Effects of including cotton byproducts in a finishing ration on the fecal score and fecal pH of crossbred feedlot steers

	Treatments[1]			
Item	CON	CTN	SEM[2]	*P*-value
Fecal score[3]				
d 0	2.33	2.50	0.110	0.30
d 14	3.03	3.06	0.182	0.91
d 28	2.78	2.76	0.115	0.89
d 56	3.19	2.93	0.087	0.03
d 84	3.00	2.83	0.161	0.43
d 112	3.06	2.88	0.103	0.18
Final[3]	3.06	2.95	0.100	0.26
Fecal score change[5]				
d 0 to 14	0.70	0.56	0.205	0.62
d 14 to 28	-0.25	-0.30	0.247	0.88
d 28 to 56	0.41	0.17	0.138	0.24
d 56 to 84	-0.19	-0.09	0.136	0.63
d 84 to 112	0.06	0.04	0.172	0.93
d 112 to final	0.00	0.07	0.101	0.62
d 0 to 28	0.45	0.26	0.128	0.32
d 28 to final	0.28	0.19	0.159	0.63
d 0 to final	0.73	0.45	0.157	0.21
Fecal pH				
d 0	8.14	8.18	0.048	0.54
d 14	6.88	6.96	0.063	0.39
d 28	6.82	6.97	0.075	0.09
d 56	6.66	6.69	0.062	0.72
d 84	6.74	6.72	0.064	0.80
d 112	6.78	6.87	0.085	0.42
Final	6.80	6.88	0.083	0.48
Fecal pH change[5]				
d 0 to 14	-1.27	-1.22	0.098	0.81
d 14 to 28	-0.06	-0.02	0.083	0.21
d 28 to 56	-0.16	-0.28	0.107	0.40
d 56 to 84	0.08	0.03	0.098	0.71
d 84 to 112	0.04	0.16	0.096	0.10
d 112 to final	0.02	0.01	0.115	0.96
d 0 to 28	-1.31	-1.20	0.098	0.38
d 28 to final	-0.02	0.09	0.120	0.64
d 0 to final	-1.34	-1.29	0.077	0.71

[1] Treatments included (DM basis); (CON) = 7% hay, 15% Sweet Bran, 67.25% rolled corn, 5% liquid supplement, or (CTN) = 7% cotton gin trash, 15% whole cottonseed, 72.25% rolled corn. Both rations contained 5% dry supplement and 0.75% urea.

[2] n = 8 pens per treatment
[3] Fecal score adapted from Ireland-Perry and Stallings (1993) and Woolsoncroft et al. (2017), with a greater score indicating a looser fecal consistency on a scale of 1 to 5 with a 1 representing a cow on dry hay and 5 being the consistency of water.
[4] Cattle were harvested in 2 groups; d 140 (n = 4 pens per treatment) and d 168 (n = 4 pens per treatment)
[5]The difference between collection periods; the later date was subtracted from the earlier date

Table 2.6: Effects of including cotton byproducts in a finishing ration on the plasma metabolite levels of crossbred feedlot steers

	Treatments[1]				Days on feed								
Variable	CON	CTN	SEM[2]	*P*-Value	0	14	28	56	84	112	Final[3]	SEM[2]	P-Value
Glucose, mg/dL	93.4	92.7	1.30	0.67	96.3[a]	95.0[a]	86.9[b]	96.3[a]	96.7[a]	95.6[a]	84.9[b]	3.10	< 0.001
Lactate, g/L	0.258	0.256	0.013	0.91	0.373[a]	0.253[b]	0.254[b]	0.246[b]	0.257[b]	0.233[b]	0.182[c]	0.0195	< 0.001

[1] Treatments included (DM basis); (CON) = 7% hay, 15% Sweet Bran, 67.25% rolled corn, 5% liquid supplement, or (CTN) = 7% cotton gin trash, 15% whole cottonseed, 72.25% rolled corn. Both rations contained 5% dry supplement and 0.75% urea.

[2] n = 8 pens per treatment

[3] Cattle were harvested in 2 groups; d 140 (n = 4 pens per treatment) and d 168 (n = 4 pens per treatment)

[4] Within row, values with unlike superscripts are different ($P < 0.05$)

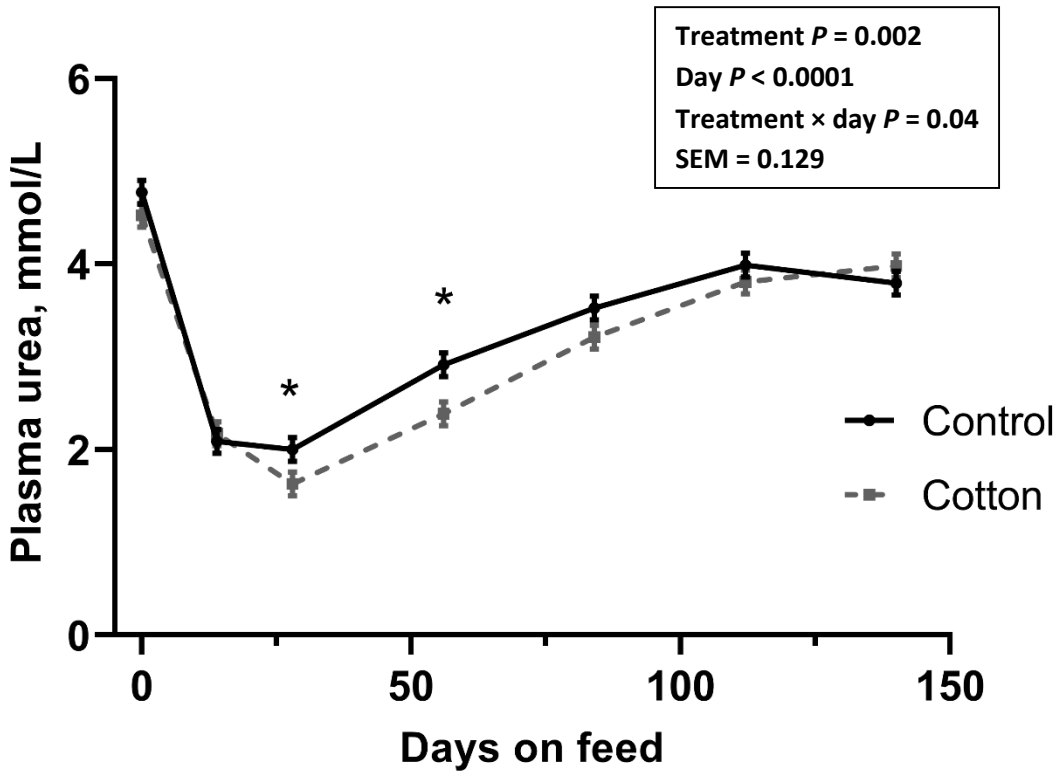

Figure 2.1: Concentration of plasma urea nitrogen in finishing steers consuming a control (7% hay, 15% Sweet Bran, 67.25% rolled corn, 5% liquid supplement, 5% dry supplement, 0.75% urea) or cotton byproduct (7% cotton gin trash, 15% whole cottonseed, 72.25% rolled corn, 5% dry supplement, 0.75% urea) diet. An * represents a significant difference between treatments.

[1]Cattle were harvested in 2 groups; d 140 (n = 4 pens per treatment) and d 168 (n = 4 pens per treatment). In this figure, 140 days on feed is representative of the final measurement, regardless of harvest date.

CHAPTER III

EVALUATION OF RUMINAL DEGRADABILITY AND METABOLISM OF FEEDLOT FINISHING DIETS WITH OR WITHOUT COTTON BYPRODUCTS

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ABSTRACT: Cotton byproducts have potential to be an economical source of protein, fat, and fiber in cattle finishing diets. The objectives of this study were 1) to assess the effects of whole cottonseed (WCS) and cotton gin trash (CGT) inclusion in finishing diets on in situ ruminal digestibility; and 2) to determine the effects of including cotton byproducts in a finishing diet on rumen fluid pH, lactate, and VFA concentrations. Six ruminally cannulated steers were used in a crossover design. Treatments included a control diet (CON; 7% prairie hay (PH), 15% Sweet Bran, 67.25% rolled corn, 5% liquid supplement) and a cotton byproduct diet (CTN; 7% CGT, 15% WCS, 72.25% rolled corn, 5% water). Both diets included 0.75% urea and 5% dry supplement. In situ bags containing individual diet ingredients and whole diet samples were incubated in the rumen for up to 96 h. Rumen fluid samples were collected over a 24 h period. No treatment × substrate interactions were detected for any fraction of DM or OM

degradability for individual ingredients or whole diets. The A, B, and C fractions, Kd and effective degradability of DM and OM differed between diet ingredients ($P \leq 0.04$) but were not different between CON and CTN substrates ($P \geq 0.25$). A treatment × substrate interaction ($P = 0.04$) was detected for the effective degradability of NDF of CGT and PH but there was no interaction for any other fraction. The A fraction of NDF was greater ($P < 0.001$) for CGT than prairie hay however, the B fraction of NDF tended to be greater ($P = 0.08$) for prairie hay than CGT. No differences ($P \geq 0.37$) were detected for the % NDF disappearance at 48 h between CON and CTN substrates. A tendency for a treatment × substrate interaction ($P = 0.10$) was observed for the effective degradability of starch among diets however, when the CON substrate was incubated in steers consuming the CON diet, effective degradability of starch was not different ($P = 0.84$) from when the CTN substrate was incubated in steers consuming the CTN diet. There was no treatment × time interaction or treatment effect for rumen pH, however, there was a time effect ($P = 0.03$). Steers consuming the CTN diet had greater molar proportions of acetate and decreased molar proportions of propionate compared to CON steers ($P \leq 0.002$). This experiment suggests that there are minimal differences between the digestibility of finishing diets containing cotton byproducts and those comprised of more common finishing diet ingredients.

INTRODUCTION

A recent increase in cotton production in the Southwestern United States has increased the availability of cotton byproducts for use in cattle diets. Cotton gin trash (CGT) consists of the leaves, sticks, burrs, stems, and soil remaining after the ginning process and can be an inexpensive source of physically effective (PE) fiber compared to

other medium-to low-quality forages in feedlot diets. Whole cottonseed (WCS) is unique in that WCS provides a substantial amount of protein and fat while also providing additional PE fiber in the diet. Previous experiments have been conducted to determine the effects of including cotton byproducts in finishing feedlot diets on performance and carcass characteristics. Cranston et al. (2006) included various levels and sources of WCS and cottonseed meal in feedlot finishing diets and reported little to no adverse effects on performance or carcass characteristics. Warner et al. (2020) supplied protein, fat, and fiber in the finishing diet using WCS and CGT. Steers consuming the cotton byproduct based diet (CTN) had increased dry matter intakes (DMI), average daily gains (ADG), and final body weights (BW) compared with steers fed a control diet (CON) without cotton products. Additionally, Warner et al. (2020) reported that steers consuming the CTN diet had heavier hot carcass weights (HCW), greater dressing percentages (DP), back fat (BF) thicknesses, yield grades (YG), and percentages of kidney, pelvic, and heart fat (KPH) compared with steers consuming the CON diet.

Understanding the digestion kinetics of cotton byproducts and common feed ingredients could help to explain the results of previous feeding trials. Therefore, the objectives of this experiment were 1) to assess in situ ruminal degradability of dry matter (DM), organic matter (OM), neutral detergent fiber (NDF), and starch of traditional diet ingredients, cotton byproducts, and whole diets; and 2) to determine the effects of including cotton byproducts in a finishing diet on rumen fluid pH, lactate, and volatile fatty acid (VFA) concentrations.

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-16-17).

Cattle and Diets

Six ruminally cannulated crossbred beef steers (BW = 898 ± 21.6 kg) were used in this experiment. Steers were individually housed in partially covered, soil surfaced 6.1 × 10.9 m feedlot pens with a shared 76-L concrete water tank between adjacent pens (model J 360-F; Johnson Concrete, Hastings, NE). Treatment diets (Table 1) included a CON finishing diet that consisted of 7% prairie hay (PH), 15% Sweet Bran (SB; Cargill Inc., Dalhart, TX), 67.25% dry-rolled corn (DRC), and 5% of a corn steep and molasses based fat supplement or a CTN diet which contained 7% CGT, 15% WCS, 72.25% DRC, and 5% water to condition the diet. Both diets contained 0.75% urea and 5% dry supplement. Feeding occurred once daily at 0800 h and steers had ad libitum access to feed and water throughout the experiment.

This experiment was organized as a crossover design. Steers were randomly assigned to 1 of the 2 treatment diets for period 1 and were transitioned to the opposite diet for period 2. On d 0, steers began a 14 d transition from a common receiving diet (Table 1) to the respective finishing diet by increasing the amount of finishing diet delivered by 4 to 5 percent each d. Once steers were consuming 100 percent of the finishing diet, a 21 d acclimation period was allowed for the rumen environment to adapt to the diet. Once steers were acclimated to the finishing diets, a 96 h in situ incubation and a 24 h rumen fluid collection was completed. After the period 1 incubation and collection was completed, steers were transitioned from the period 1 diet to the period 2 diet over a 14 d period by increasing the amount of the new diet delivered by 4 to 5

percent each d. Steers were consuming 100 percent of the respective finishing diet for period 2 on d 56 and were then again allowed 21 d for the rumen environment to adapt before period 2 collections began. Once steers were acclimated to the period 2 finishing diets, another 96 h in situ incubation and a 24 h rumen fluid collection was completed.

Sample Preparation and Collection

In situ procedures for this experiment were adapted from Vanzant et al. (1998). Throughout this manuscript, the term" substrate" refers to the feedstuff item placed into the in situ bags for incubation. The 7 substrates used for in situ incubation included the diet components (PH, CGT, WCS, SB, and DRC), as well as whole ration samples for both the CON, and CTN diets. Each substrate was ground to pass through a 6 mm screen (Wiley Cutting Mill Model 4; Thomas Scientific, Swedesboro, NJ) and dried for 48 h at 55°C in a convection oven. Substrates were then placed into a benchtop desiccator and allowed to equilibrate to room temperature before being weighed into woven nylon in situ bags (10 × 20 cm R1020 Forage Bag; 50µm pore size, ANKOM Technology, Macedon, NY). Each bag contained 4.0 g of substrate on a DM basis to achieve a sample size:bag surface area ratio of 10 mg/cm^2, based on recommendations from Vanzant et al. (1998). After each substrate was weighed into the in situ bag, a tabletop impulse sealer (ULINE, Pleasant Prairie, WI) was used to seal the bag. In situ bags that were to be incubated for 0, 3, 6, 12 and 24 h were made in triplicate, while bags that were to be incubated for 48, 72, and 96 h were made in quadruplicate in an attempt to ensure adequate substrate was available for post-incubation analysis. All 7 substrates were incubated in every steer for both periods, regardless of treatment. For each time point, all in situ bags were placed into a mesh bag with a string attached for ease of removal.

In situ bags were inserted into the ventral sac of the rumen 96, 72, 48, 24, 12, 6, and 3 h before simultaneous removal. Immediately upon removal, bags were shocked in an ice bath and gently rinsed until rinse water ran clear. Hour 0 bags were also rinsed to estimate the immediately soluble fraction of each substrate. After rinsing, bags were placed into a forced air oven at 55°C for a minimum of 168 h and were rotated daily to ensure all bags received direct airflow.

Rumen fluid samples were collected 2 d after the in situ collections in each period. Sampling began at 0730 to represent a 0 h sample. Following the h 0 rumen fluid collection, steers were returned to home pens and fed at approximately 0800 h. Rumen fluid was collected at 2, 4, 6, 8, 10, and 12 h post-feeding. A 50 mL sample was collected from each steer through the rumen cannula using a suction strainer. Immediately after collection, pH was measured using a portable pH meter (pH 6+ Meter; Oakton Instruments, Vernon Hills, IL). The 50 mL sample was aliquoted into 2 microcentrifuge tubes each containing 1 mL of rumen fluid to be stored for subsequent analysis (1 aliquot for lactate analysis and 1 aliquot for VFA analysis). The aliquot designated for VFA analysis included 100 µL of meta-phosphoric acid and 100 µL of a 2-ethyl butyrate internal standard. Rumen fluid samples were stored at -20°C until analysis.

Laboratory Analysis

Upon removal of in situ bags from the drying ovens, bags were placed into a tabletop desiccator and allowed to equilibrate to room temperature. Bags were individually removed from the desiccator, weighed, and the weight of each bag was recorded. Substrates were composited by period, animal, and hour and stored for further

analysis. All post-incubation in situ substrates were ground to pass a 2mm screen (Wiley Mini-Mill; Thomas Scientific, Swedesboro, NJ) prior to analysis.

All in situ samples were analyzed for DM in duplicate by weighing 1.0 g of substrate into a crucible and placing the crucible into a convection oven at 100°C for a minimum of 12 h. Crucibles were then removed from the oven, cooled in a desiccator to equilibrate to room temperature, and weighed again. Dry matter was determined using the equation: DM, % = (dry sample weight ÷ wet sample weight) × 100. After DM analysis, crucibles were placed into a muffle furnace at 600°C for a minimum of 3 h to determine ash content to calculate OM. Samples were removed from the muffle furnace and immediately placed into a desiccator to equilibrate to room temperature before weighing. Organic matter was determined using the equation: OM, % = 100 - (ash weight ÷ sample weight × 100).

Neutral detergent fiber was analyzed in duplicate for the CGT, PH, CON, and CTN in situ samples post-incubation. Samples were analyzed in an ANKOM 2000 automated fiber analyzer (ANKOM Technology; Macedon, NY) according to manufactures instructions.

Starch was analyzed for all post-incubation DRC, CON, and CTN samples using methods adapted from the acetate buffer method as described by Hall (2009). A 0.17 g sample was weighed into glass screw top tubes and 30 mL of acetate buffer and 100 µL of heat stable alpha amylase (ANKOM Technology; Macedon, NY) were added to each tube. The glass tubes were then incubated for 1 h in a 100°C water bath and vortexed at 10, 30, and 50 min of incubation. After tubes were removed from the water bath and cooled, 50 µL of amyloglucosidase (Megazyme; Bray, Ireland) was added to the tubes,

vortexed, placed into a 60°C water bath, and vortexed again after 1 h of incubation. After removal from the water bath, 20 mL of water was added to the tubes and vortexed. Then, 1.5 mL of liquid from each tube was transferred into a microcentrifuge tube, centrifuged at 12,000 × g for 10 min, and the supernatant was transferred to a 96 well plate for glucose to be determined using an immobilized enzyme system (YSI Model 2950 D; YSI Inc., Yellow Springs, OH).

For $_{L}$-lactate analysis, rumen fluid was centrifuged at 21,100 × g for 15 min at 20°C (Sorvall Legend Microcentrifuge; Thermo Scientific, Hampton, NH). The supernatant was analyzed using an immobilized enzyme system (YSI Model 2950 D; YSI Inc., Yellow Springs, OH). The VFA concentrations of rumen fluid were analyzed at the University of Kentucky Ruminant Nutrition Laboratory using gas chromatography with a flame ionization detector (Foote et al., 2013).

Calculations

The following were calculated for each substrate post-incubation. Dry matter remaining (DMR) was calculated as 100 × (total dry weight – empty bag weight) ÷ initial sample weight. Percent DM disappearance was calculated as 100 – DMR. Organic matter remaining (OMR) was calculated as 100 × (dry sample weight × OM of incubated sample) ÷ (initial sample weight × OM of original sample). Percent organic matter disappearance was calculated as 100 – OMR. Neutral detergent fiber remaining (NDFR) was calculated as 100 × (dry sample weight × NDF of incubated sample) ÷ (initial sample weight × NDF of original sample). Percent NDF disappearance was calculated as 100 – NDFR. Percent starch remaining was calculated as 100 × (dry sample weight × starch of

incubated sample) ÷ (initial sample weight × starch of original sample). Percent starch disappearance was calculated as 100 – percent starch remaining.

Fractions of DM, OM, NDF, and starch in this experiment were originally defined as follows by Ørskov and McDonald, (1979). The A fraction is defined as the immediately soluble fraction, disappearing at a rapid rate upon insertion into the rumen. The B fraction is defined as the amount of DM, OM, NDF, or starch that disappears at a measurable rate. The C fraction is defined as undegradable, or the amount which did not disappear over the period of observation. The A fraction was determined by the calculation 100 – (B + C). The B and C fractions, disappearance rate (Kd), and lag time were determined using the nonlinear regression model. The effective degradability of DM, OM, NDF, and starch was calculated by the Ørskov and McDonald (1979) equation $A + \{B \times [Kd/(Kd + Kp)]\}$ where passage rate (Kp) was assumed to be 4%/h, an average passage rate for feed particles in beef cattle diets (NASEM, 2016).

Statistical Analysis

In situ disappearance curves for each steer and substrate were analyzed by nonlinear regression using the NLIN procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). The parameters for each fraction were defined as follows: B fraction: 20 to 50 by 2, Kd: 0 to 0.2 by 0.1, L: 0 to 10 by 1, and C fraction: 10 to 40 by 2. Bounds for the model were specified as follows: B fraction: 0 to 100, C fraction: 0 to 100, Kd: 0 to 30%/h, L: 0 to 48 h. If the undegradable fraction initially violated the C bound, the undegradable fraction was manually set to be the percent remaining at 96 h for the substrate. The undegradable fraction of starch was assumed to be 0 and was manually set as such for all substrates in which starch was measured. The degradable fractions of DM, OM, NDF,

and starch, and the % NDF remaining at 48 h for each substrate were compared using the MIXED procedure of SAS 9.4. The model included substrate, treatment, and substrate × treatment as main effects and animal × period was included in the random statement.

Rumen fluid pH, lactate, and VFA data were analyzed using the MIXED procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). The fixed effects of treatment, time, period, and treatment × time were used in the model to evaluate the data. Time within period was included as a repeated measure with autoregressive covariance structure and individual animal was the subject. The autoregressive covariance structure was determined to provide the best fit (i.e., lowest Akaike information criterion) for the pH, lactate, and VFA data in the current experiment. For all data, significance was determined when $P \leq 0.05$ and tendencies were considered when $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

In situ DM Disappearance

There was no treatment × substrate interaction ($P \geq 0.14$; Table 2) or main effect of treatment ($P \geq 0.62$) for DM disappearance of any fraction; therefore, only the main effect of substrate is reported. The greatest A fraction was observed for SB, with 48.2% of the DM considered immediately soluble. It is well documented that wet corn gluten feed (WCGF) is rapidly and extensively degraded in the rumen due to the considerable amount of soluble steep liquor (McCoy, 1997). However, the observed A fraction of SB in this experiment was greater than the A fraction of WCGF reported by Sindt et al. (2003) who reported that 31.2% of the DM in WCGF was immediately soluble. It is important to note that not all of the previously reported research clarifies the source of WCGF used in the experiment. Sweet Bran has an increased DM (NASEM, 2016) and

varies in nutrient composition compared to unbranded WCGF sources. This variation in nutrient composition may explain the variation between results reported in the current experiment and results reported in previous literature.

Corn and WCS had similar ($P = 0.53$) A fraction values of 16.1 and 15.6%, respectively. The A fraction of WCS in this experiment was reduced compared to results from Aierli et al. (1988) who reported that 36.6% of the DM in WCS was immediately soluble, which could be due to a difference in substrate processing prior to the in situ incubation. Aierli et al. (1988) used WCS that was ground to pass through a 1-mm screen instead of a 6-mm screen. Decreasing particle size could have increased the amount of small particles that were able to escape the pores of the in situ bag immediately upon insertion. The C fraction of WCS was over twice that of SB (47.0 vs 18.5%, respectively) which was likely attributed to the greater fiber content (35.7% vs 40.0% for SB and WCS, respectively) of the WCS as well as the greater A fraction of the SB. Despite the differences observed among the A and C fractions of the byproducts, there was no difference ($P = 0.43$) in the B fraction between SB and WCS.

The CGT had an increased A fraction compared to PH by approximately 14% ($P < 0.001$). The increased A fraction value of the CGT was likely due to the large amount of small particles that were able to escape the pores of the in situ bags upon insertion into the rumen. The C fraction, or the percent of DM undegradable in the rumen, was greatest for PH at 73.6% of DM, while the CGT had a decreased ($P < 0.001$) C fraction of 59.3% of DM compared to the PH. The observed difference between the C fraction of PH and CGT was likely associated with the greater ($P < 0.001$) immediately soluble fraction of the CGT compared to the PH. Despite the differences observed in both the A and C

fractions among primary roughage sources, the amount of DM that disappeared at a measurable rate was almost identical between the CGT and PH (15.7 vs 15.6%, respectively; $P = 0.98$).

As expected, the Kd of DM was determined to be slowest for the primary roughage sources, CGT and PH. The Kd of DM did not differ between CGT and PH (2.6 vs 3.2%/h, respectively; $P = 0.47$). The SB, DRC, and WCS had similar Kd (4.1, 5.2, and 4.9%/h, respectively; $P > 0.10$). Sindt et al. (2003) reported a similar Kd of 4.3%/h for WCGF in cannulated Jersey cattle consuming a diet comprised of 6% alfalfa hay, 24% WCGF, and 60% steam flaked corn. However, Firkins et al. (1985) reported a slightly faster Kd of 4.9% per h for WCGF in steers consuming a diet comprised of corn silage, soybean meal, WCGF, and dry distiller's grains. The lag time observed for DM was similar ($P = 0.11$) between CGT and PH. The lag times observed for all other substrates ranged from 1.7 to 5.6 h and were not found to be different from each other ($P > 0.10$) which is likely due to the variance observed in the data for this fraction of DM.

The effective degradability of DM was different among all substrates ($P \leq 0.05$). As predicted, SB had the greatest effective degradability of DM (64.8%) among substrates. The WCS had an effective degradability of 34.8% of DM in the current experiment, which was decreased compared to the value reported by Arieli et al. (1989), who reported that in WCS 48.4% of the DM was ruminally degradable. The effective degradability of DRC was observed to be 58.7% of DM, and is consistent with in situ DM digestibility results previously reported in the literature when corn was ground through a 4mm screen prior to incubation (56.8%; Lee et al., 2002). The primary roughage sources displayed the least effective degradability of DM among substrates.

Among roughage sources, the PH had a decreased effective degradability of 14.7% of DM, compared to the CGT, which had an effective degradability of 29.4% of DM. The effective degradability calculation includes the A and B fractions, Kd, and Kp. The observed difference of effective degradability among primary roughage sources was likely a result of the increased A fraction associated with the CGT compared to the PH, as the B fraction and Kd were similar among the 2 substrates.

The effective degradability of CGT in this experiment was decreased compared to results previously reported in the literature, however the difference in observed results may possibly be due to the variance of particle size among experiments. Pordesimo et al. (2005) investigated the effects of particle size of CGT on in vitro dry matter digestibility (IVDMD), and reported that CGT with a larger particle size had a decreased percentage of IVDMD. Gin trash ground to pass a screen size of 2.0 mm had only a 33.8% IVDMD while CGT ground to pass a 0.5 mm screen had an IVDMD of 47.8% (Pordesimo, 2005). In the current experiment, CGT was ground to pass a 6.0 mm screen, which could be a source of variation between the DM disappearance observed between this experiment and the results from previous literature. Other low to medium quality roughages have had varied results concerning effective degradability of DM. For example, rice straw was reported to have a DM effective degradability of 20.2% in cannulated steers consuming a basal diet comprised primarily of corn, alfalfa meal, and rice straw (Li et al., 2018). This value was greater than the results of PH and less than the CGT in the current experiment.

***In situ* OM Disappearance**

There was no treatment × substrate interaction ($P \geq 0.21$; Table 3) or main effect of treatment ($P \geq 0.25$) for OM disappearance for any fraction, therefore only the main

effect of substrate is reported. In contrast to the DM lag time results, the lag time observed for OM for the primary roughage sources was greater for PH than CGT (10.6 and 6.0 h, respectively; $P = 0.05$). Aside from lag time, the observed patterns regarding OM in situ disappearance results were similar to the patterns observed regarding DM in situ disappearance results for all fractions.

In Situ NDF Disappearance

No treatment × substrate interaction ($P \geq 0.27$; Table 4) or main effect of treatment ($P \geq 0.42$) was observed for the A, B, and C fractions, Kd, or lag time variables; therefore, only substrate differences are reported. Similar to DM and OM results, the A fraction of NDF was greater for CGT than PH (12.7 vs 6.0%, respectively; $P < 0.001$). However, the B fraction tended to be greater for PH than CGT ($P = 0.08$), and no differences ($P = 0.81$) were observed for the C fraction between primary roughage sources. The calculated Kd of NDF for PH was not different than the Kd of NDF for CGT (4.3 vs 3.5%/h, respectively; $P = 0.70$), and lag time did not differ between PH and CGT ($P = 0.46$).

A significant treatment × substrate interaction (Figure 1; $P = 0.04$) was observed for the effective degradability of NDF of primary roughage sources in the treatment diets. The interaction for effective degradability of NDF was due to the CGT having a greater effective degradability when incubated in CTN steers when compared to the effective degradability of PH when incubated in CON steers ($P = 0.02$). Overall, the CGT had a greater ($P < 0.001$) effective degradability than the PH by approximately 5.6% regardless of treatment. The ruminal NDF degradability of CGT observed in this experiment (15.9%) is increased in comparison to other low to medium quality roughages such as

alfalfa hay and wheat straw. Poore et al. (1990) reported that alfalfa hay had a ruminal NDF digestibility of 10.7% while wheat straw was reported to have a ruminal NDF digestibility of 6.0% in steers fed a 90% concentrate diet. The ruminal NDF degradability of PH observed in this experiment (10.3%) was similar to alfalfa hay and greater than wheat straw as reported by Poore et al. (1990).

In Situ Starch Disappearance of Dry Rolled Corn

Based on results from substrates incubated in the rumen for 96 h, the undegradable fraction of starch for the DRC, CON, and CTN substrates were estimated to be 0. In practice, it is unlikely that DRC would remain in the rumen for an extended amount of time if steers were consuming a high concentrate ration. Karr et al. (1966) reported that only 62.3% of starch was digested in the rumen of steers consuming a diet comprised of 80% ground corn, likely due to an increased passage rate. Results from this experiment determined that 95.5% of the starch in DRC disappeared at a measurable rate, and only 4.5% of the starch was immediately soluble. Regardless of treatment, DRC had a similar (51.2 and 53.0%; $P = 0.71$) effective degradability of starch.

In Situ Disappearance of Whole Diets

When comparing the in-situ DM degradability of the CON and CTN substrates, the CON had a greater A fraction than the CTN ($P < 0.001$). This difference may be a function of the differences observed among the individual ingredients in the whole diet. For example, SB was reported to have an A fraction of 48.0% while WCS had an A fraction of only 15.5% of DM. Since both SB and WCS were included in the diet at 15% DM, this could have influenced the overall A fraction of the diets. Interestingly, the differences observed between the A fraction of PH and CGT may have suggested that the

CTN sample would have a greater A fraction than the CON sample. However, since the primary roughage sources were only included in the diets at 7% of DM, it appears that the differences observed among individual roughage ingredients were not enough to influence the A fraction of the whole diets. The differences among the A fraction of individual ingredients were not reflected in the effective degradability of the DM of the whole diets ($P = 0.32$). No differences were observed between the B or C fractions, lag time, or Kd of DM between whole diets ($P \geq 0.24$).

Following in-situ incubation, there was not enough substrate for the 72 and 96 h sampling intervals to complete all analyses for the CON and CTN substrates therefore, NDF was only analyzed for the CON and CTN substrates through 48 h of incubation. When creating the disappearance curves for NDF disappearance of CON and CTN, data were not fitting the nonlinear model as expected due to a low amount of NDF disappearance observed and missing data from the 72 and 96 h incubations. Because of these circumstances, the mean % of NDF disappearance at 48 h was analyzed for the CON and CTN substrates. There was no treatment × substrate interaction ($P = 0.38$), or main effects of substrate ($P = 0.37$) or treatment ($P = 0.51$) observed for the % NDF disappearance of whole diets after 48 h of ruminal incubation (Figure 2). The mean % of NDF disappeared at 48 h was 33.4% for the CON diet and 36.1% for the CTN diet ($P = 0.37$).

No treatment × substrate interaction ($P \geq 0.21$) or main effect of treatment was observed for the A or B fractions, or Kd of starch for the whole diets. Therefore, only substrate differences will be discussed. Identical values were reported for the A (14.4% of DM) and B (85.6%) fractions of CON and CTN ($P \geq 0.99$) when the C fraction of

starch was assumed to be 0%. The Kd of starch was determined to be more rapid ($P < 0.01$) for the CTN diet compared to the CON diet (6.3 vs 4.6%/h, respectively). No treatment × substrate interaction ($P = 0.44$) or main effect of substrate ($P = 0.23$) was observed for lag time. However, a main effect of treatment ($P = 0.03$) was observed for the lag time of starch disappearance between the CON and CTN treatment (2.8 vs 5.5 h, respectively).

A tendency for a treatment × substrate interaction was observed for the effective degradability of starch ($P = 0.10$). This interaction is likely a result of the different Kd among substrates, as the A and B fractions of starch did not differ between whole diets, and Kd is the only other source of variance in the equation for effective degradability. When the CON substrate was incubated in steers consuming the CTN treatment diet, the effective degradability was less than when the CON substrate was incubated in steers consuming the CON treatment diet ($P = 0.05$). The effective degradability of starch was increased when substrates were incubated in steers consuming the same treatment as the substrate, indicating that microorganisms in the rumen have the ability adapt to the treatment diet, and can influence the differential digestibility of the alternative treatment diets and ingredients. The observed interaction is likely of minimal importance because when the CON substrate was incubated in steers consuming the CON treatment diet, effective degradability of starch did not differ ($P = 0.84$) from the CTN substrate when incubated in steers consuming the CTN diet. In summary, the ruminal starch degradability was similar between the CON and CTN, despite the observed differences in Kd.

The reason for the similar effective degradability observed for DM, OM, and starch is likely because the greatest proportion of both diets was DRC. Although some differences were observed between individual substrates that are included in the diet, the substrates were not included in the ration at a great enough amount to cause an overall difference in total diet degradability of any measured component.

Rumen Fluid pH

There was no treatment × time interaction ($P = 0.47$) or treatment ($P = 0.35$) effect for rumen fluid pH, however there was main effect of time ($P = 0.03$; Table 6). Rumen fluid samples collected at h 2 and 24 post-feeding had the greatest pH values, 6.06 and 6.07, respectively. The lowest rumen fluid pH value, 5.82, was observed 12 h after feeding (Table 6). This result is similar to Robles et al. (2007), who also reported a decrease in rumen fluid pH 12 h post feeding for heifers fed a high concentrate diet once daily. Although differences among hours post feeding were detected in the current study, pH values over time were relatively constant with an average range of 5.82 to 6.07 in a 24 h period. This is within the range of the average ruminal pH of feedlot cattle consuming high concentrate diets, between 5.6 and 6.2 (Schwartzkopf-Genswein, 2003).

Rumen Fluid Lactate

There was no treatment × time interaction ($P = 0.32$), main effect of treatment ($P = 0.84$), or main effect of time ($P = 0.98$) for concentration of rumen fluid lactate (Table 6). These results were expected, as the pH results were not indicative of steers experiencing acidosis. Generally, lactate concentration decreased from feeding through h 6, increased and peaked at h 10, and decreased again through h 24.

Rumen Fluid VFA Concentrations

There was no treatment × time interaction for any VFA ($P \geq 0.71$; Table 7); therefore, only the main effects of treatment and time will be discussed. Diets had similar ($P = 0.91$) total VFA concentrations of approximately 112 mM which is within the expected normal range of 70 to 130 mM as reported by NASEM, (2016). However, there were differences among specific VFA proportions observed between treatments. The proportion of propionate was decreased ($P < 0.0001$) while acetate was increased ($P \leq 0.002$) in steers consuming the CTN diet compared with steers consuming the CON diet. Additionally, the acetate to propionate ratio was greater ($P < 0.001$) for the CTN steers compared to the CON steers. These results are likely due to the increased physically effective NDF (**peNDF**) content of the CTN diet compared to the CON diet. Increased fiber in the diet promotes the production of acetate, while increased amounts of starch in the diet promote propionate production at the expense of acetate (Rumsey et al., 1970). Beauchemin and Yang (2005) also reported decreases in propionate and increases in acetate in the rumen fluid of dairy cows as levels of peNDF in the total mixed ration were increased.

Warner et al. (2020) reported an increase in the fat composition of carcasses in steers consuming the CTN diet compared to the CON diet. The increase of ruminal acetate proportions observed in steers consuming the CTN diet in this experiment could help explain the increase in BF, YG, and KPH observed by Warner et al. (2020), as acetate is the primary substrate for the synthesis of fatty acids in ruminants (Hansen and Ballard, 1967). Acetate primarily increases the deposition of subcutaneous adipose tissue compared to intramuscular adipose tissue (Rhoades et al., 2007), thus supporting the

results of the increased BF of CTN carcasses compared to CON carcasses with no change in marbling among treatments as reported by Warner et al. (2020).

No other VFA proportions differed between treatments ($P \geq 0.13$) and no time effect was observed for total VFA concentrations ($P = 0.15$). It may be possible that sampling intervals were not frequent enough to detect a pattern in VFA concentrations over time. However, these results are more likely due to the fact that cattle were fed ad libitum and could have consumed multiple meals throughout the day, creating variable amounts of VFA in the rumen depending upon time and amount of feed consumption. If cattle are fed limit-fed, the concentration of VFA has been reported to rapidly increase immediately following feed consumption and steadily decline beginning approximately 4 h after consumption until the next feeding event (Church, 1988). A time effect ($P < 0.01$) was observed for the molar proportion of isobutyrate. In general, isobutyrate proportions were increased at h 2, decreased through h 12, and greatest at h 24. No time effects ($P = 0.24$) were observed for any other proportion of VFA.

CONCLUSION

Although differences were observed among individual diet components for ruminal degradability of DM, OM, NDF, and starch, it does not appear that ruminal degradability differed between the total diets. Additionally, there were no differences between the diets concerning rumen fluid pH or lactate concentration. Although total VFA concentrations were not different between treatments, the molar proportion of propionate was greater while the molar proportion of acetate was less in steers consuming the CON diet compared to steers consuming the CTN diet. These differences in VFA are likely attributed to the greater amount of peNDF in the CTN diet compared to the CON

diet. The increase in acetate in the rumen fluid of CTN steers helps to explain the increase in fat on the carcasses of steers consuming the CTN diet as reported by Warner et al. (2020), as acetate is the primary substrate for fatty acid synthesis specifically in subcutaneous tissue. Results from this experiment suggest that the performance results reported by Warner et al. (2020) are likely not due to differences in ruminal degradability or fermentation of the treatment diets, but rather attributed to the observed increased DMI and total energy intake of steers consuming the CTN diet. In conclusion, this experiment suggests that WCS and CGT can be included in a finishing diet without negatively impacting ruminal degradability of the diet or the of rumen environment.

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Table 3.1: Ingredient and nutrient composition of treatment diets

	Diet		
Ingredient, % of DM	RCV[1]	CON[2]	CTN[3]
Rolled corn	12.7	67.25	72.25
Prairie hay	22.5	7.0	-
Cotton gin trash	-	-	7.0
Whole cottonseed	-	-	15.0
Sweet Bran[4]	60.7	15.0	-
Liquid supplement[5]	-	5.0	-
Dry supplement[6]	4.1	5.0	5.0
Urea	-	0.75	0.75
Nutrient composition, DM basis			
Dry matter, %	70.10	80.70	84.34
Crude protein, %	16.70	14.16	14.13
Neutral detergent fiber, %	- [7]	25.15	27.33
Acid detergent fiber, %	23.90	8.59	15.28
peNDF[8], %	-	8.80	9.82
TDN, %	68.90	79.30[9]	78.20[9]
Fat, %	-	3.25	5.82
NE_m, Mcal/kg	1.00	1.72[10]	1.69[10]
NE_g, Mcal/kg	0.69	1.10[10]	1.07[10]
Ca[11], %	0.53	0.62	0.85
P, %	0.53	0.57	0.46
K, %	0.93	1.00	0.84
S, %	-	0.22	0.19
Na, %	-	0.11	0.05
Mg, %	-	0.29	0.28
Cu, mg/L	-	20.00	24.60
Fe, mg/L	-	144.57	165.93
Zn, mg/L	-	161.03	145.97
Mn, mg/L	-	58.32	57.86

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

[2] Control diet (CON); representative of a typical finishing diet

[3] Cotton diet (CTN); cotton byproducts used as the primary protein, fat, and fiber source in the diet

[4] Cargill Inc., Dalhart, TX

[5] 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

[6] 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), 0.10% vitamin E (500 IU/g), 0.009% vitamin D (30,000 IU/g), 0.20 % tylosin (Tylan-40, Elanco Animal Health, Greenfield IN) and 0.33% monensin (Rumensin- 90; Elanco Animal Health)

[7] A missing value under nutrient composition indicates nutrient not analyzed in the receiving ration

[8] Physically effective fiber provided by the roughage and byproducts in the diet

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

[10] Calculated according to NASEM (2016)

[11] Minerals analyzed by the Oklahoma State University Soil, Water and Forage Analytical Laboratory (Stillwater, OK

Table 3.2: In situ dry matter disappearance of diet ingredients[1]

	A[2]	B[3]	C[4]	L[5]	K[6]	EDeg[7]
Item		% of DM				
Prairie hay	10.8 ± 0.66^{e}	15.6 ± 2.83^{e}	73.6 ± 2.81^{a}	6.4 ± 2.92^{ab}	2.6 ± 0.70^{c}	14.7 ± 1.43^{e}
Cotton gin trash	25.0 ± 0.63^{b}	15.7 ± 2.70^{de}	59.3 ± 2.67^{b}	12.5 ± 2.38^{a}	3.2 ± 0.67^{bc}	29.4 ± 1.39^{d}
Corn	16.1 ± 0.63^{cd}	77.4 ± 2.70^{a}	6.8 ± 2.67^{e}	6.0 ± 2.13^{b}	5.2 ± 0.67^{a}	58.7 ± 1.39^{b}
Sweet Bran[8]	48.2 ± 0.66^{a}	34.4 ± 2.83^{c}	18.5 ± 2.81^{d}	2.0 ± 3.07^{b}	4.1 ± 0.70^{ab}	64.8 ± 1.43^{a}
Whole cottonseed	15.6 ± 0.63^{d}	37.4 ± 2.70^{bc}	47.0 ± 2.67^{c}	1.7 ± 2.38^{b}	4.9 ± 0.67^{ab}	34.8 ± 1.39^{c}

[1] No treatment × substrate interaction or treatment effect was observed for any fraction ($P > 0.05$), therefore only substrate differences are reported ($P \leq 0.05$)

[2] A fraction is defined as the immediately soluble fraction (100 – (B + C))

[3] B fraction is defined as the fraction disappeared at a measurable rate

[4] C fraction is defined as the fraction undegradable in the rumen

[5] Lag time, h

[6] Rate of disappearance, % per h

[7] Effective degradability calculated as A + {B × [Kd/(Kd + Kp)]}, with Kp assumed to be 4%/h

[8] Cargill Inc., Dalhart, TX

[9] Within column, values with varying superscripts ^{abcd} differ by $P \leq 0.05$

Table 3.3: In situ organic matter disappearance of diet ingredients[1]

	A[2]	B[3]	C[4]	L[5]	K[6]	ED[7]
Item		% of OM				
Prairie hay	8.9 ± 0.72[a]	14.1 ± 1.57[a]	77.0 ± 1.36[a]	10.6 ± 1.45[a]	2.7 ± 0.69[by]	13.0 ± 1.46[e]
Gin trash	17.9 ± 0.79[c]	12.0 ± 1.74[a]	70.1 ± 1.50[b]	6.0 ± 1.73[b]	2.4 ± 0.77[b]	20.6 ± 1.56[c]
Corn	15.4 ± 0.69[b]	77.8 ± 1.50[c]	6.8 ± 1.31[e]	5.7 ± 1.20[b]	5.2 ± 0.66[a]	57.9 ± 1.41[b]
Sweet Bran[8]	45.0 ± 0.69[d]	35.7 ± 1.50[b]	19.3 ± 1.31[c]	1.3 ± 1.73[c]	4.3 ± 0.66[ax]	63.1 ± 1.42[a]
Whole cottonseed	14.4 ± 0.69[b]	37.6 ± 1.50[b]	47.9 ± 1.31[d]	1.8 ± 1.34[c]	4.8 ± 0.66[a]	33.4 ± 1.42[d]

[1] No treatment × substrate interaction or treatment effect was observed for any fraction ($P > 0.05$), therefore only substrate differences are reported

[2] A fraction is defined as the immediately soluble fraction (100 – (B + C))

[3] B fraction is defined as the fraction disappeared at a measurable rate

[4] C fraction is defined as the fraction undegradable in the rumen

[5] Lag time, h

[6] Rate of disappearance, % per h

[7] Effective degradability calculated as A + {B × [Kd/(Kd + Kp)]}, with Kp assumed to be 4%/h

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

[9] Within column, values with varying superscripts [abcd] differ by $P \leq 0.05$; values denoted with [xy] tend to differ by $(0.05 < P \leq 0.10)$

Table 3.4: In situ neutral detergent fiber disappearance of diet roughage ingredients[1]

	A[2]	B[3]	C[4]	L[5]	K[6]
Item[7]		% of NDF			
PH	6.0 ± 0.79[b]	16.2 ± 2.62[x]	77.9 ± 2.71[a]	11.9 ± 5.74[a]	4.3 ± 1.95[a]
CGT	12.7 ± 0.76[a]	10.2 ± 2.48[y]	77.1 ± 2.56[a]	17.8 ± 6.14[a]	3.5 ± 1.86[a]

[1] No treatment × substrate interaction or treatment effect was observed for any reported fraction ($P > 0.05$), therefore only differences in the main effect of substrate are reported

[2] A fraction is defined as the immediately soluble fraction (100 – (B + C))

[3] B fraction is defined as the fraction disappeared at a measurable rate

[4] C fraction is defined as the fraction undegradable in the rumen

[5] Lag time, h

[6] Rate of disappearance, % per h

[7] PH = prairie hay; CGT = cotton gin trash

[8]Within column, values with varying superscripts [ab] differ by $P \leq 0.05$; values denoted with [xy] tend to differ by $0.05 < P \leq 0.10$

Table 3.5: In situ dry matter, organic matter, and starch disappearance of treatment diets[1]

	A[2]	B[3]	C[4]	L[5]	K[6]	ED[7]
Dry matter						
Control diet	26.9 (± 0.63)[a]	57.0 (± 2.70)[a]	16.2 (± 2.67)[a]	4.5 (± 2.38)[a]	4.5 (± 0.67)[a]	56.0 (± 1.39)[a]
Cotton diet	20.4 (± 0.63)[b]	61.4 (± 2.70)[a]	18.2 (± 2.67)[a]	1.4 (± 2.91)[a]	5.5 (± 0.67)[a]	54.6 (± 1.39)[a]
Organic matter						
Control diet	25.4 (± 0.69)[a]	59.1 (± 1.50)[a]	15.5 (± 1.31)[a]	4.7 (± 1.34)[x]	4.5 (± 0.66)[a]	55.5 (± 1.42)[a]
Cotton diet	18.7 (± 0.69)[b]	63.8 (± 1.50)[a]	17.5 (± 1.31)[a]	1.3 (± 1.39)[y]	5.5 (± 0.66)[a]	54.0 (± 1.42)[a]
Starch						
Control diet	14.4 (± 2.05)[a]	85.6 (± 2.05)[a]	0.0[8]	4.5 (± 0.94)[a]	4.6 (± 0.44)[a]	--[9]
Cotton diet	14.4 (± 2.38)[a]	85.6 (± 2.38)[a]	0.0[8]	2.8 (± 1.10)[a]	6.3 (± 0.50)[b]	--[9]

[1] No treatment × substrate interaction or main effect of treatment was observed for any reported fraction ($P > 0.05$), therefore only differences in the main effect of substrate are reported

[2] A fraction is defined as the immediately soluble fraction (100 – (B + C))

[3] B fraction is defined as the fraction disappeared at a measurable rate

[4] C fraction is defined as the fraction undegradable in the rumen

[5] Lag time, h

[6] Rate of disappearance, % per h

[7] Effective degradability calculated as A + {B × [Kd/(Kd + Kp)]}, with Kp assumed to be 4% per h

[8] The undegradable fraction of starch was assumed to be 0%

[9] The main effect of substrate is not presented in table due to a treatment × substrate interaction

[10] Within column, values with varying superscripts [ab] differ by $P \leq 0.05$; values denoted with [xy] tend to differ by $0.05 < P \leq 0.10$

Table 3.6: Effects of including cotton byproducts in a finishing ration on rumen fluid pH values and lactate concentrations over time

	Treatment[1]				Time[3]								
Variable	CON	CTN	SEM[2]	*P*-Value	2	4	6	8	10	12	24	SEM[2]	*P*-Value
pH	5.90	5.99	0.073	0.35	6.06[a]	5.94[abc]	5.87[bc]	5.91[abc]	5.93[abc]	5.82[c]	6.07[ab]	0.082	0.03
Lactate, g/L	0.78	0.72	0.076	0.84	0.80	0.71	0.62	0.76	0.95	0.73	0.67	0.134	0.98

[1]Treatments included (DM basis); (CON) = 7% prairie hay, 15% Sweet Bran (Cargill Inc., Dalhart, TX), 67.25% rolled corn, 5% liquid supplement, or (CTN) = 7% cotton gin trash, 15% whole cottonseed, 72.25% rolled corn. Both rations contained 5% dry supplement and 0.75% urea.

[2] n = 6 animals per treatment

[3] Time refers to h post-feeding

[4] Within row, values with unlike superscripts differ ($P < 0.05$)

Table 3.7: Effects of including cotton byproducts in a finishing ration on rumen fluid volatile fatty acid (VFA) total concentration and molar proportions

	Treatment[1]		
VFA	CON	CTN	*P* value
Total, mM	112.8 ± 4.76	112.1 ± 1.34	0.91
Proportion, mol/100 mol			
Acetate:Propionate	2.02 ± 0.311	2.68 ± 0.306	< 0.001
Acetate	51.1 ± 1.78	56.2 ± 1.69	0.002
Propionate	27.0 ± 1.91	22.6 ± 1.89	< 0.001
Butyrate	14.6 ± 1.17	13.8 ± 1.12	0.34
Isobutyrate	0.99 ± 0.062	1.08 ± 0.057	0.23
Valerate	2.22 ± 0.521	1.65 ± 0.502	0.13
Isovalerate	4.19 ± 0.823	4.63 ± 0.815	0.14

[1]Treatments included (DM basis); (CON) = 7% prairie hay, 15% Sweet Bran (Cargill Inc., Dalhart, TX), 67.25% rolled corn, 5% liquid supplement, or (CTN) = 7% cotton gin trash, 15% whole cottonseed, 72.25% rolled corn. Both rations contained 5% dry supplement and 0.75% urea.

[2] No treatment × time interaction was observed for any VFA ($P \geq 0.71$)

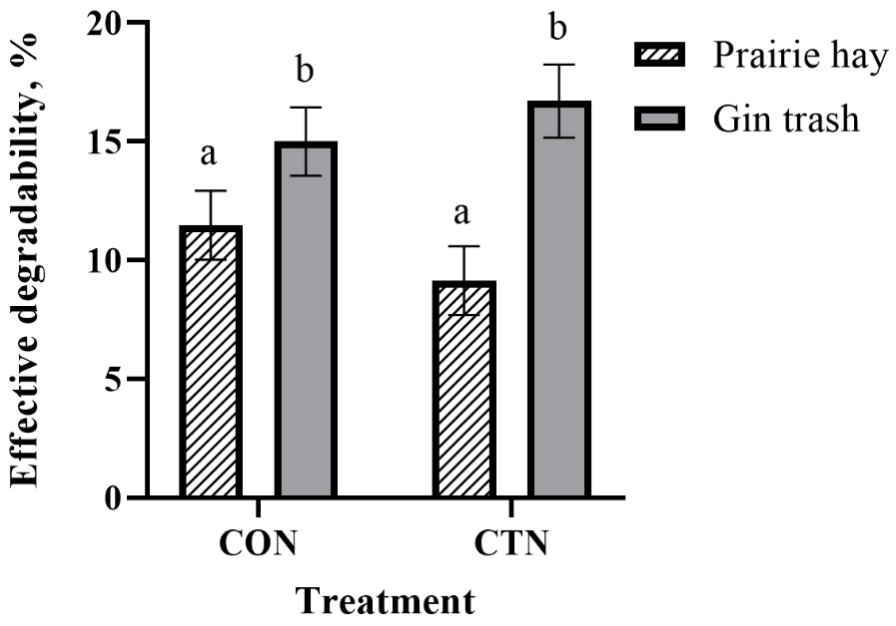

Figure 3.1: Effective degradability of neutral detergent fiber of prairie hay and cotton gin trash in steers consuming a CON (7% hay, 15% Sweet Bran [Cargill Inc., Dalhart, TX], 67.25% dry-rolled corn, 5% liquid supplement, 5% dry supplement, 0.75% urea) or a CTN (7% cotton gin trash, 15% whole cottonseed, 72.25% dry-rolled corn, 5% dry supplement, 0.75% urea) diet. A treatment × substrate interaction ($P = 0.04$) and a main effect of substrate ($P < 0.001$) was observed. Regardless of treatment, the ruminal degradability of neutral detergent fiber was greater for cotton gin trash ($P < 0.02$).

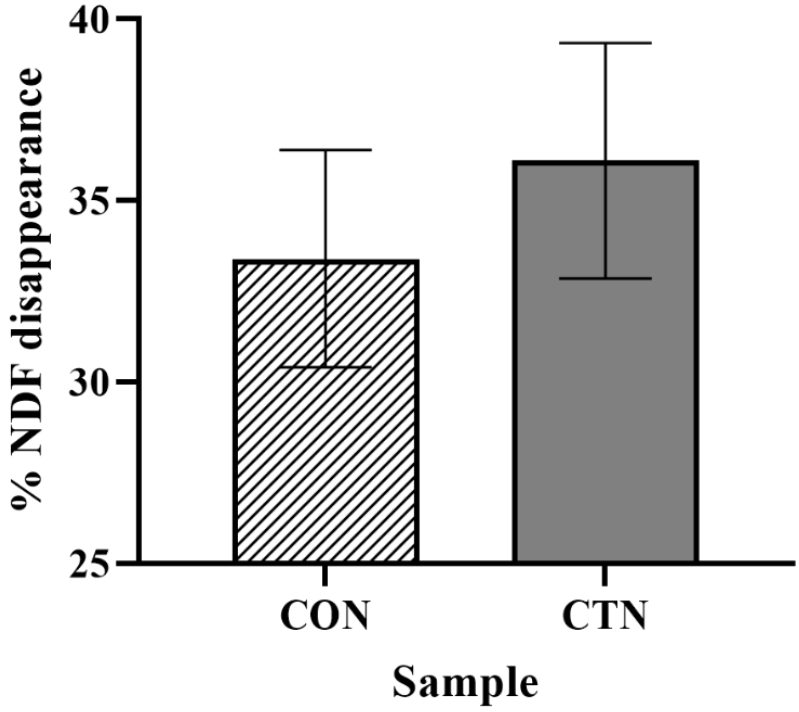

Figure 3.2: Percent neutral detergent fiber disappearance of whole diets after 48 hours of ruminal incubation in steers consuming a CON (7% hay, 15% Sweet Bran [Cargill Inc., Dalhart, TX], 67.25% dry-rolled corn, 5% liquid supplement, 5% dry supplement, 0.75% urea) or a CTN (7% cotton gin trash, 15% whole cottonseed, 72.25% dry-rolled corn, 5% dry supplement, 0.75% urea) diet. No treatment × substrate interaction, or main effects of substrate or treatment were observed ($P \geq 0.37$). Therefore, only substrate means are presented in this figure

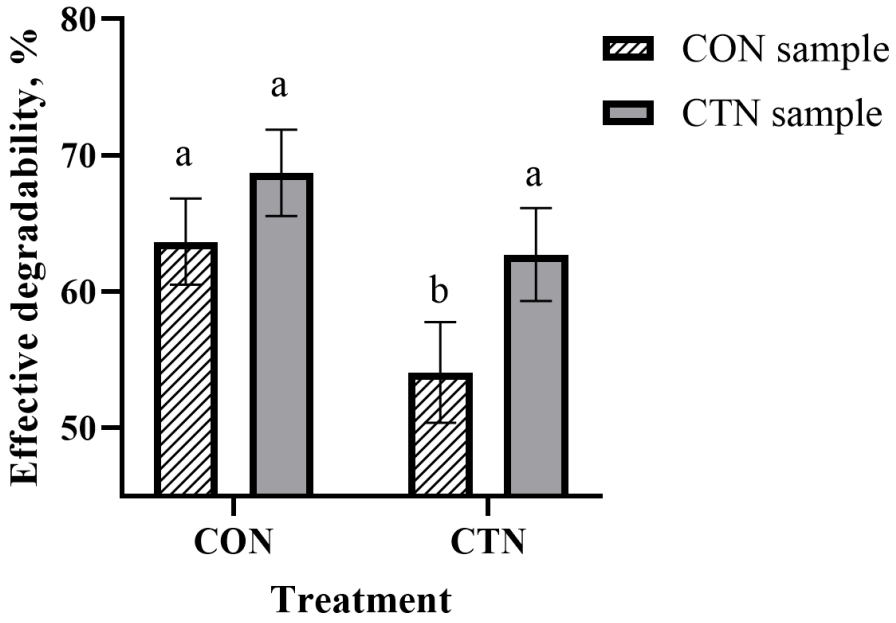

Figure 3.3: Effective degradability of starch in whole diets in steers consuming a CON (7% hay, 15% Sweet Bran [Cargill Inc., Dalhart, TX], 67.25% dry-rolled corn, 5% liquid supplement, 5% dry supplement, 0.75% urea) or a CTN (7% cotton gin trash, 15% whole cottonseed, 72.25% dry-rolled corn, 5% dry supplement, 0.75% urea) diet. A tendency for a treatment × substrate interaction ($P = 0.10$) and main effect of substrate ($P < 0.01$) were observed. No main effect of treatment ($P = 0.15$) was detected. Although the interaction tended to be significant, it is important to note that when each substrate was incubated in the rumen of a steer consuming the same diet, the effective degradability of the starch was not different ($P = 0.84$).

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