ABSTRACT

HUGGINS, MICHAEL JEFFERY Cotton Gin Byproduct in Growing Diets for Beef Steers (Under the direction of Drs. Matt H. Poore and Deidre D. Harmon).

The purpose of these studies was to evaluate the performance of beef cattle during the stocker phase when fed different concentrations of cotton gin byproduct (CGB). In the first experiment, 50 Angus steers (initial BW 349 ± 66 kg) were stratified by body weight and grouped in slatted floor pens (10 steers/pen). Steers were assigned randomly within a pen (2 per pen) to one of five diets containing 0, 10, 20, 30, and 40% CGB (dry matter basis). Diets were balanced for protein and energy, and were individually fed via Calan Gates for 84 days. Steers were weighed on d -1, 0, 28, 56, 83, and 84 for the stocker phase with d -1 and 0, 83 and 84 averaged to give start and end weights. Following the growing period, steers were switched to the same finishing diet and fed for an additional 55 days prior to being transported to Pennsylvania for harvest and carcass data collection. Data was analyzed using procMIXED of SASv9.4 to determine the significance of linear, quadratic, cubic, and quartic trends. During the growing phase, dry matter intake increased linearly (P = <.0001) with 10.16, 11.23, 11.59, 11.86, and 11.96 kg/day for 0, 10, 20, 30, and 40% CGB, respectively. Average daily gain tended to increase (P = 0.0637) with a cubic trend, increasing with the first addition of CGB, declining at the intermediate levels, and then increasing again at the 40% level (1.34, 1.54, 1.36, 1.39, and 1.52 kg/day for 0, 10, 20, 30, and 40% CGB, respectively). Feed efficiency showed a similar cubic trend (P = 0.069) with 0.133, 0.138, 0.119, 0.117, and 0.128 for 0, 10, 20, 30, and 40% CGB, respectively. Treatment did not influence (P > 0.10) marbling or carcass quality grade. In the second experiment, 75 Angus steers (initial BW 353 ± 66 kg) were stratified by body weight into groups of 15, and each weight group was assigned to one of 5 pens representing a weight block (3 steers/pen). Each pen

was randomly assigned to one of five diets containing 0, 10, 20, 30, and 40% CGB (dry matter basis). Diets were balanced for protein and energy, and were bunk fed for 84 days. Steers were weighed on d -1, 0, 28, 56, 83, and 84 for the stocker phase with d -1 and 0, 83 and 84 averaged to give start and end weights. Following the growing period, steers were switched to the same finishing diet and fed for an additional 70 days prior to being transported to Pennsylvania for harvest and carcass data collection. Data was analyzed the same as in experiment 1. During the growing phase, dry matter intake increased linearly ($P = 0.0006$) with 11.17, 11.19, 13.92, 14.84, and 13.96 kg/day for 0, 10, 20, 30, and 40% CGB, respectively. Average daily gain increased linearly ($P = 0.0095$) with 1.80, 1.93, 1.95, 1.97, and 2.00 kg/day for 0, 10, 20, 30, and 40% CGB, respectively. Feed efficiency had a linear ($P = 0.0029$) and cubic ($P = 0.011$) effect with 0.163, 0.175, 0.141, 0.135, and 0.145 for 0, 10, 20, 30, and 40% CGB, respectively. Both marbling and quality grade increased linearly ($P = 0.042$; $P = 0.0141$, respectively). Marbling scores were 6.33, 6.13, 6.38, 6.5, and 6.83 for 0, 10, 20, 30, and 40% CGB, respectively. Quality grade scores were 17.8, 17.73, 18, 18.21, and 18.4 for 0, 10, 20, 30, and 40% CGB, respectively. Data suggest CGB supported good animal gains with only minor impact on feed intake and feed efficiency for stocker steers up to an inclusion rate of 40%.

Cotton Gin Byproduct in Growing Diets for Beef Steers

by
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BIOGRAPHY

Michael Jeffery Huggins was raised on his family's grain farm in Liverpool, Pennsylvania. Throughout his life, Michael always had an interest in agriculture as he helped his family raise row crops, hay, and freezer beef. During the latter portion of his childhood, he raised layer hens and produce for several years as his passion for production agriculture grew. In high school, Michael was actively involved in FFA where he earned his American FFA degree. Michael attended Pennsylvania State University from 2017-2021 where he earned his Bachelor of Science in Animal Science, and it was the start of him wanting to pursue a career in ruminant nutrition. With a desire to learn more about ruminant nutrition, Michael then attended North Carolina State University to pursue a Master of Science in Animal Science where he studied feeding different levels of cotton gin byproduct to beef stocker steers. After graduating with a Master's degree, Michael's desire in life will be to have a career where he will educate and assist producers with their farm's production and increase their profitability as well as raise his future family on his own farm with beef cattle, layer hens, field crops, and produce.

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CHAPTER 1: LITERATURE REVIEW

Beef Cattle Industry

In North Carolina and the United States, the beef cattle industry is an important agricultural commodity. The United States has over 89 million head of both beef and dairy cattle (NASS, 2023). Within North Carolina, there are about 740,000 head of cattle, including both beef and dairy (NASS, 2023). The total value of cattle in North Carolina is estimated to be about 673.4 million dollars (NASS, 2023).

Beef production within the United States consists of three typical phases: cow-calf, growing, and finishing (Johnson et al. 2010). The growing phase generally uses the term "stocker," which is referring to a weaned calf primarily grown on forage that might include supplementation (Johnson et al. 2010). In the southern United States, stockering calves has been economically viable for beef cattle operations over the decades (Rankins and Prevatt, 2013). Stocker operations can be managed using different methods. One method involves improving the health and appearance of purchased cattle that have been mishandled and then selling them at a higher value to feeder operations (Rhinehart and Poore, 2013). Another method includes profiting off of marketing strategies through purchasing small groups or single calves with great appearance and group them into uniform lots (Rhinehart and Poore, 2013). A common practice for stocker operations involves purchasing intact males, castrating them, and selling them as steers after they have gained body weight and have healed (Rhinehart and Poore, 2013). Generally, stocker calves will weigh from 300 to 800 pounds and represent a valuable part of the beef industry and marketing chain as emphasis is placed on animal performance utilizing forage or grazing-based systems versus fattening with concentrate feeds (Johnson et al., 2010).

Typically, a stocker operation aims towards adding 200 to 400 pounds to weaned calves within 3 to 8 months before being finished at a feedlot (Peel, 2003). While stocker calves are focused on growth, forage-based rations are widely variable in availability and quality in a production system. Stocker gains can vary widely ranging from less than 1 pound per day to about 3 pounds per day depending on the quality of the forage with an average of 1.5 to 2.5 pounds of gain per day (Peel, 2003).

Within the last couple decades, prices of fuel, feed, and fertilizer have increased the cost of raising stocker cattle, including the amount to purchase them (Rankins and Prevatt, 2013). In the stocker segment of the beef industry, it is important for producers to achieve profitability by utilizing an optimal system with high-quality forages and byproduct supplementation (Rankins and Prevatt, 2013).

Byproduct Feeds

The cost of feed represents the largest cost in most beef cattle operations and equates to around 60 to 70% (Mullenix et al., 2023). To lower feed costs, cattle producers may look towards utilizing cheaper feed alternatives, particularly when prices for traditional feeds are high (Myer and Hall, 2003). Feed costs may also be lowered when alternative feed production is high and demand is low, typically in the summer and fall (Rogers and Poore, 1994). Most "alternative" feeds are waste products from processing various food and fiber crops, known as byproducts (Myer and Hall, 2003). While most beef producers will consistently use byproduct feeds throughout the year, some producers may use them occasionally when forage availability is limited, particularly during periods of drought (Rankins, 2002; Mullenix et al., 2023). If utilization of a byproduct is being considered on an operation, handling, processing, and storage

should be evaluated as potential problems may occur (Rogers and Poore, 1994). The main reason producers use byproduct feeds for their beef cattle is because of the economic value (Rankins, 2002). Rankins (2002) mentions that a byproduct's relative feed value can be calculated by an equation formulated by Petersen (1932) utilizing a feedstuff's nutrient composition along with its cost. Calves that are grown at 1.5 to 2.5 lb per day in the southeastern United States can range from $0.25 to $0.30 per pound of gain when fed byproducts for 400 to 500 lb calves (Rankins, 2002). Because of a ruminant's ability to digest various feedstuffs, beef cattle complement and are well suited to consume many different kinds of byproducts (Rankins, 2002). Most of the time, transportation is the largest expense for obtaining a byproduct feed, therefore, being close to where the byproduct is processed can lower the cost (Rankins, 2002).

It is important to identify if supplementation is needed and consider what nutrients a herd needs when choosing a byproduct. Protein may be a limiting factor for growing animals (Mullenix et al., 2023). Factors that must be considered when deciding to use a byproduct include: nutrient composition, contaminants, moisture contents, transportation, availability, storage, and regulations defined by the American Association of Feed Control Officials (Rankins, 2002). It is highly recommended that roughage-based byproducts get analyzed to determine the nutrient components before including a byproduct feed into livestock diets (Schingoethe, 1991; Mullenix et al., 2023). A feed analysis helps establish a byproduct's feeding potential and should include the following: moisture/dry matter, total digestible nutrients, crude protein, fiber content, vitamins, and minerals (Schingoethe, 1991). There can be variability in nutrient contents for forage byproducts, which can lead to problems for nutritionists or producers formulating a nutritionally balanced diet accurately (Schingoethe, 1991). The energy value of a forage byproduct is mainly determined by its fiber composition and digestibility (Schingoethe,

1991). Fiber content is commonly expressed as neutral detergent fiber (NDF) and acid detergent fiber (ADF), where NDF has lignin, cellulose, and hemicellulose while ADF only has lignin and cellulose (Schingoethe, 1991). The moisture content of a byproduct is important to consider because a higher moisture content can have an economic impact on cost of the byproduct and transportation as well as length of storage before spoilage (Schingoethe, 1991; Mullenix et al., 2023). When feeding byproducts, it is important to consider the possibility of having contaminants within the feedstuff (Rankins, 2002). For example, weed seeds and pesticide residues may be contained within cotton gin byproducts (Mullenix et al., 2023). Transportation from the processing location to the feeding location accounts for most of the cost of the byproduct, and storage of the byproduct should also be considered (Rankins, 2002). Besides the capital investment cost of establishing a storage area, the cost of storage can be influenced by the duration of a byproduct without it spoiling compared to the length of time the byproduct is stored before being used when it was purchased (Schingoethe, 1991; Rogers and Poore, 1994). The seasonality of a byproduct should be acknowledged as some are only produced at certain times of the year, and storage facilities are needed so the byproduct can be purchased at a low price and stored until needed (Mullenix et al., 2023). Byproducts can lengthen the amount of pasture availability by increasing the number of grazing days while also being an economical nutrient source for beef cattle (Mullenix et al., 2023).

Cotton and Cotton Gin History

Cotton was domesticated for its seed lint production from four individual species. Cotton is perceived as the world's most important textile crop, and processing cotton yields several byproducts (Brubaker et al., 1999). While unclear about the initial uses of the seed hairs during

domestication, they are an ideal textile fiber with unique properties (Brubaker et al., 1999). For approximately 4,000 years, the Hindu people of India were the main contributors of the cotton industry worldwide, until the cotton industry was developed in the Western Hemisphere (May and Lege, 1999). With yearly flooding providing rich soil, particularly to the Indus River Valley, the climate of India was suitable for cotton production, and the people relied on cotton to supply the fiber for their fabric manufacturing. Raw cotton was processed with manual, roller-type gins to remove the lint from the seed (May and Lege, 1999). Because of the creation of trade routes by Alexander the Great, cotton was brought into Europe from India (May and Lege, 1999). Before departing to eastern North America in the early 1600's, English colonists were given cottonseed by the British East India Company. This initial introduction in Jamestown, VA was intended to learn if the land was suitable to grow cotton as England needed cotton for its textile industry (Mayfield and Anthony, 1994; May and Lege, 1999). While cotton was capable of production in the southern colonies, England restricted the colonists from manufacturing their own cotton products, therefore, almost all cotton was exported to England. However, the colonists did produce some of their own home furnishings and clothing using cotton grown in small gardens (Mayfield and Anthony, 1994). During the Revolutionary War, England cut off exports to the colonists, which caused an expansion in cotton production to fulfill the colonists' needs, and after the war was over, the United States was able to produce enough to satisfy its own demand for cotton (Mayfield and Anthony, 1994).

A cotton gin originally referred to only removing cotton lint from the seed, but it is now known as a gin stand, and also refers to the overall integrated ginning plant that cleans and dries seed cotton, removes lint from the seed, and bales the usable fiber (Aiken, 1973). Throughout the course of the United States history, it was portrayed that the cotton gin industry was

revolutionized three different times, with the first being around the end of the eighteenth century to the beginning of the nineteenth (Aiken, 1973). Historically, cotton was ginned with a roller, but obstacles were present. One type of cotton, black seed with long staples, were not able to be grown across the entire south, and the other type of cotton, green seed with short staples, had difficulty being ginned (Aiken, 1973).

In 1794, Eli Whitney patented a process that could remove the seed from the cotton lint for both types of cotton by turning a cylinder with teeth centered in rows, which allowed the fibers to be separated from the seed through thin slots (Aiken, 1973; Mayfield and Anthony, 1994). While this method lowered the quality of cotton fibers by cutting them, it sped up the process of cotton ginning (Aiken, 1973). The second revolution occurred after the Civil War as public gins became more popular while the number of plantation gins decreased (Aiken, 1973). During this time, ways to save labor were explored. Robert S. Munger created the "ginning system" where cotton was moved throughout the gin via air, gravity, and belts from the beginning with coming off the wagon, to the end where a bale of lint was pressed and tied (Aiken, 1973). By the 1940's, the third revolution came into effect as machines were starting to overtake cotton harvesting and cotton gins acknowledged that cleaning and drying machines were necessary for operation (Aiken, 1973).

Cotton Production

Worldwide, the United States is the third largest cotton producing country, behind India and China that collectively produce about 45-50% of global cotton production (Cotton Sector at a Glance, 2020). The United States, however, contributes about 35% of cotton exports globally and is the leading exporter worldwide (Cotton Sector at a Glance, 2020). In the marketing year of

2019, which is August 2019-July 2020, the United States produced close to 20 million bales of cotton worth about $7 billion (Cotton Sector at a Glance, 2020). There are 17 southern states, stretching from Virginia to California, that make up the "Cotton Belt" where cotton is primarily grown with a planting season from March to June and a harvest season from August to December (Cotton Sector at a Glance, 2020).

There are two primary species of cotton, Pima cotton and Upland cotton, that are cultivated commercially. Pima cotton has a fiber length of 3.5 cm or longer, used in expensive apparel or sewing thread, and it makes up 3% of production in the United States (Cotton Sector at a Glance, 2020). Upland cotton has a fiber length of 2.54 to 3.18 cm, used in apparel, home use, and medical supplies, and it makes up 97% of production in the United States (Cotton Sector at a Glance, 2020). Pima cotton is typically planted earlier in the season and grown in hot and dry conditions while Upland cotton is planted later in the season and grown in warm/hot conditions and dry autumns (Cotton Sector at a Glance, 2020). Even though cotton production and usage can vary, there are factors that influence the growth of cotton supply and demand, including population and economic growth, biotechnology innovations, and farm mechanization, resulting in a long-term upward trend worldwide (Cotton Sector at a Glance, 2020).

Cotton Harvesting

Mechanical cotton harvesting had been a well sought after method of harvesting and became widely accepted after World War II, triggering a productive revolution in the cotton industry (Aiken, 1973). Innovators had developed several ways to mechanically harvest cotton, but the main interest focused towards either spindle picking or stripping (Aiken, 1973). In the United States, the spindle picker and cotton stripper are the two types of mechanical harvesting

for cotton (Williford et al., 1994). The spindle picker uses barbed spindles to selectively harvest seed cotton from only well-opened bolls, while the cotton stripper harvests well-opened, cracked, and unopened bolls as well as burs and foreign material from the cotton plant in a nonselective manner (Williford et al., 1994). Stripping harvesters were created since they were able to remove the entire boll along with other parts of the cotton plant to harvest cotton with short plant heights, relatively low yield, and closed bolls to be cost-effective (Wanjura et al., 2010). While the spindle picker makes up 73% of mechanical harvesting used in the United States, the cotton stripper is the primary method of harvesting in the High Plains and Rolling Plains of Texas as well as regions of Oklahoma and Kansas, accounting for 26% of all mechanical harvesting (Parnell et al., 1994; Wanjura et al., 2010).

Spindle pickers are mainly operated at 85-90% efficiency, but they can harvest as efficient as 95% (Williford et al., 1994). About 34-68 kg of plant material is produced from a normal 680 kg of seed cotton in order to produce a 218 kg bale of cotton lint using the spindle harvesting method (Williford et al., 1994). Cotton strippers are more efficient at harvesting cotton with an efficiency up to 99%, however, the stripper also harvests large amounts of foreign material, which consists of burs, sticks, fine leaf trash, and soil particles (Williford et al., 1994). For every 218 kg bale of cotton lint created, 318-454 kg of trash is produced (Parnell et al., 1994).

Cotton Gin Byproduct

During the ginning process, seed cotton is separated into lint, cottonseed, motes, and cotton gin byproduct (CGB) (Rogers et al., 2002). The plant components of CGB are composed of burs, bolls, cotton lint, immature cottonseed, and coarse particles of leaf and stems as well as

soil (Conner and Richardson, 1987; Roger et al., 2002). Cotton gin byproduct is more commonly known as “cotton gin trash” or “gin trash” as it was primarily considered to be a waste product. It had few understood applications such that the cost of disposal was lower than any possible value it might have (Holt et al., 2000; Rogers et al., 2002). Holt et al. (2000) commented that due to using the terminology of “trash” for decades, utilization of this byproduct remained to be an obstacle. With the mindset that “cotton gin trash” is a valuable feedstuff, removing the word “trash” can be an effective way to gain greater acceptance from the general public and potentially increase utilization for this byproduct (Holt et al., 2000). Therefore, “cotton gin trash” will be referred to as “cotton gin byproduct” for the remainder of this thesis.

Buser (2001) stated that approximately 63% of cotton gins have an additional cost of disposing the CGB in the United States. Over the decades, CGB has been extensively researched for ways to utilize it, including being used as fire logs, an energy source, livestock feed, raw material for an end product, and compost, instead of direct application back to crop land (Holt et al., 2000). Cotton gin byproduct is successfully applied in creating composts and as a livestock feed, but the majority of it is still being applied back to crop field (Holt et al., 2000).

Cotton gin byproduct is a roughage source with varying plant components of mostly cellulose, hemicellulose, lignin, and minerals, and it can provide some energy for cattle that have low nutrient requirements (Conner and Richardson, 1987; Stewart and Rossi, 2010). For certain ruminant rations, free choice macro mineral supplementation should be added along with trace mineral salt as the calcium level of CGB is low (Stewart and Rossi, 2010). With CGB being at its maximum maturity level, there is little leaf material and is mainly composed of burs and stems (Conner and Richardson, 1987; Holt et al., 2003). The stems and leaves that remain have gone through physiological changes that make them less digestible as a feed source (Conner and

Richardson, 1987). While CGB has high fiber and a low amount of energy, it is an inexpensive feed source along with having physically effective fiber, allowing it to be an economical option as a hay replacement (Myer and Hall, 2003; Warner et al., 2020). In the southeast, it is not uncommon for CGB to be fed to brood cows in close range to cotton gins, with CGB being used as a hay substitute (Poore, 2022).

Myer (2007) commented that while CGB is an economical feed for beef cattle diets, the additional costs that need to be considered include; handling, transportation, and storage. Due to having a low bulk density, CGB can be expensive to transport over long distances in a loose form (Stewart and Rossi, 2010; Jacobs et al., 2022). The solution to transporting the low bulk density product is to compact the CGB into bales, cubes, or large modules (Rogers et al., 2002). This method can potentially widen the availability of CGB to beef cattle producers (Jacobs et al., 2022). Poore (2022) mentioned that CGB being baled in the southeast has allowed it to be sold in a wider geographical area of a cotton gin and allowing it to be used more in growing cattle TMR diets. Once the loose CGB is compressed and formed into 0.6 m x 0.6 m x 1.8 m bales, they are bound with plastic lashing strips or metal wires to preserve the structure (Jacobs et al., 2022). Bulk density of CGB increases from 160 kg/m^3 in its loose form to about 593 kg/m^3 once it is baled, and it may add value to beef cattle producers by increasing accessibility (Jacobs et al., 2022).

Cotton gin byproduct is a very dusty feedstuff when being handled, but baling can reduce the amount of dust (Mullenix et al., 2023). Cotton gins can also reduce the amount of dust from the CGB by adding water to it as it is being expelled from the gin to lower potential dust problems (Mullenix et al., 2023). Because of this method, however, baled CGB could experience a heating period, which is a similar situation to what occurs in high moisture hay (Mullenix et al.,

2023). Wet CGB can also become moldy, which would decrease palatability. If feeding is a desired use, care should be taken to ensure that the CGB does not have added water, and that it is then stored in a dry, well-ventilated place to reduce the risk of overheating and spontaneous combustion (Myer, 2007; Mullenix et al., 2023).

The disposal of CGB is commonly done through the direct application of crop fields (Buser, 2001). Because of the potential of CGB to contain weed seeds, Norsworthy et al., (2009) conducted a study to determine the most frequently found weed species from cotton gins within the Arkansas, western Tennessee, and western Mississippi area. Twenty-five weed species were found within the CGB with 14 species being broadleaf and 11 species being grass weeds (Norsworthy et al., 2009). The weed species that were found most frequently were Palmer amaranth, red sprangletop, goosegrass, barnyardgrass, and large crabgrass (Norsworthy et al., 2009). To reduce the amount of weed seeds within CGB, composting should be utilized for the disposal of CGB (Norsworthy et al., 2009).

While CGB is used as an inexpensive roughage source for livestock, particularly cattle, the supply of CGB and distribution of it to cattle is not well understood (Mullins, 2021). A survey was conducted in North Carolina asking cotton gins about CGB (Mullins, 2021). Based on the 20 responses from the survey, the average amount of CGB produced from a NC cotton gin is about 1,187 metric tons (Mullins, 2021). The total amount of CGB produced from the 20 cotton gins that responded was 23,732 metric tons, but with a total of 34 cotton gins in NC, the actual amount of CGB produced in NC would roughly be 40,300 metric tons (Mullins, 2021). Results from this research also indicated 40% (10 out of 25) of gins sell their CGB as cattle feed while the other 60% was given away as cattle feed or composted due to concerns with liability from the possibility of chemical residue residing in the CGB (Mullins, 2021). Because only 40%

of cotton gins sell their CGB, there is a tremendous opportunity for increasing the utilization of this feedstuff (Mullins, 2021). However, there's a lack of a distribution infrastructure in which approximately 26% of cotton gins compact their CGB, and only 29% arrange a way to transport it to cattle producers (Mullins, 2021).

Nutrient Composition of Cotton Gin Byproduct

Most byproducts are classified as a roughage, protein, or energy source with energy sources generally having more than 70% total digestible nutrients (TDN) and protein sources with more than 20% crude protein (CP) (Mullenix et al., 2023). Cotton gin byproduct has nutritional values that are similar to other roughage feedstuffs that creates an interest of adding it to ruminant feed rations (Buser, 2001). Myer (2007) compared CGB to low quality bermudagrass or bahiagrass hay in regards to having a similar feed value. Poore (2022) commented that CGB can be a good replacement for medium-quality hay when fed free choice as it is high in fiber and moderate in crude protein. A potential drawback to the success of using CGB in a feeding program is that the nutrient composition can vary greatly (Myer, 2007; Stewart and Rossi, 2010). Stewart et al. (1998) sampled CGB from different cotton gins with representative harvest seasons, ginning dates, and storage methods (Jacobs et al., 2022). Jacobs et al. (2022) determined CGB to contain on average 79.5% dry matter (DM), 46.6% TDN, and 11.7% CP, and Myer (2007) ranges of 40-92% DM, 16-62% TDN, and 7-16% CP. Myer (2007) stated that the drastic range in dry matter was due to the practice of some cotton gins spraying water to either control dust from the CGB or aid in the composting process, while other CGB was left outside and exposed to rainfall. Because of the practice of wetting the CGB, it can decrease palatability and lead to mold growth that may also be toxic to cattle (Stewart and Rossi,

2010). It is recommended that a nutrient analysis be done to properly formulate a feeding program using CGB because of the wide range of its nutrient composition (Myer, 2007).

Nutritional value of CGB from 6 studies is summarized in Appendix Table 1. Rogers et al. (2002) summarized that CGB had a TDN of 44% and CP of 7%, along with a calcium concentration of 0.65% and 0.12% phosphorus. Myer (2007) reported a similar analysis of 90% DM, 7% CP, 44% TDN, 0.8% calcium, and 0.2% phosphorus in CGB on a DM basis. In a study conducted in Alabama, an average of 40% TDN, 12.5% CP, 73% NDF, 56% ADF, and 12.9% ash was observed in CGB on a DM basis from cotton gins within Alabama (Jacobs et al., 2022). Stewart and Rossi (2010) summarized that CGB has 90% DM, 11.7% CP, 46.6% TDN, 0.9% calcium, and 0.2% phosphorus on a DM basis. Mullenix et al. (2023) reported that CGB contained about 40-48% TDN and 10-13% CP from cotton gins within Alabama. Kennedy and Rankins (2008) conducted a study using a CGB analysis of 69.2% NDF, 60.8% ADF, and 12.4 % CP. Myer and Hall (2003) summarized that CGB had a DM of 92%, 6% CP, 44% TDN, 0.6% calcium, and 0.2% phosphorus. From 5 different cotton gins in Turkey, CGB had a range of CP from 6.6 to 12.55% and an ash content of 9 to 17.7%, and NDF ranged from 49.2 to 62.2% while ADF ranged from 40.7 to 48.3% (Ozkan et al., 2014).

During the ginning process, CGB may go through the cotton gin twice to remove extra seed, known as “double ginning”, which lowers the feed value of it even further by leaving more lignin and ash contents with no energy value and keeping TDN and protein concentrations low (Myer, 2007). Jacobs et al. (2022) conducted a study comparing the nutritive qualities of CGB in a baled or loose form. While baled CGB had a crude protein of 13.9%, its loose form contained a crude protein of 11.0% (Jacobs et al., 2022). While the nutritive form of CGB may differ, an

analysis should be done to allow for more strategic use of it for beef cattle operations and feed diets (Jacobs et al., 2022).

Cotton Gin Byproduct Production

In the United States, cotton gins produce about 2.8 million tons of CGB (Rogers et al., 2002). About 1.82 million hectares of cotton are grown each year with an average yield of 3.7 bales per hectare in the southeastern United States (Myer, 2007; Stewart and Rossi, 2010). From the amount of cotton that is produced during harvest in the southeast United States, 500,000 to 700,000 tons of CGB is produced, which might have the capability of feeding 300,000 to 400,000 cows for 100 days (Stewart and Rossi, 2010). The amount of CGB produced is determined by the geographical area, method of harvesting, and the year-to-year variation in weather during the cropping season (Conner and Richardson, 1987; Baker et al., 1994). In arid regions of the country where cotton varieties have been developed for better drought tolerance, the cotton stripping harvesting method is the most popular (Conner and Richardson, 1987). From a 218 kg bale of cotton, cotton that was harvested with a spindle picker usually produces about 34 to 91 kg of CGB (Myer, 2007). “Seed cotton cleaning” is an interchangeable term in the ginning industry as it refers to the entire cleaning and extracting system or specific machinery (Baker et al., 1994). The cleaning and extracting system extracts large plant components that are relatively easy to remove from the seed cotton to allow the gin stand to operate at peak performance. Afterwards, the seed cotton is cleaned from the smaller particles that are typically entangled in the fiber to obtain an optimum grade of cotton at market value (Baker et al., 1994). Once the cotton is ginned, the CGB is stacked outside in large piles (Mullenix et al., 2023). The CGB can be of concern for disposal because of environmental awareness and regulations

(Rogers et al., 2002). Disposal methods include direct land application and composting, but CGB can still pose as a concern because of its slow rate of decomposition (Roger et al., 2002; Myer, 2007). However, it can be used as a roughage source due to having some nutritional value for beef cattle (Myer, 2007). If beef cattle operations are nearby a cotton gin, then there is a potential for them to utilize the CGB as an inexpensive feed source by feeding it as a winter feed for dry cows, a roughage source for feedlot cattle consuming a high-concentrate diet, and a partial substitute for pasture or hay (Rogers et al., 2002). Although CGB has a limited protein availability and relatively poor digestibility, incorporating it into livestock rations could reduce other disposal options, increase gin profits, and add another roughage option to the livestock industry (Buser, 2001).

Beef Cattle Production Using Cotton Gin Byproduct

The cost of feed makes up the majority of total cost to maintain a beef cow, particularly in the winter as costs are incurred for supplementation, but reducing feed costs can be achieved with alternative feeding programs (Rogers and Poore, 1994). Rogers and Poore (1994) state that alternative feeds are simply feeds that have not been commonly used in the past and often reduce feed costs. During the winter, hay has been the main feed source for beef cattle, but to reduce cost, crop residues have been utilized as well as CGB as an option to replace low to medium quality hay, however, it is not commonly utilized by cattle producers (Stewart and Rossi, 2010; Jacobs et al., 2022). When compared to high fiber feeds, like crop residues, the intake of CGB is greater than expected based on the very high fiber content (Poore, 2022). One way CGB can be fed is by placing an electric fence wire in front of a module or bale to decrease waste and limit availability to obtain about 75% utilization (Rogers et al., 2002; Stewart and Rossi, 2010).

Cotton gin byproduct is highly suitable for dry pregnant cows as they have the lowest nutrient requirements and can be maintained with a body condition score of 5 or greater using high levels of CGB (Stewart and Rossi, 2010). Hill et al. (2000) conducted an experiment using nonpregnant beef cows for 55 days fed with only ad-libitum CGB or ad-libitum CGB supplemented with corn. Although the intake of CGB was low during the first 10 days of the trial, it increased quickly over the trial (Hill et al., 2000). While initially unpalatable to beef cattle, it may take several days to adjust to consuming CGB, especially when fed high amounts or if it has high contamination of soil (Myer, 2007; Stewart and Rossi, 2010). During the training period in a Calan Gate System, Jacobs et al. (2022) did not observe a decrease in intake due to the acclimation of CGB in beef cows.

Over the course of a 55 day study, beef cows consumed an average of 12.7 kg/head per day (Hill et al., 2000). Cows solely fed CGB lost some body condition and body weight while the cows supplemented with corn were able to maintain body condition and weight (Hill et al., 2000). Sagebiel and Cisse (1984) fed varying levels of CGB to gestating beef cows either alone or in combination with other feedstuffs. The body weight of beef cows increased when they were supplemented with other feedstuffs, such as silage and whole cottonseed, compared to a diet of only CGB (Sagebiel and Cisse, 1984).

Jacobs et al. (2022) conducted a research trial looking at the dry matter intake of CGB in its loose or baled form when fed ad libitum to 24 nonlactating beef cows and heifers. Cattle that consumed CGB in its loose form with supplementation had dry matter intake at 2% of their body weight compared to cattle that consumed 1.8% of their body weight from the baled form (Jacobs et al., 2022). While the nutritive value of CGB in its loose form was lower in TDN (1.3%) and CP (2.9%) than its baled form (TDN=39.1%, 40.4%; CP=11%, 13.9%; NDF=74.5%, 71.5%,

respectively), the physical form of differing volumes and bulk densities may have been the reason why there was an increase in dry matter intake (Jacobs et al., 2022). From this study, Jacobs et al. (2022) concluded that CGB can be fed in either its loose or baled form to bred, nonlactating cows as both treatments were able to maintain body weight and condition with supplementation. When using supplementation with CGB, an energy supplement is typically required for beef cows, but a protein supplement is likely unnecessary (Stewart and Rossi, 2010). However, young cows and heifers have a higher nutrient requirement than more mature cows, so CGB should not be the main roughage source until they are pregnant with their third calf (Stewart and Rossi, 2010).

Cotton gin byproduct may also be used for other classes of beef cattle as a roughage source (Myer, 2007). In Western feedlots, CGB has been used in rations where roughage costs can be high (Rogers et al., 2002). Myer (2007) recommended that CGB should only be included at a low percentage of the total diet, such as 5% or less for a finishing cattle diet to help the digestive system with maintaining proper function. Likewise, Stewart and Rossi (2010) suggest that feedlot diets should contain 5 to 10% of CGB because of its low energy content. Warner et al. (2020) compared a control diet using prairie hay and corn-based supplements to a diet of CGB, whole cottonseed, and rolled corn in feedlot cattle. Dry matter intake was greater for the CGB diet than the control diet (12.4 vs 11.7 kg/day, respectively), but there was no difference in feed efficiency (0.167 vs 0.167, respectively) (Warner et al., 2020). There was also a tendency for the CGB diet to have a higher average daily gain than the control (2.09 vs 1.95 kg, respectively) (Warner et al., 2020).

Cotton gin byproduct has the potential to also be fed to growing beef steers. Stocker cattle need to gain moderate rates of at least 0.68 kg per day in order to be profitable (Stewart

and Rossi, 2010). When stocker steers were fed high levels of CGB from 43 to 76%, there were dramatic associative effects with reducing diet digestibility as the level of corn increased and CGB decreased towards 43% (Hill et al., 2000; Stewart and Rossi, 2010). This concludes that CGB could only be viable as a roughage source in high concentrate diets and had little potential for growing cattle being fed the byproduct at high levels because steers could not maintain 0.68 kg per day (Hill et al., 2000; Stewart and Rossi, 2010).

Kennedy and Rankins (2008) fed with 40 Angus x Continental steers with an initial body weight of 233 kg 4 different diets with 2 of them containing 45% CGB and the other 2 diets consisting of 45% peanut hulls. There were also 2 diets that both contained 8% cottonseed meal, one with 45% CGB and the other with 45% peanut hulls. In this trial, steers fed CGB had a higher average daily gain at 1.19 kg per day than steers fed peanut hulls (0.94 kg per day). Dry matter intake was also greater at 10.3 kg/day for the CGB diets versus 7.6 kg/day for the peanut hulls diets (Kennedy and Rankins, 2008). This study showed that while CGB is a low quality feed, it is better suited for growing cattle diets than peanut hulls due to the difference in dry matter intake.

Hill et al. (2013) conducted separate experiments with CGB. The first study used 30 beef steers with an average body weight of 454 kg which were individually fed different treatment diets; ad-libitum hay; ad-libitum hay with either whole cottonseed, dried distiller's grains, or CGB; or ad-libitum CGB. Both CGB diets had over twice as much dry matter intake compared to the other three diets. The hay plus CGB diet had an intake of 15.51 kg/day and the ad-libitum CGB had an intake of 15.64 kg/day. The three other diets were ad-libitum hay, ad-libitum hay with whole cottonseed, and ad-libitum hay with dried distiller's grains with dry matter intakes of 6.77, 7.2, and 6.67 kg/day, respectively. Another experiment fed 52 steers with an average body

weight of 321 kg either free-choice CGB blocks on pasture or soybean hull and dried distiller's grains supplement on pasture (Hill et al., 2013). Hill et al. (2013) concluded that, on pastures, ad-libitum CGB had a dry matter intake of 11.18 kg/day and an average daily gain of 0.69 kg compared to a treatment of a soybean hull and dried distillers grains supplement with a dry matter intake of 6.53 kg/day and an average daily gain of 0.76 kg.

Holloway et al. (1974) saw results from a study where steers being fed mostly CGB as their main source of energy had less efficient feed conversion (32.33 kg of feed to kg of gain) and lower average daily gain (0.14 kg), resulting in lighter weights, compared to feed conversions and average daily gains for steers in other treatments, including steers only fed sorghum silage (8.55 and 0.53 kg, respectively) or CGB with silage (9.64 and 0.5 kg, respectively), ground corn (10.7 and 0.52 kg, respectively), and ground corn with charcoal (16.75 and 0.35 kg, respectively). Steers fed during the experimental phase of cottonseed meal and CGB appeared permanently "stunted," which resulted in an overall decreased slaughter weight (392 kg) compared to the other diets (441 to 452 kg) (Holloway et al., 1974). Steers being fed CGB with supplementation had similar average daily gains compared to rations containing no CGB (Holloway et al., 1974). While drought or high prices of traditional feed may increase the use of byproducts, beef producers can utilize CGB to replace some of their forage sources to obtain optimal production and sustain profitability in the current competitive market (Smith, 2020; Warner et al., 2020).

Mullins (2021) evaluated the performance of 56 yearling Angus steers being fed different diets of cotton byproducts, specifically whole cottonseed, a high protein and energy feed, and CGB, a low energy roughage, to determine which diet resulted in better performance of weight gain, feed efficiency, and economical value. The trial had 4 treatment diets with all diets

formulated to 73% TDN and 14% CP. The first diet was the control, which contained 75.5% corn silage and supplemented with ground corn and soybean meal, while the second treatment diet had 15% whole cottonseed, 75.5% corn silage supplemented with ground corn and soybean meal. The third treatment diet had 25% CGB and 23% corn silage supplemented with ground corn and soybean meal, and the last diet included both 15% whole cottonseed and 25% CGB along with 23% corn silage supplemented with ground corn and soybean meal (Mullins, 2021). While dry matter intake for treatments 1 and 2 were similar (8.86 kg and 8.52 kg, respectively), diet 3 (11.31 kg) was significantly the greatest of all diets while diet 4 (10.23 kg) was the significantly greater than the first two diets but significantly lower than diet 3 (Mullins, 2021). This concludes that diets with 25% CGB will have a greater dry matter intake than diets without the CGB. As for average daily gain, diet 3 (1.53 kg) was again the greatest while the other treatments were not different (1=1.29 kg, 2=1.17 kg, 4=1.32 kg), which means that growing beef steers will gain more as well being fed CGB in addition to corn silage supplemented with ground corn and soybean meal (Mullins, 2021). Treatments 1 and 2 (6.76 kg and 6.81 kg, respectively) were again similar for feed conversion as well as treatments 3 and 4 (8.65 kg and 8.24 kg, respectively), but treatment 3 was still the greatest numerically, which signifies that treatments 3 and 4 consumed more feed to achieve the same weight gain as treatments 1 and 2 (Mullins, 2021). Overall, diet 3 was the best performing diet with greater dry matter intake and average daily gain and shows that utilizing this inexpensive roughage source can improve performance levels (Mullins, 2021).

Newsome (2023) evaluated the growth of 64 Angus yearling steers fed different amounts of wet brewers' grains and CGB, both common byproduct feeds produced in North Carolina. Eight diets were used for this study in a 2 x 4 factorial design with 2 levels of CGB at 0 and 25%

inclusion and 4 levels of wet brewers grain, ranging from 0-30% in 10% integer increases (Newsome, 2023). Average daily gain (CGB growing: 0%=1.65kg and 25%=1.6kg, CGB finishing: 0%=1.5kg and 25%=1.6kg) was not different in either the growing phase or finishing phase from any of the treatment diets. However, dry matter intake (0%=11kg and 25%=12kg) and feed conversion (0%=6.75 and 25%=7.6%) was increased for steers fed CGB in the growing phase (Newsome, 2023). Therefore, feed consumption increases for steers being fed CGB and could still have similar average daily gains in a stocker operation (Newsome, 2023).

Physical Treatment of Cotton Gin Byproduct

There have been multiple techniques developed to improve the quality of CGB over the decades where some of these techniques are physical treatments (Holt et al., 2003). Holt et al. (2003) states that removing some of the ash content that is collected during harvest can make CGB more uniform and improve both digestibility and feeding value to ruminants. Pelleting CGB did not decrease weight gain or dry matter intake, but it did decrease feed efficiency, which may have been caused by the reduction in particle size and increased passage rate with reduced fermentation time (Conner and Richardson, 1987). The potential benefits of physical processing of CGB are to reduce sorting and increase consumption to improve animal performance (Holt et al., 2003). While several techniques exist, no single technique has been accepted for practical use and economical feasibility in animal production (Holt et al., 2003).

Chemical Treatment of Cotton Gin Byproduct

While CGB is available in large amounts, it has a slow rate of decomposition and is suggested that chemical treatment should be considered for use as an economical source of

dietary energy (Conner and Richardson, 1987). Being very mature at harvest, crop residues are a low-quality roughage with highly lignified structural carbohydrates (Klopfenstein, 1978; Arndt et al., 1980). Chemical treatment of sodium hydroxide can solubilize hemicellulose while not changing the cellulose content, and it can break the bonds between the lignin and hemicellulose or cellulose to potentially allow rumen microbes to better digest those carbohydrates from the CGB (Klopfenstein, 1978; Arndt et al., 1980). It has been shown that more energy and higher digestibility can be derived from CGB with chemical treatment, but nutritional responses from CGB can vary depending on the kind of chemical that is used as well as the concentration of the chemical (Conner and Richardson, 1987).

In Georgia, urea and ammonium hydroxide was used to try to improve the digestibility of the CGB. Treating CGB with urea resulted in a 6% increase in vitro dry matter digestibility while treatment of the ammonium hydroxide resulted in a 21% in vitro dry matter digestibility (Stewart and Rossi, 2010). Sodium hydroxide appeared to be more effective on in vitro digestibility than ammonium hydroxide when used on CGB (Klopfenstein, 1978). Arndt et al. (1980) tested the apparent dry matter digestibility using sodium hydroxide and observed that increasing amounts of the chemical within the diet did increase apparent digestibility by 35.4%, however, it decreased the potassium, chlorine, and magnesium balance, resulting in an increase for the animal's requirement for those 3 nutrients. When treated with anhydrous ammonia, CGB fed to growing ruminants resulted in performance levels that were similar as receiving nitrogen supplementation from soybean meal (Conner and Richardson, 1987). While chemical treatment of CGB has potential, there has not been much research done in recent years regarding chemical treatment for livestock, and the development of a modern-day system would be expensive as well as be dependent on chemicals that are difficult to manage (Stewart and Rossi, 2010).

Gossypol

The use of cotton products on beef cattle operations in the southern United States have been limited partially because of the concern towards gossypol toxicity (Rogers and Poore, 1995). Gossypol is a yellow pigment that is primarily found in cottonseeds but can also be found throughout the cotton plant, including the roots, stalk, leaves, and bolls (Morgan, 1989; Stewart and Rossi, 2010). The amount of gossypol of CGB can be variable depending on the quantity of cottonseed in it (Stewart and Rossi, 2010). Gossypol is specifically located in glands that can be seen as small, dark spots scattered throughout the tissue of the cottonseed kernel (Rogers et al., 2002). It is believed that the function of gossypol is related to insect resistance for the cotton plant (Morgan, 1989). Gossypol is also chemically structured as polyphenolic binaphthyl dialdehyde (Rogers and Poore, 1995). If consumed in large quantities, gossypol can be toxic to cattle (Stewart and Rossi, 2010). High levels of gossypol greater than 1800 ppm are toxic to ruminants (Morgan, 1989). Two stereoisomers exist naturally as a mixture in gossypol, which is known as (+) and (-) gossypol where the minus isomer has higher biological activity and is reproductively more detrimental, particularly in bulls with reproductive failure, than the plus isomer (Rogers et al., 2002; Stewart and Rossi, 2010). There are two forms of gossypol, a free and bound form where the free form is toxic and the bound form is nontoxic because the gossypol binds to proteins (Morgan, 1989). The physiological process by which ruminant animals detoxify gossypol is unknown (Arshami and Ruttle, 1988). While the free form of gossypol is known to be toxic to nonruminants, ruminants bind the free gossypol to soluble proteins in the rumen to detoxify it, hence, turning it into a bound form. However, bound gossypol is undigestible and cannot be absorbed by the ruminant nor be reversed in the gastrointestinal tract (Morgan, 1989). If there is too much free gossypol or not enough protein to

bind it, the detoxification system will be overwhelmed, resulting in gossypol toxicity (Morgan, 1989). Decreased intake, lower milk production, panting, elevated heart rate, ruminal stasis, conception failures, and sudden death are symptoms of gossypol toxicity in mature cattle (Rogers et al., 2002). Gossypol toxicity can result from animals being fed feedstuffs containing gossypol over a long period of time, suggesting the toxic level can be achieved through accumulation, resulting in damage or death (Morgan, 1989). Chances for gossypol toxicity can be increased through a high concentration diet, specifically containing cottonseed, and potentially from a faster rate of passage as the free, toxic gossypol passes through the rumen and into the small intestine (Rogers et al., 2002). The variety of cotton can affect the amount of gossypol contained within the plant (Rogers et al., 2002). The two varieties of cotton, Upland and Pima, have different levels of gossypol as Upland, the most common variety in the United States, usually contains less gossypol and a lower amount of the detrimental minus isomer compared to the Pima (Stewart and Rossi, 2010). Another factor that can influence the amount of gossypol contained within a cotton plant is climate condition (Rogers et al., 2002). Rainfall has a positive correlation to the gossypol content of a cotton plant, but a higher average daily temperature has an inverse relationship to change the amount of gossypol (Rogers and Poore, 1995). Soil conditions, including fertilizer composition and water supply, can affect the gossypol content as well as changes in plant growth during the vegetative stage (Rogers and Poore, 1995).

While adult ruminants have some resistance to gossypol, nonruminants and preruminants are sensitive to gossypol (Rogers et al., 2002). Reports of low levels of gossypol of less than 400 ppm have been toxic to young calves and lambs (Morgan, 1989). At less than 4 months old, young calves and lambs cannot detoxify the amount of free gossypol that mature cattle and sheep can even though they are ruminant animals (Morgan, 1989). Instead, young ruminants are similar

to hogs in their detoxification capacity as they are functionally preruminal and have yet to develop a fully function rumen (Morgan, 1989). An experiment was conducted where 0 to 800 ppm of free gossypol was fed to Holstein bull calves that were 1-120 days old throughout the trial, and symptoms of gossypol toxicity was found in treatment groups of 400 and 800 ppm free gossypol (Risco et al., 1992). From this data, it was concluded that up to 200 ppm is safe, 400 ppm can be toxic, and 800 ppm of free gossypol results in death for bull calves (Risco et al., 1992). Morgan (1989) summarized that no more than 0.01% of free gossypol should be fed to calves and lambs younger than 4 months old, but it can be a "gray area" for calves and lambs being affected by free gossypol toxicity (Morgan, 1989).

A common concern when feeding bulls, especially young, developing bulls, diets that contain gossypol is reproductive failure from toxicity (Stewart and Rossi, 2010). Arshami and Ruttle (1988) fed whole cottonseed or cottonseed meal containing gossypol to bulls. Authors found that the seminiferous tubules had larger lumens, smaller wall thickness, and a lower number of cell layers when compared to bulls fed a diet with no gossypol. Rogers and Poore (1995) report that other reproductive failures, such as mitochondrial damage to sperm tails, spermatogenesis depression, and testicular damage, have also been observed. Compared to other organs, the testicle seems to have more gossypol sensitivity (Rogers and Poore, 1995). There are detrimental effects to these histological changes on the spermatogenic tissues and associated cells, but research has also shown that these effects can be partially reversible (Morgan, 1989). Arshami and Ruttle (1988) compared gossypol as a male contraceptive drug as it directly or indirectly alters spermatozoa development. Gossypol's contraceptive effect has been associated with spermatogenesis impairment, reduced sperm output, and immobile, morphologically abnormal spermatozoa in the duct systems of rabbits, rats, hamsters, and bulls (Arshami and

Ruttle, 1988). Compared to bulls, female ruminants have shown to be more resistant to reproductive failure from gossypol toxicity (Stewart and Rossi, 2010). While female ruminants seem to have some insensitivity to gossypol causing reproductive effects, data indicates an inhibition of embryonic development and ovarian steroidogenesis with in vitro studies (Rogers and Poore, 1995).

Being a cardiotoxin, gossypol toxicity can cause cardiac failure as it leads to death (Morgan, 1989). Being fed over a long period of time, gossypol can cause lesions associated with heart failure because of necrosis of cardiac musculature (Morgan, 1989; Rogers et al., 2002). Also affecting the blood, reports of calves and mature cattle experiencing gossypol toxicosis have decreased hematocrit and hemoglobin concentrations along with a higher number of fragile erythrocytes and an increased time for blood clotting (Rogers et al., 2002).

Even though gossypol can cause death in cattle, death is unlikely to occur if cottonseed and cottonseed meal are fed at the recommended levels because the amount of gossypol in those feedstuffs are lower than the amount needed to cause death (Stewart and Rossi, 2010). When the price of cottonseed products is low, feeding the upper end of recommended levels can become common, and a gossypol analysis may be helpful in preventing gossypol toxicosis (Rogers et al., 2002). The upper end of recommended feeding levels of cottonseed products depends on the stage of production, such as 0.5% of body weight for mature cows and 0.3% of body weight for stocker cattle fed whole cottonseed (Jacobs et al., 2019). In the case of feeding low levels of cottonseed products, it may not be economical to test for gossypol as there is a very low risk of toxicity (Rogers and Poore, 1995). Regardless of the possibility of gossypol toxicity, cottonseed products can be fed as a safe byproduct feed to cattle at recommended levels (Rogers and Poore, 1995).

Chemical Residues

Cotton ginning produces a massive amount of CGB, and it has been recognized that there are some limitations to its use because of the application of chemicals during the cotton growing season, potentially leaving residues on the CGB (Winterlin et al., 1986). The presence of chemical residues in CGB fed to cattle can pose a concern as several chemicals applied in cotton production are labeled “do not feed ginning residues to livestock” (Stewart and Rossi, 2010). Chemical residues can include herbicides or other pesticides, or harvest-aid chemicals (Jacobs et al., 2022). Arsenic is not a concern when feeding CGB as it is no longer commonly used in cotton defoliants as it was decades ago (Stewart and Rossi, 2010). Defoliation, or the loss of leaves, can happen naturally as the plant reaches maturity or it may be induced from drought, insect damage, light frost, disease, or mineral deficiency (Dodds et al., 2016). Defoliants or harvest aids may also be used to achieve defoliation artificially (Dodds et al., 2016). For ground application, there should not be less than 15 gallons of water per acre for the application of the defoliant (Dodds et al., 2016). Defoliation improves leaf removal for better lint grades, more efficient harvesting, lowering moisture, and removing more plant material from the seed cotton modules during harvest (Dodds et al., 2016).

While there have been benefits to incorporating CGB in livestock diets, discouragement of wide-spread use of CGB as a feed came from a lack of establishment in chemical residue tolerance levels (Buser, 2001). A common defoliant used in the cotton industry is S,S,S-tributyl phosphorotrithioate or tribufos/DEF (Myer, 2007). Jacobs et al. (2022) conducted a study involving sampling CGB for chemical residues, and only tribufos was found. A study in Georgia sampled CGB from 21 cotton gins and only tribufos was found at a significant level with a range of 0 to 25.6 ppm and an average of 4.49 ppm (Rogers et al., 2002). While no tolerance level for

any chemical residues have been established for CGB, whole cottonseed has a tolerance level of 4 ppm for tribufos and cottonseed hulls have a tolerance level of 6 ppm for cattle (Stewart and Rossi, 2010). Liability can become a concern when feeding CGB because it is a novel feed without a legal definition from the American Association of Feed Control Officials (AAFCO). It has also been recommended that evaluations of nutrient content, chemical residues, and toxins should be made before being fed to livestock (Rogers and Poore, 1994). Contaminated Australian beef caused a negative perception of feeding CGB, establishing a long lasting effect that still impacts the industry today (Smith, 2020). Substantial amounts of chemical residues may contribute to above-tolerance residues in milk and meat, so considerations should be made when using CGB for cattle being fed for slaughter or milk production (Winterlin et al., 1986; Rogers et al., 2002). Chemical compounds have been created to help mitigate the amount of residues, and heat from an extruder may help reduce some residues in CGB (Buser, 2001). Testing CGB for chemical residues and defining tolerance levels can help mitigate concern for feeding it to cattle (Jacobs et al., 2022). Testing for chemical residues is uncommon and not practical for most farm operations. Feeding CGB is generally safe and typically does not pose a concern, but more research is needed as there is a lack of an established tolerance level for chemical residues.

CHAPTER 2: EVALUATION OF COTTON GIN BYPRODUCT IN GROWING DIETS FOR BEEF STEERS

Introduction

Byproducts are utilized as a cheaper feed alternative to reduce input costs. In a cotton gin, the plant material from harvested cotton is removed from the seed cotton in the beginning of the ginning process, and cotton gin byproduct is produced (Rogers et al., 2002). Roughly 40,000 metric tons of CGB is produced in North Carolina each year as about half of it is utilized as cattle feed and the other half is composted within the state (Mullins, 2021). The production of cotton gin byproduct allows beef cattle producers who are relatively near a cotton gin the opportunity to utilize this byproduct to improve their profitability for their operation as it is an inexpensive feedstuff. While CGB has a low bulk density, it can be compacted into bales to improve transportation (Rogers et al., 2002; Stewart and Rossi, 2010). Cotton gin byproduct is also dusty, but baling it can reduce the amount of dust (Mullenix et al., 2023). Cotton gin byproduct can vary in its nutrient content, but it is comparable to low to medium quality hay as it is low in total digestible nutrients and moderate in crude protein (Stewart and Rossi, 2010; Poore, 2022). Mullenix et al. (2023) reported that CGB contained about 40-48% TDN and 10-13% CP from cotton gins within Alabama. Cotton gin byproduct is a dry feedstuff. Myer (2007) and Stewart and Rossi (2010) reported CGB having a dry matter of 90%.

The availability of cotton gin byproduct in North Carolina for beef cattle producers led to the objective of both studies evaluating the performance of beef cattle during the stocker phase when fed different concentrations of CGB. It was hypothesized that stocker steers fed intermediate levels (20% or 30%) of CGB would peak in animal weight gain and have a

quadratic effect. This was hypothesized because Mullins (2021) and Newsome (2023) reported results with similar inclusion rates of CGB that performed well compared to diets that did not include CGB.

Materials and Methods

Two experiments were conducted evaluating the performance of beef steers fed different levels of CGB during the growing phase. The experiments were conducted in 2023 and 2024 at the Butner Beef Cattle Field Lab (BBCFL), a research station of North Carolina State University, located in Bahama, NC. Experimental procedures used for these trials were approved by the Institutional Animal Care and Use Committee (IACUC #22-443) at North Carolina State University.

Experiment 1

Treatment of Animals

Fifty yearling purebred Angus steers (349 ± 66 kg) were selected by weight from heaviest to lightest without outliers and temperament from a group of 73 steers from the BBCFL resident herd. Temperament observations with no quantitative measurements were made 7 weeks before the start of the study. Steers with no mal temperament observations were selected for the study. Steers were also specially selected based on pink eye scars as those with severe scars were not considered for the study. Each steer received Bovi-Shield Gold FP5VL5 (Zoetis Inc., Kalamazoo, MI) and Vision 7 (Merck Animal Health division of Intervet Inc., Omaha, NE) at time of weaning (7 months prior to the study). The steers were dewormed using Safe-Guard (Merck Animal Health division Intervet Inc., Madison, NJ) 3 weeks prior to the start of the

experiment as well as given Bimectin Pour-On (Bimeda, Schaumberg, IL) 7 weeks prior to the start of the experiment. The steers were stratified by body weight and grouped into 5 pens with 10 steers per pen. All 10 ft x12 ft pens had concrete slatted floors for waste management, an automatic waterer, and electronic Calan gate feeders (American Calan, Northwood, NH). Three weeks prior to the start of the collection period, each steer was fitted with a radio frequency identification key with a plastic chain necklace to unlock their individual Calan gate within their assigned pen. During this 21 day period, steers were acclimated to the CGB by feeding a diet consisting of 20% CGB, 46% corn silage, and 34% concentrate supplement.

Two steers within a pen were randomly assigned to one of five treatment diets containing 0, 10, 20, 30, and 40% CGB on a dry matter basis, representing 10 steers per treatment. Initial (day 0) and final (day 84) weights were calculated from the average body weight of each steer on two consecutive days prior to feeding at approximately 0800 hours. On days 28 and 56, body weights were also recorded prior to feeding at approximately 0800 hours. Initial and final body weights were used to calculate average daily gain (ADG), feed conversion, and feed efficiency.

At the end of the 84-day growing phase, the steers were transitioned to the same finishing diet for a 55-day finishing phase. The finishing diet was composed primarily of corn, soybean meal, and corn silage throughout the finishing phase and ended at d 139. The final two consecutive weights from the growing phase (d 83 and d 84) were used as the initial weight for the finishing phase. During the finishing phase, steers were weighed every 28-d. At the end of the finishing phase, steers were weighed on two consecutive days. Blood samples were collected during the growing phase, but they were not collected during the finishing phase. During the finishing phase, each steer stayed in their pen and retained their key for their assigned Calan gate.

Feeding, Feed Sampling, and Analysis

The corn silage used for all diets was grown, harvested, and stored in silage bags by the NCSU Butner Beef Cattle Field Lab. The corn silage was taken from two separate silage bags. The CGB was purchased from Edwards Cotton Company Inc. (Scotland Neck, NC) in the form of 300 kg bales, and it cost $99.80 per metric ton. The CGB was delivered to BBCFL in one load prior to the start of the study.

One composited sample of each corn silage and CGB were sent to Cumberland Valley Analytical (Waynesboro, PA) for a standard wet chemistry nutrient analysis prior to diet formulation. The chemical composition of those samples reported in Table 2. On a dry matter basis, all 5 treatment diets were formulated to meet nutrient requirements at 72% TDN, 12.5% CP, 0.22% phosphorus (P), and 0.35% calcium (Ca). The National Research Council (NRC) guidelines were used to set nutrient requirements for an ADG of 1.1 kg/day for a 363 kg growing steer (NRC, 2000), with the assumption that CGB had a TDN of 50%.

Diet formulations are reported in Table 3. Diet 1 had 0% CGB, 87.8% corn silage, 0% ground corn, and 11.1% soybean meal. Diet 2 had 10% CGB, 69% corn silage, 10.18% ground corn, and 9.9% soybean meal. Diet 3 had 20% CGB, 46% corn silage, 24.7% ground corn, and 8.58% soybean meal. Diet 4 had 30% CGB, 26% corn silage, 36.2% ground corn, and 7.3% soybean meal. Diet 5 had 40% CGB, 5% corn silage, 48.7% ground corn, and 6% soybean meal. The remaining portion of each diet was composed of trace mineral salt, limestone, Rumensin, and vitamins A, D, and E. Diet 1 was fairly moist and homogenous, and as the diets included more CGB, the diets became drier and more heterogenous with CGB and the concentrate supplement.

Samples of corn silage and CGB were collected biweekly throughout the trial. Batches of concentrate mixes were made as needed, and each time a batch of the concentrate mix was made, a sample of the concentrate mix was collected. All feed samples were stored in a freezer (-10°C) immediately after collection. After completion of the growing and finishing phases, feed samples were composited to represent the first and second half of the growing period and sent to Cumberland Valley Analytical Services in Waynesboro, Pennsylvania for nutrient analyses.

Every morning at 0800h, treatment diets were made as a total mixed ration (TMR) and fed to the steers. Feed given to each steer was recorded daily. Visual observations of feed refusals for each steer were made prior to the morning feeding, and adjustments were made and recorded to increase or decrease the amount of feed given to each steer based on those observations. Feed bins were cleaned once a week by removing orts and weighing them, or they were removed and weighed more often depending on the amount of refusal determined by the nutrition manager at BBCFL. The removed orts were not analyzed. Feed offered and feed refusal were used to calculate feed consumption.

Blood Sampling and Analysis

Blood samples were collected prior to feeding on d -22, 0, 28, 56, and 84 to analyze Blood Urea Nitrogen (BUN) and gossypol. Blood was drawn from the jugular vein using 10 mL vacutainer tubes with no additives along with 3.81 cm x 20-gauge needles. Immediately after collecting, blood samples were placed in a cooler with ice packs until they were transported to the laboratory for processing. The blood samples were centrifuged at 2,500 x g for 30 minutes to collect the serum. Serum was stored in plastic vials and frozen (-10°C), awaiting analysis. The BUN assay used the microtiter plate method, which is modified for blood serum from Jung et al.

(1975) and Zawada et al. (2009). The serum samples were diluted with distilled water at a 1:5 ratio, and a Biotek Synergy HT (Winoski, VT) microplate reader was utilized to read the colorimetric assay on a 96-well plate at 430nm.

Gossypol

Serum samples were pipetted out of the plastic serum tubes into 2 mL bullet tubes. Weights of the sample vials were taken, and 1 mL of serum was added to the sample vial. A gross weight of the sample vial and serum were taken to calculate the weight of serum added to the vial as the analysis will result in micrograms of gossypol per vial. All weights were recorded in milligrams. The bullet tubes were then frozen (-10°C).

Samples of CGB were ground to 1 mm using the Wiley Mill. Ground CGB was mixed together, and a subsample of the ground CGB was collected into a 50 mL test tube for transport. All samples of serum and ground CGB were shipped to the USDA lab in New Orleans for a gossypol analysis which was modified from (Hron et al., 1999; Bullock et al., 2010).

Carcass Measurements

On June 27, 2023, steers were loaded onto a commercial truck and shipped to the Cargill Wyalusing Protein Processing plant in Wyalusing, Pennsylvania. After the steers were slaughtered on June 28, 2023, data on hot carcass weights (HCW) were recorded. Dressing percentage (dressing%) was calculated with the formula: Dressing% = (HCW/(final weight*0.96))*100. This equation involves a 4% shrink loss due to transportation. Quality grade, marbling scores, back fat thickness (BF), ribeye area (REA), and kidney, pelvic, and heart fat (KPH) for each steer was evaluated by the Pennsylvania State University carcass data service.

The carcass characteristics of BF, KPH, HCW, and REA were used to calculate yield grade (YG) from the formula: YG = 2.5 + (2.5 x BF) + (0.2 x %KPH) + (0.0038 x HCW) – (0.32 x REA) (Holland and Loveday, 2013). Quality grade was evaluated on every individual steer based on the maturity of the steer carcass and the marbling of the carcass between the 12^{th} and 13^{th} rib. Both marbling and quality grade were coded numerically for statistical analysis. Marbling was coded on a scale from 4.0 to 11.0 with 4.0 being Slight and 11.0 indicating the highest classification of marbling (Abundant). For the code number, the ones place signifies the marbling degree, and the tenths place indicates the subunit of the marbling degree. Quality grade was coded using whole numbers on a scale from 14 to 22 with 14 being (Select –) and 22 indicating the highest quality, (Prime +) (Capucille et al., 2004).

Statistical Analysis

Data was analyzed using PROC MIXED procedure of SAS version 9.4 (SAS Institute, Cary, NC). The main effect was the treatment diet for steer performance. Pen was a random term. Contrasts were used to determine the significance of linear, quadratic, cubic, and quartic effects or trends of dry matter intake, average daily gain, feed conversion, and feed efficiency for the growing and finishing phases as well as the overall trial. Blood urea nitrogen data was analyzed using a repeated measures analysis. The main effects were treatment, day, and treatment x day interaction for the blood urea nitrogen analysis. Carcass characteristics of marbling and quality grade were also determined for linear, quadratic, cubic, and quartic effects or trends. The pen number and treatment diets were the class variables, but the pen numbers were not significant for this trial, therefore, the effects of treatment diets were only stated. The

significance was set at $P \leq 0.05$, and trends were discussed when the P value was >0.05 but <0.10.

Experiment 2

Treatment of Animals

Seventy-five yearling purebred Angus steers (353 ± 66 kg) were selected by weight from heaviest to lightest without outliers and temperament from a group of 75 steers from the BBCFL resident herd and 45 steers from the Upper Piedmont Research Station (UPRS). Temperament observations were made with no quantitative measurements 4 weeks before the start of the study. Steers with no undesirable temperament observations were selected for the study. Each steer received Bovi-Shield Gold FP5VL5 (Zoetis Inc., Kalamazoo, MI) and Vision 7 (Merck Animal Health division of Intervet Inc., Omaha, NE) at time of weaning (7 months prior to the study). Before the research trial began, the steers were dewormed using Safe-Guard (Merck Animal Health division Intervet Inc., Madison, NJ) and Bimectin Pour-On (Bimeda, Schaumberg, IL) the waterer, and a feed bunk at the NCSU Butner Beef Cattle Field Lab. All steers were put into their assigned pen 1 week prior to the start of the study to get acclimated to the feed bunk and CGB by feeding a common diet consisting of 20% CGB (diet 3).

Each pen within a weight block was randomly assigned to one of five treatment diets containing 0, 10, 20, 30, and 40% CGB on a dry matter basis. Initial (day 0) and final (day 84) weights were calculated from the average body weight of each steer on two consecutive days prior to feeding at approximately 0800 hours to use as each steer's initial and final weight. On days 28 and 56, body weights were also recorded prior to feeding at approximately 0800 hours.

Body weights were used to calculate average daily gain (ADG), feed conversion ratios, and feed efficiency ratios during the growing phase.

At the end of the 84-day growing phase, the steers were switched to a finishing diet for 70-d. All steers were fed the same finishing diet which was composed of corn, soybean meal, and corn silage throughout the finishing phase and ended at d 154. The final two consecutive weights from the growing phase (d 83 and d 84) were used as the initial weight for the finishing phase. During the finishing phase, steers were weighed every 28-d. At the end of the finishing phase, steers were weighed on two consecutive days. Blood samples were collected during the growing phase, but they were not collected during the finishing phase.

Feeding, Feed Sampling, and Analysis

The corn silage used for all diets was grown, harvested, and stored in silage bags by the NCSU Butner Beef Cattle Field Lab. The corn silage was taken from three separate silage bags. The CGB was purchased from Edwards Cotton Company Inc. (Scotland Neck, NC) in the form of 300 kg bales, and it cost $99.80 per metric ton. The CGB was delivered to BBCFL in one load prior to the start of the study.

One composited sample of each corn silage and CGB were sent to Cumberland Valley Analytical (Waynesboro, PA) for a standard wet chemistry nutrient analysis prior to formulating the diet. Values of DM, CP, soluble protein, ADF, aNDF, TDN, ME, NEg, and minerals were reported on the nutrient analyses (Table 4). On a dry matter basis, all 5 treatment diets were formulated to meet nutrient requirements at 72% TDN, 12.5% CP, 0.22% phosphorus (P), and 0.35% calcium (Ca) based on the nutrient analysis reports. The National Research Council (NRC) guidelines were used to set nutrient requirements for an ADG of 1.1 kg/day for 363 kg

growing steers (NRC, 2000). To calculate nutrient requirements and formulate balanced rations, the NCSU Ruminant Diet Evaluator (Moore and Poore, 1993) was utilized.

The same 5 levels of CGB were used as for Experiment 1. Diet formulations can be found in Table 5.

Samples of corn silage and CGB were collected biweekly throughout the trial. Batches of concentrate mixes were made as needed, and each time a batch of the concentrate mix was made, samples were collected. All feed samples were stored in a freezer (-10°C) after collection. After the research trial was complete, the feed samples were composited and sent to Cumberland Valley Analytical Services in Waynesboro, Pennsylvania for nutrient analyses.

Every morning, treatment diets were prepared as a total mixed ration (TMR) and fed to the steers. Feed amount given to each steer was recorded daily. Visual observations of feed amount left over from each feed bunk were made each morning prior to feeding, and adjustments were made and recorded to increase or decrease the amount of feed given to each pen based on those observations. Feed bunks were cleaned once a week by removing orts and weighing them, or they were removed and weighed more often depending on the amount of refusal determined by the nutrition manager at BBCFL. The removed orts were not analyzed. Feed amount given and feed refusal were used to calculate feed consumption for each week.

Blood Sampling and Gossypol Analysis

Blood samples were collected prior to feeding on d -5, 0, 28, 56, and 84 to analyze BUN and gossypol. The analytical procedure was the same as Experiment 1.

Carcass Measurements

On July 9, 2024, steers were loaded onto a commercial truck and shipped to the Cargill Wyalusing Protein Processing plant in Wyalusing, Pennsylvania. After the steers were slaughtered on July 10, 2024, data on HCW were recorded. Dressing percentage was calculated with the formula: Dressing% = (HCW/(final weight*0.96))*100. This equation involves a 4% shrink loss due to transportation. Quality grade, marbling scores, BF, REA, and KPH for each steer were determined as described for Experiment 1.

Statistical Analysis

Data was analyzed using PROC MIXED procedure of SAS version 9.4 (SAS Institute, Cary, NC). The main effect was the treatment diet for the steer performance. Block was a random term. Contrasts were used to determine the significance of linear, quadratic, cubic, and quartic effects or trends of dry matter intake, average daily gain, feed conversion, and feed efficiency for the growing and finishing phases as well as the overall trial. Blood urea nitrogen data was analyzed using a repeated measures analysis. The main effects were treatment, day, and treatment x day interaction for the blood urea nitrogen analysis. Carcass characteristics of marbling and quality grade were also tested for linear, quadratic, cubic, and quartic effects or trends. The weight block and treatment diets were the class variables, but the weight blocks were not significant for this trial, therefore, the effects of treatment diets were only stated. The statistical significance was set at $P \leq 0.05$, and trends were discussed when the P value was >0.05 but <0.10.

Results

Experiment 1

Feed Composition

Nutrient analyses for CGB, corn silage, and all TMRs can be found in Table 6. The CGB contained an average of 89.2% DM, 9.8% CP, and 54.2% NDF throughout the growing phase. The analysis of TDN for CGB was not available by Cumberland Valley Analytical Service (Waynesboro, PA). The corn silage used during the growing phase had an average DM of 39.1%, 8.9% CP, and 70.8% TDN. The corn silage used during the finishing phase had an average DM of 35.2%, 9.7% CP, and 69% TDN. Treatment diets varied with a CP concentration of 12.25 ± 1.55% and varied in TDN (65.25 ± 2.95%) with all diets falling short of the formulated 72% TDN. In general, as CGB inclusion increased, CP concentration of the diet decreased. Soluble protein was similar for TRT 1 (7.1%) and 2 (6.9%), and TRT 3 (4.7%) and 4 (4.8%) were lower but also similar. Treatment 5 had the lowest soluble protein at 3.3%. Each treatment diet's NDF ranged from 34.8% to 46.1%, but each treatment diet's corresponding ADF had TRT 1 with the most digestible fiber and continuously decreased to TRT 5 with the lowest digestible fiber. The finishing phase TMR diet contained 72% DM, 12.2% CP, and 82.5% TDN.

Steer Performance

For the growing phase, DMI increased linearly (P=<0.0001) as steers on TRT 1 consumed 10.16 kg DM per day and increased up to 11.96 kg DM per day for steers on TRT 5 (Figure 1). Average daily gain tended to have a cubic trend (P=0.0637) where there was an increase from TRT 1 to TRT 2 (1.34 kg and 1.54 kg, respectively), a decrease in TRT 3 and 4 (1.36 kg and 1.39 kg, respectively), and increased again at TRT 5 (1.52 kg; Figure 2). With a standard error mean (SEM) of 0.0786, TRT 2 and 5 were different from TRT 1, 3, and 4. Feed

conversion (feed to gain) did not differ ($P > 0.05$) among treatments in the growing phase. Feed efficiency (gain to feed) tended to have a cubic trend ($P=0.069$) where efficiency increased from TRT 1 to TRT 2 (0.133 and 0.138, respectively), decreased in TRT 3 and 4 (0.119 and 0.117, respectively), and increased in TRT 5 (0.128; Figure 3). With a SEM of 0.00782, TRT 1 and 2, and 5 were different from TRT 3 and 4, and TRT 2 was different from TRT 5.

During the finishing phase, DMI had a quadratic trend ($P \geq 0.0825$) with TRT 1 (10.65 kg) decreasing to TRT 3 (9.5 kg) and increasing to TRT 5 (10.06 kg; Figure 4). With a SEM of 0.4995, TRT 3 was different from TRT 1, 2, and 5, and TRT 4 was different from TRT 1 and 2. Treatment 5 was different from TRT 1. Average daily gain exhibited a quadratic effect ($P = 0.0259$) where TRT 1 was the highest (1.54 kg), decreased down to 1.18 kg for TRT 3, and increased back up to 1.33 kg for TRT 5 (Figure 5). With a SEM of 0.1066, TRT 1 was different from all other treatments, and TRT 5 was different from TRT 3 and 4. Feed conversion and feed efficiency (Figure 6) were not different among dietary treatments in the finishing phase ($P \geq 0.1394$ and $P \geq 0.1195$, respectively).

Throughout the entire feeding trial, DMI had a linear effect ($P = 0.0385$) with TRT 1 (10.35 kg) increasing to TRT 5 (11.21 kg; Figure 7). Average daily gain had no difference between treatments ($P \geq 0.1166$; Figure 8). Feed conversion had a quadratic effect ($P = 0.0345$) where TRT 1 (7.37) increased to TRT 3 (8.62) and decreased to TRT 5 (7.92; Figure 9). With a SEM of 0.47, TRT 3 and 4 were different from TRT 1, 2, and 5, and TRT 5 was different from TRT 1. Feed efficiency had a quadratic trend ($P = 0.0684$) where TRT 1 (0.138) decreased down to TRT 3 (0.12) and increased to TRT 5 (0.131; Figure 10). With a SEM of 0.00777, TRT 3 and 4 were different from TRT 1, 2, and 5. The values of each category can be found in Table 7.

Blood Urea Nitrogen

There was no treatment effect ($P \geq 0.1087$) on blood urea nitrogen (BUN) among the 5 treatment diets over the 84 day period blood was collected. Treatment 1 had 52.05 mg/dl, TRT 2 had 47.54 mg/dl, TRT 3 had 45.87 mg/dl, TRT 4 had 55.7 mg/dl, and TRT 5 had 50.49 mg/dl with a SEM of 3.42 mg/dl. There was a time effect ($P = <.0001$) where BUN increased from day 0 to day 28, and days 28-84 were similar (Figure 11). Day 0 was different from days 28-84. There was no individual treatment effect ($P = 0.2798$). The treatment x time interaction also had no effect ($P = 0.1088$). The BUN values can be found in Table 8.

Carcass Quality

There were no significant differences between treatment diets for marbling, quality grade, HCW, dressing%, BF, YG, and KPH ($P > 0.05$). Hot carcass weight ranged from 309 to 324 kg; dressing% ranged from 59.7% to 60.5%; BF ranged from 1.09 to 1.19 cm, REA ranged from 74.75 to 83.94 cm^2; KPH ranged from 1.7 to 1.94%; and YG ranged from 2.59 to 2.98 across all treatment diet means. Ribeye area had a quadratic trend ($P = 0.0892$) with TRT 1 (79.16 cm^2) decreasing to TRT 3 (74.75 cm^2) and increasing to TRT 5 (83.94 cm^2). With a SEM of 3.08, TRT 3 was different from TRT 1, 2, and 5, and TRT 4 was different from TRT 2 and 5. Treatments 2 and 5 were also different from each other. There was no impact on marbling, and all scores ranged from 6.17 to 6.91, indicating all treatment diets had an average modest marbling. Quality grade was also not significant, and all scores ranged from 17.7 to 18.5. The carcass values of each category can be found in Table 9.

Experiment 2

Feed Composition

Nutrient analyses for CGB, corn silage, and all TMRs can be found in Table 10. The CGB contained an average of 89.1% DM, 11.55% CP, and 56.55% NDF throughout the growing phase. Total digestible nutrient value was not analyzed by Cumberland Valley Analytical Service (Waynesboro, PA) for CGB. The corn silage used during the growing phase had an average DM of 31.55%, 9.55% CP, and 69.95% TDN. The corn silage used during the finishing phase had an average DM of 38.9%, 8% CP, and 73.5% TDN. Treatment diets varied with a CP concentration of 12.58 ± 0.73% and varied in TDN (72.0 ± 3.0%). Soluble protein was similar for TRT 1 (4.5%) and 2 (4.75%). Treatments 3 and 4 had 3.4% and 2.45% soluble protein, respectively. Treatment 5 had the lowest soluble protein at 3.3%. Each treatment diet's NDF ranged from 27% to 38.2%, but each treatment diet's corresponding ADF had TRT 1 with the most digestible fiber and continuously decreased to TRT 5 with the lowest digestible fiber. The finishing phase TMR diet contained 73.7% DM, 12.4% CP, and 84% TDN.

Steer Performance

For the growing phase, DMI had a linear effect ($P = 0.0006$) as steers on TRT 1 consumed 11.17 kg of DM/d and increased up to TRT 5 with 13.96 kg DM/d (Figure 12). Average daily gain exhibited a linear increase ($P = 0.0095$) and ranged from 1.802 kg/hd/d for steers on TRT 1, up to 2.004 kg/hd/d for steers on TRT 5 (Figure 13). Feed conversion and feed efficiency were both significant with linear ($P = 0.0009$; P = 0.0029, respectively) and cubic ($P = 0.0069$; P = 0.011, respectively) effects (Figures 14 and 15). From TRT 1 to TRT 2, feed conversion improved by decreasing from a 6.27 ratio to a 5.93 ratio, increased up to TRT 4 with a 7.62 ratio, and decreased back down again to TRT 5 with a 7.09 ratio. With a SEM of 0.3752,

TRT 3, 4, and 5 were similar while all other treatments were different from each other. Feed efficiency saw the inverse where it improved from TRT 1 to TRT 2 by increasing from 0.163 to 0.175, decreased down to 0.135 in TRT 4, and increased again to 0.145 in TRT 5. With a SEM of 0.008805, TRT 3 was similar to TRT 4 and 5, but TRT 4 and 5 were different from each other. Treatments 1 and 2 were different from each other as well as all other treatments.

For the finishing phase, DMI showed a linear decrease ($P = 0.005$) with increasing amounts of CGB in the diet during the growing phase as well as a quadratic effect with TRT 1 (12.6 kg/d) decreasing to TRT 3 (11.0 kg/d) and increasing to TRT 5 (11.41 kg/d; Figure 16). With a SEM of 0.3577, TRT 4 was similar to TRT 3 and 5, but TRT 3 and 5 were different from each other. Treatments 1 and 2 were different from each other as well as all other treatments. Average daily gain had linear ($P = 0.0363$), quadratic ($P = 0.0049$), and quartic ($P = 0.0024$) effects (Figure 17). There was an increase from TRT 1 with 1.48 kg to TRT 2 with 1.51 kg before ADG dropped at TRT 3 with 1.08 kg, but increased again to 1.37 kg for TRT 5. With a SEM of 0.06116, TRT 1 and 2 were similar, and all other treatments were different from each other. Feed conversion had a quartic ($P = 0.0178$) effect where it decreased from TRT 1 (8.66) to TRT 2 (8.19), increased for TRT 3 (11.35), and decreased again for TRT 5 (8.55) (Figure 18). With a SEM of 0.7384, TRT 2 was different from TRT 3 and 4, while TRT 3 different from all other treatments. Treatment 2 had the best feed conversion. Feed efficiency had the inverse effect where it increased from TRT 1 (0.118) to TRT 2 (0.125), decreased for TRT 3 (0.098), and increased again to TRT 5 (0.121) with a quartic effect ($P = 0.014$; Figure 19). With a SEM of 0.006097, TRT 3 was different from all other treatments, and TRT 2 was different from TRT 1 and 4 while TRT were similar. Treatment 5 was similar to TRT 1, 2, and 4.

For the overall feeding trial, DMI had a linear (P = 0.0196) effect, ranging from 11.64 to 13.13 kg/d (Figure 20). Average daily gain exhibited a quadratic (P = 0.0162), cubic (P = 0.0084), and quartic (P = 0.0016) effect, where it increased from TRT 1 (1.66 kg) to TRT 2 (1.74 kg), dropped at TRT 3 (1.56 kg), and increased again to TRT 5 (1.72 kg; Figure 21). With a SEM of 0.03194, TRT 1 and 4 were similar, and TRT 2 and 5 were similar, but all other comparisons were different. Feed conversion had a linear (P = 0.0253) and cubic (P = 0.0116) effect where there was a decrease from TRT 1 (7.18) to TRT 2 (6.79), an increase up to TRT 3 (8.21), and decreased again to TRT 5 (7.52; Figure 22). With a SEM of 0.3352, TRT 3 and 4 were similar, and all other comparisons were different. There were linear (P = 0.0189), cubic (P = 0.0087), and quartic effects (P = 0.0274) for feed efficiency as an increase occurred from TRT 1 (0.141) to TRT 2 (0.15), then decreased at TRT 3 (0.124), and increased again up to TRT 5 (0.134; Figure 23). Similarities and differences were the same as in feed conversion. The values of each category can be found in Table 11.

Blood Urea Nitrogen

There was no treatment effect ($P \geq 0.4425$) on BUN among the 5 treatment diets over the 84 day period blood was collected. Treatment 1 had 52.64 mg/dl, TRT 2 had 47.95 mg/dl, TRT 3 had 50.87 mg/dl, TRT 4 had 49.8 mg/dl, and TRT 5 had 49.54 mg/dl with a SEM of 2.79 mg/dl. There was a time effect (P = <.0001) where BUN increased from day 0 to day 28, and days 28-84 were similar. Day 0 were different from days 28-84 (Figure 24). There was no individual treatment effect (P = 0.8189). The treatment x time interaction also had no effect (P = 0.8623). The BUN values can be found in Table 12.

Carcass Quality

There were no differences between treatment diets for BF, YG, and KPH ($P > 0.05$). Back fat thickness ranged from 1.32 to 1.5 cm, KPH ranged from 1.7 to 1.95%, and YG ranged from 3.02 to 3.25 across all treatment diet means. Hot carcass weights had linear ($P = 0.0718$) and cubic ($P = 0.0594$) trends with TRT 1 (345 kg) increasing to TRT 2 (351.9 kg), decreasing to TRT 3 (343.2 kg), and increasing again to TRT 5 (357.2 kg). With a SEM of 9.9354, TRT 1 and 3 were similar to each other and different from TRT 5 while TRT 2 and 4 were similar to each other and all other treatments. Dressing percentage had a quartic effect ($P = 0.0304$) with a SEM of 0.3124. Treatment 1 was similar to TRT 2 and 4, but TRT 2 was different from TRT 4. Treatments 3 and 5 were similar to each other and different from all other treatments. Ribeye area had a quartic trend ($P = 0.0919$) where TRT 1 (82.85 cm^2) increased to TRT 3 (85.06 cm^2), decreased to TRT 4 (81.42 cm^2), and increased again to TRT 5 (83.65 cm^2). With a SEM of 2.1832, TRT 4 was different from TRT 3 and 5, and TRT 3 was also different from TRT 1. Treatments 1 and 5 were different from each other, and TRT 2 was similar to all treatments. There was a linear effect ($P = 0.042$) on marbling where TRT 1 with a score of 6.33 and increased up to TRT 5 with a score of 6.83, indicating all treatment diets had an average modest marbling score (Figure 25). Quality grade linearly increased ($P = 0.0141$) with increasing levels of CGB in the growing phase, with TRT 1 having a score of 17.8 and TRT 5 having a score of 18.4. Interpretation of marbling score calculation indicated treatment diets 1 and 2 had an average score of "Choice –" and treatment diets 3, 4, and 5 had an average score of "Choice" (Figure 26). The carcass values of each category can be found in Table 13.

Discussion

Feed Composition

Based on the nutrient analysis, the average DM of CGB used during the growing phase was similar at 89.2% compared to the 88.5% DM used to formulate the treatment diets for experiment 1. In experiment 2, the average DM of CGB was again similar at 89.1% than the 88.9% DM used to formulate the treatment diets. Crude protein (CP) of CGB in experiment 1 was lower at 9.8% compared to the 11.2% CP used for the diet formulations. For experiment 2, CP of CGB was also lower at 11.55% than the CP of 12.9% utilized to formulate the treatment diets. The likely explanation for this difference is that CGB is a heterogenous feedstuff with a fluffy, fibrous portion and a nutritious, fines portion that makes it difficult to sample without much sampling error. Nutrient values from other studies show that the CGB used in both studies are within a reasonable range. Myer (2007) and Stewart and Rossi (2010) reported that CGB has a DM of 90%. The CGB used in both studies had similar DM content to other literature. Myer (2007) and Rogers et al. (2002) reported that CGB had 7% CP. Jacobs et al. (2022) and Kennedy and Rankins (2008) have reported CP values up towards 12.5%. From 5 Turkish cotton gins, Ozkan et al. (2014) reported a range of CP between 6.6-12.55%, and the CGB from both studies were within the range of CP reported from other literature with the CGB from the second experiment having CP towards the higher end of the range. While TDN was not analyzed for CGB, it was assumed TDN was 50%. Rogers et al. (2002), Myer (2007), and Myer and Hall (2003) reported that CGB had a TDN of 44%. Mullenix et al. (2023) also reported a range of TDN containing 40-48% for CGB from many Alabama cotton gins. The assumed 50% TDN for both experiments were similar to the reported TDN of CGB from other literature. For diet formulation, the amount of ground corn increased as the amount of CGB increased so that all

treatment diets could have be isocaloric. The NDF value for the CGB from experiment 1 was 61.5%, and the NDF value from experiment 2 was 56.6%. Jacobs et al. (2022) and Kennedy and Rankins (2008) reported CGB having an NDF of 73% and 69.2%, respectively. However, Ozkan et al. (2014) reported an NDF range of 49.2% - 62.2%, and the NDF values of CGB from both experiments fall within that range. The ash content from the first experiment was 6.72%, and the ash content from the second experiment was 7.71%. Ash content is the most variable component of CGB that is influenced by the variety of cotton, growing conditions, and harvesting method (Ozkan et al., 2014). Dairy One – Feed Composition Library (2024) reported an ash content range of 1.88% - 25.35% with an average of 13.61%. Myer (2007) reported CGB of having 10% ash, and Stewart and Rossi (2010) reported an ash content of 11.1%, indicating that the CGB used in both experiments had lower ash content compared to other studies. In North Carolina, Mullins (2021) reported a CGB nutrient analysis of 86.75% DM, 13.3% CP, 42.85% NDF, and 10.2% ash content. Newsome (2023) also reported a nutrient analysis with CGB from North Carolina consisting of 89.9% DM, 11.2% CP, 61.2% NDF, and 7.39% ash content. Based on the average nutrient values from experiments 1 and 2, CGB had 89.2% DM, 10.68% CP, 55.4% NDF, and 7.22% ash content. Based on all these nutrient analyses of CGB produced in North Carolina, CGB will generally have about 12% CP, 50% NDF, 89% DM, and a low ash content of 8%.

During the growing phase of experiment 1, the average DM of 39.1% and CP of 8.9% for corn silage were greater than 36.3% DM and 7.4% CP used for diet formulation. The average TDN of 70.8% was lower than the 71.2% TDN used prior to the study. In experiment 2, the average DM of corn silage used during the growing phase was 31.55%, which was lower than the DM of 35.5% used for the diet formulations. The average CP at 9.55% was greater than the

7.7% CP used for the formulations. The average TDN was the same as the TDN for diet formulations at 69.9%. From Dairy One (2024), the average DM, CP, and TDN of corn silage is 33.37%, 8.29%, and 71.86%, respectively, from over 230,000 nutrient analyses within the software program. While the average DM of corn silage used for the first experiment was greater and lower during the second experiment, both are close to a broad DM average and within the range of 27.29% - 39.45% DM from Dairy One (2024). Both experiments during the growing phase utilized corn silage that had a greater average CP than the average CP reported from Dairy One (2024), but the average CP from experiment 1 was within the range of 7.2% - 9.38% CP while the average CP from experiment 2 was slightly greater than the high end of the range. The average TDN in corn silage that was used in both experiments was lower than the broad average TDN from Dairy One (2024), but both average TDN were within the range of 67.51% - 76.21% from Dairy One (2024). The corn silage used during the growing from the first experiment was typical in its nutrient composition for DM, CP, and TDN. From the second experiment, the CP from the corn silage during the growing phase was a slightly greater than the high end of the range of CP from Dairy One (2024), but DM and TDN had common nutrient values for corn silage, indicating that this corn silage was fairly typically.

The corn silage used during the finishing phase had an average 35.2% DM, 9.7% CP, and 69% TDN for experiment 1. Both the average DM and TDN were lower than the DM and TDN used to formulate the finishing phase diet, while the average CP was greater than the CP of corn silage used the create the finishing diet. From experiment 2, the average DM (38.9%), CP (8%), and TDN (73.5%) were all greater than the respected nutrient values used to formulate the finishing diet. The average DM from both experiments were greater than the 33.37% DM average from Dairy One (2024), but they were both within the DM range of 27.29% - 39.45%.

From the first experiment, the average CP of corn silage during the finishing phase is greater than the 8.29% CP average from Dairy One (2024) as well as above the high end of the range of 7.2% - 9.38% CP. On the other hand, the average CP from the corn silage in experiment 2 is slightly lower than the average CP from Dairy One (2024), but it is still within the CP range. The average TDN from experiment 1 is lower than the average 71.86% TDN from Dairy One (2024), but it is still within the 67.51% - 76.21% TDN range, whereas, the average TDN from the second experiment is greater than the average TDN from Dairy One (2024), but it is also within the TDN range. The corn silage used during the finishing phase of experiment 1 had typical averaged DM and TDN values, but the average CP was slightly greater than normal. The corn silage used in experiment 2 during the finishing phase had average DM and TDN that were higher than reported by Dairy One (2024). Average CP that was slightly lower than reported by Dairy One (2024), but they were all within the range of their respected nutrient values, indicating that the corn silage was fairly typical.

The treatment (TRT) diet values from experiment 1 were formulated to have 72% TDN, 12.5% CP, 0.35% calcium, 0.22% phosphorus, and most macrominerals as well as microminerals. For TDN, all average treatment diets were below the 72% TDN target. Since all treatment diets lacked the formulated TDN, it is possible that CGB had less than the assumed 50% TDN used to formulate the treatment diets. For CP, it varied between treatment diets. While treatments 2, 3, and 4 were within 1% of that formulated CP, TRT 1 was above the target CP and TRT 5 was below it. A potential issue with lower CP for TRT 5 was sampling error due to the diet being heterogenous. Even though TRT 5 was not at its formulated CP, steer performance and the BUN assay results suggest that the steers on TRT 5 received a sufficient amount of protein. Soluble protein levels for TRT 1 and 2 were slightly over half of what the CP was for

those two treatments, whereas TRT 3 and 4 were over a third of the CP for those two treatments. The soluble protein for TRT 5 was about 30% of the CP, which indicated that soluble protein decreased as the amount of CGB increased in the treatment diets. As expected, DM concentration increased as the level of CGB inclusion increased, primarily from the replacement of higher moisture corn silage with higher DM CGB. While NDF did not have a consistent pattern with a range of 34.8% to 46.1%, the NDF and ADF from each diet calculated that the hemicellulose was greatest for TRT 1 and decreased to TRT 5, signifying that fiber digestibility decreased as the amount of CGB increased in the treatment diets.

The treatment diet values from experiment 2 were also formulated to have 72% TDN, `12.5% CP, 0.35% calcium, 0.22% phosphorus, and most macrominerals as well as microminerals. For TDN, all treatment diets varied slightly. TRT 1, 2, and 3 were below the target TDN value, whereas, TRT 4 and 5 were above the target value. TRT 5 and TRT 2 resulted in a 6% difference in TDN. Crude protein concentration varied slightly between treatment diets. While there was some variation, the difference between TRT 2 at 13.3% CP and TRT 5 at 11.85% CP is less than 2% CP, and all diets were within 1% of the target CP concentration. Because of the nutrient values from experiment 1, particularly with CP, a better extent was taken to have good samples and less sampling error for experiment 2 as the nutrient value of CGB can vary. Soluble protein levels for TRT 1 and 2 were over a third of what the CP was for those two treatments, whereas TRT 3 was slightly over a quarter its CP. The soluble protein for TRT 4 was nearly 20% of its CP, and TRT 5 was nearly 15% of its CP, which indicated that soluble protein decreased as the amount of CGB increased in the treatment diets. As expected, DM increased as CGB inclusion increased, primarily from the replacement of higher moisture corn silage with higher DM CGB. With a NDF range of 27% to 38.2%, the NDF and ADF from each diet

calculated that the hemicellulose was greatest for TRT 1 and decreased to TRT 5, signifying that fiber digestibility decreased as the amount of CGB increased in the treatment diets.

The finishing phase diets for both experiments were formulated to be 82% TDN and 12.5% CP. In experiment 1, the average finishing diet nutrient values were 82.5% TDN and 12.2% CP. Both TDN and CP were within 0.5% of their respected target nutrient value, indicating the finishing diet was mostly consistent throughout the finishing phase. The average nutrient values from experiment 2 were 84% TDN and 12.4% CP. While TDN was 2% greater than the formulated TDN, both TDN and CP were consistent overall in the finishing phase.

Steer Performance

During the growing phase of both experiments 1 and 2, dry matter intake (DMI) increased linearly (P = < .0001; P = 0.0006, respectively) as the level of CGB in the diet increased. This indicates that including more CGB into a diet will stimulate more DMI. When Warner et al. (2020) conducted a study comparing a control diet of prairie hay and corn-based supplements to a diet of CGB, whole cottonseed, and rolled corn, DMI was greater for the CGB diet. Kennedy and Rankins (2008) also saw a greater DMI in beef steers when fed 45% CGB in a diet versus a diet that contained 45% peanut hulls. Mullins (2021) had greater DMI in two of the diets that contained CGB compared to two other diets that did not. Newsome (2023) also had greater DMI for diets that contained 25% CGB versus diets that did not. Typically, DMI would decrease as more of a fibrous feedstuff with a high NDF is added to a diet (Arelovich et al., 2008). Warner et al. (2020) suggested that the physically effective neutral detergent fiber (peNDF) influenced a greater DMI for the CGB diet, but CGB was not analyzed for peNDF in either experiment. Balch and Campling (1962) suggested that feedstuffs in bulk due to cellular

water can affect voluntary intake. Lahr et al. (1983) reported from their study that DMI linearly increased as the dry matter content of the diet increased. From Balch and Campling (1962) and Lahr et al. (1983), it could be likely that the reason DMI increased for both experiments was because the dry matter content of the treatment diets increased as the inclusion rate of CGB increased.

There was a cubic trend for average daily gain (ADG) in experiment 1 where steers in TRT 2 and 5 gained faster compared to the other treatment diets. In experiment 2, there was a linear increase for ADG with TRT 5 being greatest. Warner et al. (2020), Kennedy and Rankins (2008), and Mullins (2021) all reported greater ADG for the diets that contained CGB compared to diets that did not. Although conducted in the finishing phase, Warner et al. (2020) utilized 7% CGB and reported a tendency ($P = 0.08$) of ADG at 2.09 kg compared to the control diet that had 1.95 kg ADG. Kennedy and Rankins (2008) utilized 45% CGB and reported an ADG of 1.19 kg compared to an ADG of 0.94 using peanut hulls ($P < 0.01$). Mullins (2021) utilized a diet containing 25% CGB with an ADG of 1.53 kg and had greater ($P < 0.0001$) ADG than diets without CGB. Newsome (2023) reported that there was no change in ADG with diets consisting of 25% CGB versus diets that did not during the growing phase. Even though CP was lower in diets from both experiments that contained a higher amount of CGB, the increased DMI likely increased the amount of CP being consumed in terms of grams of protein, which helps explains why ADG was greater in diets with a higher level of CGB compared to the control diet, particularly in experiment 2, as the steers were able to gain more weight. While there was a cubic pattern from the first experiment, it can be inferred that the inclusion of CGB up to 40% in stocker beef cattle diets can perform the same or better than diets without the use of CGB, and results from other studies with similar inclusion rates of CGB have also had better performance.

In experiment 1, feed conversion and feed efficiency were not significant. However, feed efficiency did exhibit a cubic trend ($P = 0.069$) where TRT 1, 2, and 5 performed well compared to TRT 3 and 4. On the other hand, the second experiment had linear and cubic effects for both feed conversion and feed efficiency. Treatment 1 and 2 performed well compared to the other diets. Warner et al. (2020) observed no difference in feed efficiency when comparing the control without CGB to a diet that included CGB at 7% (0.167; 0.167, respectively). Mullins (2021) and Newsome (2023) both reported lower feed efficiency for diets that contained 25% CGB compared to diets that did not. Based on experiment 1, there was no change, but in experiment 2, feed efficiency and feed conversion worsened as CGB increased.

During the finishing phase of experiment 1, DMI exhibited a quadratic effect, whereas in experiment 2, there was a linear effect for DMI to decrease as the CGB inclusion level increased. Treatments 1, 2, and 5 performed better than TRT 3 and 4 in experiment 1, and for experiment 2, TRT 1 had the greatest DMI and decreased down to TRT 5. Newsome (2023) reported no effects in DMI and ADG during the finishing phase from steers that had 25% CGB diets versus steers that had diets not containing CGB during the growing phase. In the first experiment, ADG had a quadratic effect where TRT 1 was the greatest, dropped at TRT 3, and increased up to TRT 5. In experiment 2, there was a linear, quadratic, and quartic effect as TRT 1 slightly increased to TRT 2, dropped at TRT 3, and increased again at TRT 5. Following the growing phase from both experiments, steers on TRT 1 performed well when converting to a finishing diet and had the greatest DMI, along with TRT 2 and 5. TRT 3 exhibited a carryover effect from the growing phase and did not perform as well when switching to a finishing diet compared to the other treatments because of lower DMI and ADG.

In experiment 1, feed conversion nor feed efficiency during the finishing phase, was impacted, whereas in experiment 2, there were quartic effects for both feed conversion and feed efficiency. Newsome (2023) reported a tendency for finishing diets without CGB to have a greater feed efficiency than diet with CGB. Based on experiment 2, no treatment group performed better at feed conversion and feed efficiency in the finishing phase, except TRT 3 that did worse compared to the rest of the diets. The quartic effect in the experiment 2 resulted from the lower performance on TRT 3, and it is not clear why this response would have occurred, but there is some carryover effect.

When combined over the growing and finishing phase, DMI had a linear effect with greater consumption as the level of CGB increased, and ADG did not have any significant effects in experiment 1. For the second experiment, DMI had a linear effect, and ADG had a quadratic, cubic, and quartic effect. Based on both experiments, steers on TRT 4 and 5 consumed the most DM, but TRT 2 and 5 had the greatest ADG in experiment 2. Experiment 1 had a quadratic effect for overall feed conversion and a quadratic trend feed efficiency. Experiment 2 had an overall linear and cubic effect for feed conversion and an overall linear, cubic, and quartic effect for feed efficiency. From both experiments, steers fed TRT 1, 2, and 5 performed well at utilizing feed and converting it into weight gain throughout the entire trial. In general, the carry over effects from the growing to the finishing phase of the experiment were significant, and suggest that the middle levels of CGB studied may result in lower overall performance than either very low levels or higher levels (40% of diet DM in this case). The mechanism of such a response is unclear and deserves more attention in the future, but it is hypothesized that it could be due to the environment of the rumen via pH, microbes, or rumination rates.

In experiment 1, one steer on diet 3 was removed from the trial during the finishing phase because of physical injury. For statistical analysis, diet 3 had $n = 9$ for the finishing phase and overall steer performance as well as carcass quality data. In experiment 2, three steers were removed from the trial with two steers removed during the growing phase and one steer removed during the finishing phase. The first steer was on diet 5, and it was removed from the trial for safety precautions because it became aggressive. The second steer was on diet 3, and it was removed from the trial because of physical injury. The third steer was on diet 4, and it was removed from the trial because of physical injury. For statistical analysis, diets 3 and 5 both had $n = 14$ for the growing phase, finishing phase, and overall steer performance as well as BUN and carcass quality data. Diet 4 had $n = 14$ for the finishing phase and overall steer performance as well as carcass quality data. Bunk feed intake calculations were adjusted for the 3 pens that lost a steer during the trial.

Blood Urea Nitrogen

There were no significant differences between treatment diets for blood urea nitrogen in both experiments nor was there any significance for an interaction between treatment and day. There was, however, a significance of an individual day effect where day 0 was lower than day 28-84. Measuring BUN concentration in cattle is a common technique used to determine the status of protein during livestock production research as a general indication of nitrogen content in the diet (Hammond, 1983). An optimal range for growing steers at maximum performance in serum BUN is between 11 and 15 mg/dl (Hammond, 1983). Preston et al. (1965) suggests that a BUN concentration of greater than 10mg/dl represents protein excess and wastage. Based on the results from both experiments with a BUN range from 45 – 56 mg/dl for each treatment diet, all

the steers were highly excess on protein throughout the growing phase, but there were no adverse effects observed from the high amount of protein. Zhong et al. (2022) explains that urea is produced in the liver from excess ammonia via the urea cycle before being passed into the bloodstream. While in the bloodstream, the kidneys filter and reabsorb urea if needed, and the urea is diffused across the ruminal wall or into the saliva from the blood to be broken down into ammonia by the rumen microbes to produce new amino acids (Zhong et al., 2022). Based from this understanding, steers that were on treatment diets with lower CP than the target 12.5% CP were able to reabsorb urea back into their rumen and have the rumen microbes synthesize proteins to eventually absorb those proteins and utilize for production. Mullins (2021) reported that a diet containing 25% CGB, another containing 15% whole cottonseed, and a third diet containing both 25% CGB and 15% whole cottonseed had a greater BUN concentration than the corn silage based control diet, but the CGB diets did not have a difference among them. Mullins (2021) reported that all treatment diets ranged from 3.44 to 4.18 mM. Newsome (2023) reported the CGB diets did not differ between each other with a range of 24.55 to 54.84 mg/dl over the 84-day growing phase, but there was an effect with the interaction between the CGB diet and time, signifying that the longer the steers were on the growing phase, the more urea nitrogen they had in their blood. Based on the BUN data, the latter portion of the growing phase that Newsome (2023) reported closely resembled the results from the entire growing phase of both experiments, while the beginning of the growing phase from Newsome (2023) was about half in comparison to both of our experiments during the growing phase.

Carcass Quality

For experiment 1, there were no differences between treatments for marbling, quality grade, hot carcass weight, dressing percentage, back fat thickness, yield grade, and kidney, pelvic, and heart fat, but there was a quadratic trend for ribeye area where TRT 1, 2, and 5 had a greater REA. There were also no effects in experiment 2 for back fat thickness, yield grade, and kidney, pelvic, and heart fat. Hot carcass weight exhibited linear and cubic trends with TRT 5 having the heaviest weight. Dressing percentage exhibited a quartic effect with fluctuating decreases and increases. Ribeye area exhibited a quartic trend with TRT 3 having the largest REA. Marbling and quality grade both had a linear effect along with TRT 5 having the highest score. Despite carryover impacts of the growing phase on finishing performance, the end carcass weights were not majorly impacted overall. Newsome (2023) reported that there was no effect on carcass quality with diets that included 25% CGB versus diets that did not. Warner et al. (2020) reported that the CGB diet had a greater HCW at 396 kg compared to the control diet at 382 kg ($P = 0.02$), but REA ($P = 0.64$) and marbling ($P = 0.64$) had no difference between diets. Back fat ($P = 0.03$) was greater for the CGB at 1.37 cm than the control diet at 1.24 cm, while KPH ($P = 0.09$) and YG ($P = 0.10$) had tendencies with the CGB diet being greater (1.91%; 2.83, respectively) (Warner et al., 2020). This data could indicate the possibility of having significance for carcass quality for diets containing CGB in the finishing phase compared to the growing phase, but more data would be needed. The only differences in carcass quality seen in our study favored the higher CGB diets.

Summary

Because CGB is a heterogenous feedstuff, sampling must be done carefully to collect a representative sample and reduce sampling error to acquire an accurate nutrient analysis for diet formulation. Reducing sampling error was done by repetitively mixing the fines that naturally fall to the bottom towards the top with the fluffy, fibrous portion in order to have a well-mixed sample, and the CGB was separated into sections with a couple sections subsampled. It is recommended that CGB be analyzed because its nutrient content can vary. Stewart et al. (1998) collected samples of CGB from many cotton gins in Georgia, and the nutrient composition of DM, CP, and TDN ranged from 40% - 91.7%, 7.4% - 15.8%, and 16.4% - 62.2%. During the growing phase, stocker steers can consume more dry matter when fed a higher amount of CGB, and stocker steers can perform well when fed CGB up to an inclusion rate of 40%, particularly at 10% and 40%, compared to stocker steers that do not consume CGB. Stocker steers with inclusion rates of 20% or 30% of CGB can perform similar to stocker steers that do not consume CGB during the growing phase, but overall performance can be lower or similar compared to stocker steers not fed CGB. Ten and 40% inclusion levels can benefit cattle producers who are near or further away from a cotton gin as 40% can better benefit producers near a cotton gin, and 10% can benefit cattle producers further away from a cotton gin by lowering the cost of feed and improving animal weight gain. If a cattle producer is near a cotton gin and would like to use higher levels of CGB, they should consider their animals' requirements as CGB is low in energy, but it can be difficult to formulate a diet with adequate energy for animal production that requires a greater amount of energy, particularly stocker steers. Cattle producers that are further away from a cotton gin wanting to use CGB should consider using it in terms of its nutrient value and transportation cost compared to other feed ingredients as it can help reduce feed costs because it

is an inexpensive feedstuff. There was minimal carry over effects into the finishing phase of both experiments. There was also minimal carry over effects for diets containing 25% CGB compared to diets without CGB (Newsome, 2023). An economic analysis should be assessed based on a producer's feed costs with current prices and relative location from a cotton gin if CGB is included into a diet during the growing phase for stocker steers as well as overall production for market steers.

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APPENDIX

Table 1. Summary of nutrient value of cotton gin byproduct published in literature.

	Nutrient Values of Cotton Gin Byproduct						
Dry Matter%	DM	TDN	CP	NDF	ADF	Calcium	Phosphorus
Rogers et al. (2002)	-	44	7	-	-	0.7	0.1
Myer and Hall (2003)	92	44	6	-	-	0.6	0.2
Myer (2007)	90	44	7	-	46	0.8	0.2
Kennedy and Rankins (2008)	-	-	12.4	69.2	60.8	-	-
Stewart and Rossi (2010)	90	46.6	11.7	-	-	0.9	0.2
Ozkan et al. (2014)	-	-	6.6-12.6	49.2-62.2	40.7-48.3	-	-
Jacobs et al. (2022)	-	40	12.5	73	56	-	-
Mullenix et al. (2023)	-	40-48	10-13	-	-	-	-

Table 2. Chemical composition of corn silage and cotton gin byproduct utilized prior to the start of the study to formulate diets in experiment 1.

Nutrient (%DM)	Corn Silage	Cotton Gin Byproduct
Dry Matter	36.3	88.5
Crude Protein	7.4	11.2
Soluble Protein	4.2	1.9
ADF	23.0	56.9
aNDF	40.1	61.5
TDN	71.2	----
NEg (Mcal/lb)	0.53	----
ME (Mcal/lb)	1.23	----
Ash	4.11	6.72
Calcium	0.16	1.07
Phosphorus	0.26	0.28
Magnesium	0.23	0.23
Potassium	0.93	1.34
Sodium	0.01	0.03
Iron (ppm)	199	605
Manganese (ppm)	33	56
Zinc (ppm)	31	19
Copper (ppm)	6	10

Table 3. Treatment diet formulations[1] for experiment 1.

	% ingredient of diet (DM)				
Ingredient	TRT 1[2]	TRT 2[3]	TRT 3[4]	TRT 4[5]	TRT 5[6]
Corn Silage (%)	87.8	69.0	46.0	26.0	5.0
Cotton Gin Byproduct (%)	0	10.0	20.0	30.0	40.0
Ground Corn (%)	0	10.18	24.7	36.2	48.7
Soybean Meal (%)	11.1	9.9	8.58	7.3	6.0
Trace Mineral Salt (%)	0.3	0.3	0.3	0.3	0.3
Limestone	0.8	0.62	0.42	0.2	0

[1]A vitamin A, D, and E premix was added at a rate of 1,000 IU/lb. Rumensin 90 was added at a rate of 22 grams/ton.
[2]Treatment composed of 0% cotton gin byproduct
[3]Treatment composed of 10% cotton gin byproduct
[4]Treatment composed of 20% cotton gin byproduct
[5]Treatment composed of 30% cotton gin byproduct
[6]Treatment composed of 40% cotton gin byproduct

Table 4. Chemical composition of corn silage and cotton gin byproduct utilized prior to the start of the study to formulate diets in experiment 2.

Nutrient (%DM)	Corn Silage	Cotton Gin Byproduct
Dry Matter	35.5	88.9
Crude Protein	7.7	12.9
Soluble Protein	4.1	1.8
ADF	25.1	30.6
aNDF	40.7	51.4
TDN	69.9	----
NEg (Mcal/lb)	0.51	----
ME (Mcal/lb)	1.21	----
Ash	5.42	8.74
Calcium	0.18	1.46
Phosphorus	0.45	0.31
Magnesium	0.17	0.25
Potassium	1.35	2.01
Sodium	0.01	0.02
Iron (ppm)	68	729
Manganese (ppm)	30	108
Zinc (ppm)	42	31
Copper (ppm)	6	11

Table 5. Treatment diet formulations[1] in experiment 2.

	% ingredient of diet (DM)				
Ingredient	TRT 1[2]	TRT 2[3]	TRT 3[4]	TRT 4[5]	TRT 5[6]
Corn Silage (%)	78.0	58.0	38.0	19.0	5.0
Cotton Gin Byproduct (%)	0	10.0	20.0	30.0	40.0
Ground Corn (%)	9.1	21.2	33.4	44.4	50.2
Soybean Meal (%)	11.0	9.3	7.6	6.0	4.5
Trace Mineral Salt (%)	0.3	0.3	0.3	0.3	0.3
Limestone	1.6	1.2	0.7	0.3	0

[1]A vitamin A, D, and E premix was added at a rate of 1,000 IU/lb. Rumensin 90 was added at a rate of 22 grams/ton.
[2]Treatment composed of 0% cotton gin byproduct
[3]Treatment composed of 10% cotton gin byproduct
[4]Treatment composed of 20% cotton gin byproduct
[5]Treatment composed of 30% cotton gin byproduct
[6]Treatment composed of 40% cotton gin byproduct

Table 6. Nutrient analysis of cotton gin byproduct, corn silage, treatment diets, and finisher TMR for Experiment 1.

Nutrient (%DM)	CGB[1]	Corn Silage	TRT 1[2] (Control)	TRT 2[3]	TRT 3[4]	TRT 4[5]	TRT 5[6]	Finisher TMR
Dry Matter	89.2	39.1	40.2	45.5	55.8	67.3	83.6	72
Crude Protein	9.8	8.9	13.8	13.4	12.1	12.9	10.7	12.2
Soluble Protein	2.8	5.3	7.1	6.9	4.7	4.8	3.3	6.3
ADF	45.2	22.3	23.9	28.1	36.8	27.4	38.1	7.1
aNDF	54.2	39.1	40	39	46.1	34.8	40	16.3
TDN	-	70.8	68.2	65.7	62.3	68.1	64.6	82.5
NE_g	-	0.53	0.49	0.45	0.39	0.48	0.43	0.69
ME (Mcal/lb)	-	1.23	1.17	1.12	1.06	1.17	1.1	1.46
Ash	6.73	5.04	6.61	8.41	6.96	6.75	4.82	3.91
Calcium	1.1	0.19	0.63	0.57	0.73	0.53	0.65	0.5
Phosphorus	0.25	0.32	0.37	0.37	0.33	0.33	0.29	0.34
Magnesium	0.2	0.25	0.28	0.25	0.24	0.2	0.19	0.15
Potassium	1.65	1.19	1.38	1.39	1.32	1.18	1.24	0.61
Sodium	0.03	0.03	0.16	0.17	0.18	0.15	0.16	0.09
Iron (ppm)	378	130	256	198	577	253	260	170
Manganese (ppm)	45	74	122	106	108	85	86	185
Zinc (ppm)	18	52	93	80	73	61	61	144
Copper (ppm)	6	8	28	24	26	20	24	18

[1]Cotton gin byproduct

[2]Treatment composed of 0% cotton gin byproduct
[3]Treatment composed of 10% cotton gin byproduct
[4]Treatment composed of 20% cotton gin byproduct
[5]Treatment composed of 30% cotton gin byproduct
[6]Treatment composed of 40% cotton gin byproduct

Table 7. Steer performance by treatment in experiment 1 (n = 50).

Variable	TRT 1[4]	TRT 2[5]	TRT 3[6]	TRT 4[7]	TRT 5[8]	SEM[9]	Linear P-value	Quadratic P-value	Cubic P-value	Quartic P-value
GP[1] DMI (kg)	10.16[a]	11.23[b]	11.59[bc]	11.85[c]	11.96[c]	0.5118	<0.0001[s]	0.0622[t]	0.5405	0.768
GP[1] ADG (kg)	1.34[a]	1.54[b]	1.36[a]	1.39[a]	1.52[b]	0.0786	0.4234	0.8337	0.0637[t]	0.2993
GP[1] F:G	7.77[ab]	7.46[a]	8.70[c]	8.62[bc]	8.11[b]	0.5149	0.2065	0.3122	0.1701	0.3214
GP[1] G:F	0.133[bc]	0.138[c]	0.119[a]	0.117[a]	0.128[b]	0.00782	0.1253	0.223	0.069[t]	0.3956
FP[2] DMI (kg)	10.65[d]	10.35[cd]	9.5[a]	9.75[ab]	10.06[bc]	0.4995	0.1046	0.0825[t]	0.5641	0.3641
FP[2] ADG (kg)	1.54[c]	1.25[ab]	1.18[a]	1.20[a]	1.33[b]	0.1066	0.1694	0.0259[s]	0.7644	0.8471
FP[2] F:G	7.27[a]	8.75[bc]	8.91[c]	8.56[bc]	7.97[ab]	0.9239	0.6383	0.1394	0.6756	0.9373
FP[2] G:F	0.145[b]	0.123[a]	0.125[a]	0.127[a]	0.132[a]	0.0114	0.4474	0.1195	0.4681	0.757
O[3] DMI (kg)	10.35[a]	10.88[bc]	10.71[ab]	11.02[bc]	11.21[c]	0.4854	0.0385[s]	0.8482	0.5067	0.4503
O[3] ADG (kg)	1.42[b]	1.43[b]	1.28[a]	1.32[a]	1.45[b]	0.0693	0.7831	0.1166	0.2682	0.4914
O[3] F:G	7.37[a]	7.77[ab]	8.62[c]	8.43[c]	7.92[b]	0.47	0.1117	0.0345[s]	0.4824	0.4548
O[3] G:F	0.138[b]	0.133[b]	0.122[a]	0.121[a]	0.131[b]	0.00777	0.1528	0.0684[t]	0.3464	0.75

[abcd] Means with different superscripts differ
[1] Growing Phase for 84 days
[2] Finishing Phase for 55 days
[3] Overall Trial for 139 days
[4]Treatment composed of 0% cotton gin byproduct

[5]Treatment composed of 10% cotton gin byproduct
[6]Treatment composed of 20% cotton gin byproduct
[7]Treatment composed of 30% cotton gin byproduct
[8]Treatment composed of 40% cotton gin byproduct
[st] Significance or trends

Table 8. Blood urea nitrogen measurements with treatment contrasts and overall effects in experiment 1 (n = 50).

	TRT 1[2]	TRT 2[3]	TRT 3[4]	TRT 4[5]	TRT 5[6]	SEM	Linear P-value	Quadratic P-value	Cubic P-value	Quartic P-value
BUN[1] (mg/dL)	52.048[c]	47.542[ab]	45.866[a]	55.704[d]	50.942[bc]	3.4203	0.5829	0.3911	0.1087	0.2255
Day	0	28	56	84	SEM	P-value				
Day: BUN[1] (mg/dL)	34.01[a]	66.36[b]	65.11[b]	67.84[b]	3.3085	<.0001				
Treatment						0.2798				
Treatment*Day						0.1088				

[abc] Means with different superscripts differ
[1]Blood urea nitrogen
[2]Treatment composed of 0% cotton gin byproduct
[3]Treatment composed of 10% cotton gin byproduct
[4]Treatment composed of 20% cotton gin byproduct
[5]Treatment composed of 30% cotton gin byproduct
[6]Treatment composed of 40% cotton gin byproduct

Table 9. Carcass data measurements in experiment 1 evaluated by the Pennsylvania State University carcass data service (n = 49).

Variable	TRT 1[1]	TRT 2[2]	TRT 3[3]	TRT 4[4]	TRT 5[5]	SEM	Linear P-value	Quadratic P-value	Cubic P-value	Quartic P-value
Marbling	6.31[a]	6.17[a]	6.87[b]	6.33[a]	6.91[b]	0.4326	0.2448	0.8899	0.8092	0.1631
Quality Grade	17.9[ab]	17.7[a]	18.3[bc]	17.9[ab]	18.5[c]	0.4416	0.2284	0.6525	0.8622	0.2393
Hot Carcass (kg)	317.76[ab]	317.48[ab]	309.42[a]	313.9[ab]	323.95[b]	12.4	0.6821	0.2031	0.5352	0.6415
Dressing Percentage (%)[6]	59.74[a]	59.72[a]	60.02[a]	60.34[a]	60.45[a]	0.7341	0.2071	0.885	0.7381	0.9827
Back Fat Thickness (cm)	1.18[ab]	1.09[a]	1.16[ab]	1.19[b]	1.15[ab]	0.0956	0.8708	0.8861	0.3845	0.7672
Ribeye Area (cm^2)	79.16[bc]	80.65[c]	74.75[a]	77.16[ab]	83.94[d]	3.081	0.5045	0.0892	0.1998	0.4289
Kidney, Pelvic, and Heart Fat	1.75[a]	1.7[a]	1.94[b]	1.9[b]	1.7[a]	0.1257	0.8026	0.2247	0.2642	0.5111
Yield Grade[7]	2.8[b]	2.62[a]	2.98[c]	2.9[bc]	2.59[a]	0.1555	0.7774	0.2462	0.1253	0.3843

[abcd] Means with different superscripts differ

[1]Treatment composed of 0% cotton gin byproduct

[2]Treatment composed of 10% cotton gin byproduct

[3]Treatment composed of 20% cotton gin byproduct

[4]Treatment composed of 30% cotton gin byproduct

[5]Treatment composed of 40% cotton gin byproduct

[6]Dressing percentage calculated from the equation: Dressing% = (HCW/(final weight*0.96))*100

[7]Yield grade calculated from the equation: YG = 2.5 + (2.5 x BF) + (0.2 x %KPH) + (0.0038 x HCW) – (0.32 x REA)

Table 10. Nutrient analysis of cotton gin byproduct, corn silage, treatment diets, and finisher TMR in Experiment 2.

Nutrient (%DM)	CGB[1]	Corn Silage	TRT 1[2] (Control)	TRT 2[3]	TRT 3[4]	TRT 4[5]	TRT 5[6]	Finisher TMR
Dry Matter	89.1	31.6	36.35	42.05	52.55	67.3	81.6	73.7
Crude Protein	11.6	9.6	12.95	13.3	12.95	12.4	11.85	12.4
Soluble Protein	1.6	5.5	4.5	4.75	3.4	2.45	1.75	5.4
ADF	29.4	25.6	22.2	26.75	24.05	19.6	19.3	6.1
aNDF	56.6	44	36.7	38.2	32.8	27.65	27	14.4
TDN	-	70	71	69	71.5	74.3	75	84
NE_g	-	0.52	0.53	0.5	0.54	0.58	0.59	0.71
ME (Mcal/lb)	-	1.21	1.23	1.19	1.24	1.3	1.31	1.49
Ash	7.71	4.29	6.06	5.59	5.3	4.58	3.66	3.43
Calcium	1.2	0.22	0.62	0.81	0.71	0.54	0.47	0.67
Phosphorus	0.24	0.29	0.33	0.33	0.32	0.32	0.29	0.35
Magnesium	0.21	0.19	0.2	0.2	0.21	0.16	0.15	0.15
Potassium	1.51	1.42	1.36	1.3	1.21	1.06	0.91	0.64
Sodium	0.02	0.02	0.1	0.14	0.12	0.12	0.1	0.14
Iron (ppm)	885	164	336	225	242.5	257.5	204	243
Manganese (ppm)	66	56	72.5	81	70.5	61	44	57
Zinc (ppm)	21	48	59.5	62	57	48.5	39.5	73
Copper (ppm)	12	13	19	27.5	22.5	20	17	19

[1]Cotton gin byproduct

[2]Treatment composed of 0% cotton gin byproduct
[3]Treatment composed of 10% cotton gin byproduct
[4]Treatment composed of 20% cotton gin byproduct
[5]Treatment composed of 30% cotton gin byproduct
[6]Treatment composed of 40% cotton gin byproduct

Table 11. Steer performance by treatment in experiment 2 (n = 73).

Variable	TRT 1[4]	TRT 2[5]	TRT 3[6]	TRT 4[7]	TRT 5[8]	SEM	Linear P-value	Quadratic P-value	Cubic P-value	Quartic P-value
GP[1] DMI (kg)	11.17[a]	11.19[a]	13.92[b]	14.84[c]	13.96[b]	0.7259	0.0006[s]	0.1783	0.0549[t]	0.4427
GP[1] ADG (kg)	1.80[a]	1.93[b]	1.95[bc]	1.97[bc]	2.00[c]	0.05132	0.0095[s]	0.3121	0.4648	0.8184
GP[1] F:G	6.27[b]	5.93[a]	7.29[c]	7.62[c]	7.09[c]	0.3752	0.0009[s]	0.1663	0.0069[s]	0.2006
GP[1] G:F	0.163[c]	0.175[d]	0.141[ab]	0.135[a]	0.145[b]	0.008805	0.0029[s]	0.4088	0.011[s]	0.1402
FP[2] DMI (kg)	12.60[d]	12.17[c]	11.00[a]	11.07[ab]	11.41[b]	0.3577	0.005[s]	0.0441[s]	0.355	0.3173
FP[2] ADG (kg)	1.48[d]	1.51[d]	1.08[a]	1.29[b]	1.37[c]	0.06116	0.0363[s]	0.0049[s]	0.1034	0.0024[s]
FP[2] F:G	8.66[ab]	8.19[a]	11.35[c]	9.06[b]	8.55[ab]	0.7384	0.7834	0.0623[t]	0.4384	0.0178[s]
FP[2] G:F	0.118[b]	0.125[c]	0.098[a]	0.117[b]	0.121[bc]	0.006097	0.9505	0.1039	0.3477	0.014[s]
O[3] DMI (kg)	11.82[a]	11.64[a]	12.59[b]	13.13[c]	12.80[bc]	0.4444	0.0196[s]	0.657	0.1528	0.7527
O[3] ADG (kg)	1.66[b]	1.74[c]	1.56[a]	1.64[b]	1.72[c]	0.03194	0.8274	0.0162[s]	0.0084[s]	0.0016[s]
O[3] F:G	7.18[b]	6.79[a]	8.21[d]	8.10[d]	7.52[c]	0.3352	0.0253[s]	0.0602[t]	0.0116[s]	0.0534[t]
O[3] G:F	0.141[c]	0.150[d]	0.124[a]	0.127[a]	0.134[b]	0.005624	0.0189[s]	0.1468	0.0087[s]	0.0274[s]

[abcd] Means with different superscripts differ
[1] Growing Phase for 84 days
[2] Finishing Phase for 70 days
[3] Overall Trial for 154 days
[4]Treatment composed of 0% cotton gin byproduct

[5]Treatment composed of 10% cotton gin byproduct
[6]Treatment composed of 20% cotton gin byproduct
[7]Treatment composed of 30% cotton gin byproduct
[8]Treatment composed of 40% cotton gin byproduct
[st] Significance or trend

Table 12. Blood urea nitrogen measurements with treatment contrasts and overall effects in experiment 2 (n = 73).

	TRT 1[2]	TRT 2[3]	TRT 3[4]	TRT 4[5]	TRT 5[6]	SEM	Linear P-value	Quadratic P-value	Cubic P-value	Quartic P-value
BUN[1] (mg/dL)	52.644[c]	47.948[a]	50.867[bc]	49.803[ab]	49.542[ab]	2.7904	0.6275	0.6468	0.4425	0.4915
Day	0	28	56	84	SEM	P-value				
Day: BUN[1] (mg/dL)	30.35[a]	58.35[c]	57.45[c]	54.39[b]	2.5106	<.0001				
Treatment						0.8189				
Treatment*Day						0.8623				

[abc] Means with different superscripts differ
[1]Blood urea nitrogen
[2]Treatment composed of 0% cotton gin byproduct
[3]Treatment composed of 10% cotton gin byproduct
[4]Treatment composed of 20% cotton gin byproduct
[5]Treatment composed of 30% cotton gin byproduct
[6]Treatment composed of 40% cotton gin byproduct

Table 13. Carcass data measurements in experiment 2 evaluated by the Pennsylvania State University carcass data service (n = 72).

Variable	TRT 1[1]	TRT 2[2]	TRT 3[3]	TRT 4[4]	TRT 5[5]	SEM	Linear P-value	Quadratic P-value	Cubic P-value	Quartic P-value
Marbling	6.33[ab]	6.13[a]	6.38[b]	6.50[b]	6.83[c]	0.2069	0.042	0.213	0.6952	0.5788
Quality Grade	17.80[a]	17.73[a]	18.00[b]	18.20[c]	18.40[d]	0.1941	0.0141	0.5205	0.5898	0.7717
Hot Carcass (kg)	345.03[a]	351.9[ab]	343.18[a]	347.48[ab]	357.23[b]	9.9354	0.0718	0.1447	0.0594	0.2054
Dressing Percentage (%)[6]	59.91[ab]	59.66[a]	60.47[c]	59.98[b]	60.48[c]	0.3124	0.0639	0.8419	0.9252	0.0304
Back Fat Thickness (cm)	1.34[a]	1.5[b]	1.39[a]	1.42[ab]	1.32[a]	0.1053	0.5691	0.1639	0.5119	0.2606
Ribeye Area (cm^2)	82.85[ab]	83.26[abc]	85.06[c]	81.42[a]	83.65[bc]	2.1849	0.9565	0.6968	0.2553	0.0934
Kidney, Pelvic, and Heart Fat	1.7[a]	1.87[c]	1.95[c]	1.74[ab]	1.83[bc]	0.1206	0.6848	0.2788	0.2441	0.3487
Yield Grade[7]	3.07[ab]	3.25[c]	3.02[a]	3.20[bc]	3.11[abc]	0.1578	0.8948	0.7379	0.6489	0.1011

[abcd] Means with different superscripts differ

[1]Treatment composed of 0% cotton gin byproduct

[2]Treatment composed of 10% cotton gin byproduct

[3]Treatment composed of 20% cotton gin byproduct

[4]Treatment composed of 30% cotton gin byproduct

[5]Treatment composed of 40% cotton gin byproduct

[6] Dressing percentage calculated from the equation: Dressing% = (HCW/(final weight*0.96))*100

[7]Yield grade calculated from the equation: YG = 2.5 + (2.5 x BF) + (0.2 x %KPH) + (0.0038 x HCW) – (0.32 x REA)

Figure 1. Growing Phase Dry Matter Intake in Experiment 1 (n = 50).

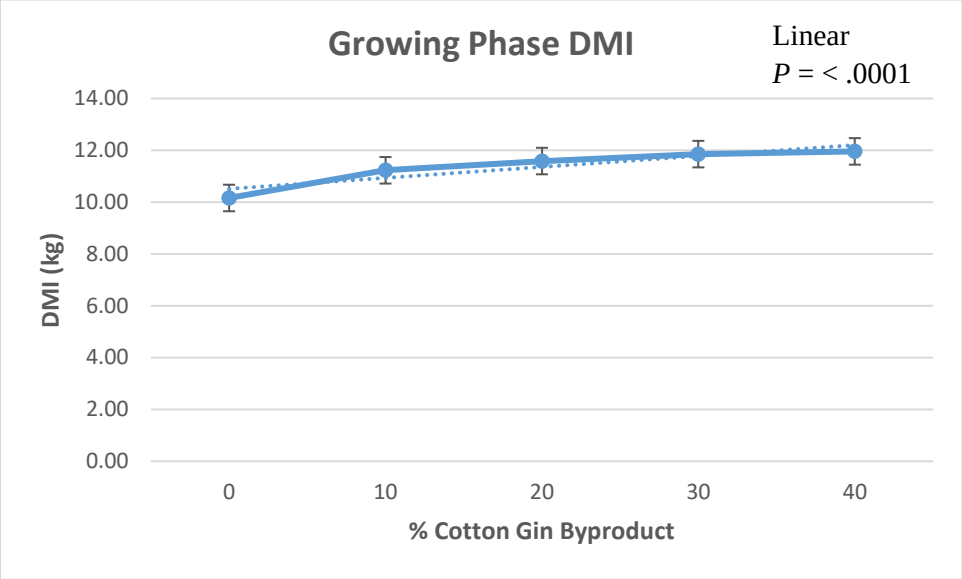

Figure 2. Growing Phase Average Daily Gain in Experiment 1 (n = 50).

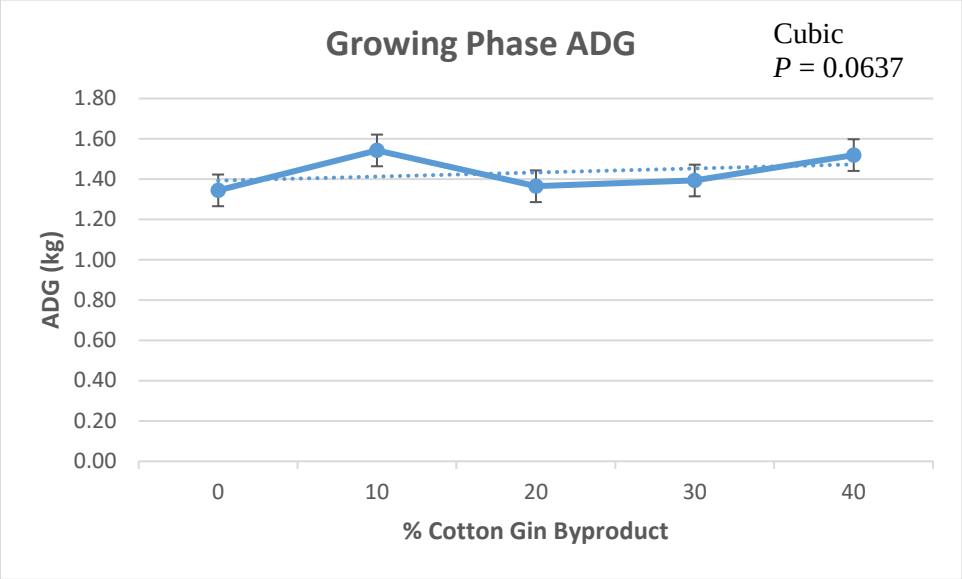

Figure 3. Growing Phase Feed Efficiency in Experiment 1 (n = 50).

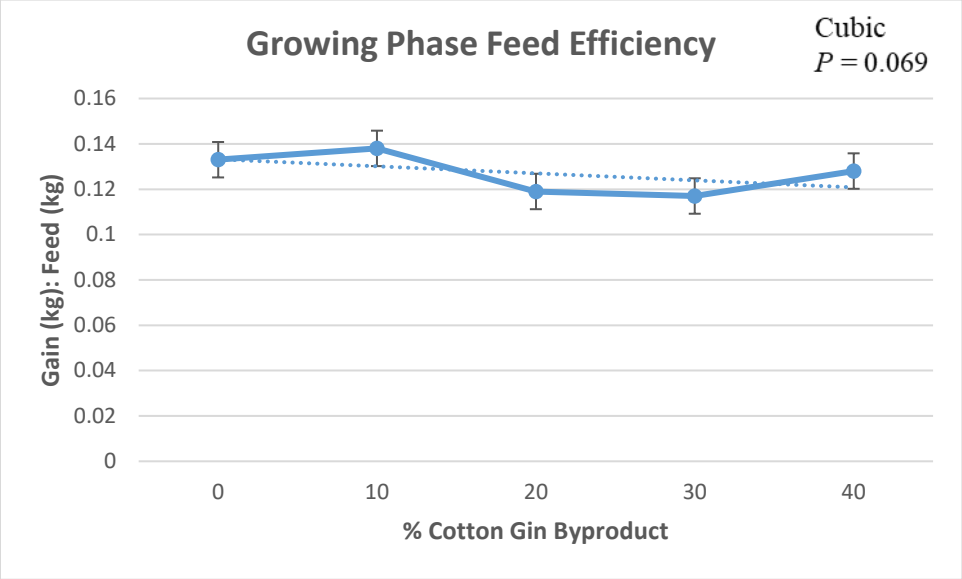

Figure 4. Finishing Phase Dry Matter Intake in Experiment 1 (n = 49).

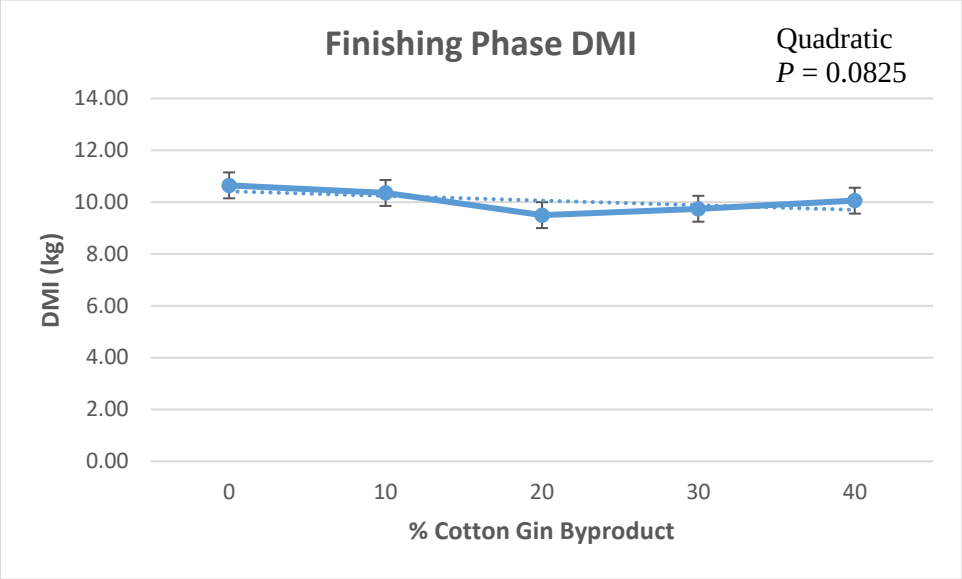

Figure 5. Finishing Phase Average Daily Gain in Experiment 1 (n = 49).

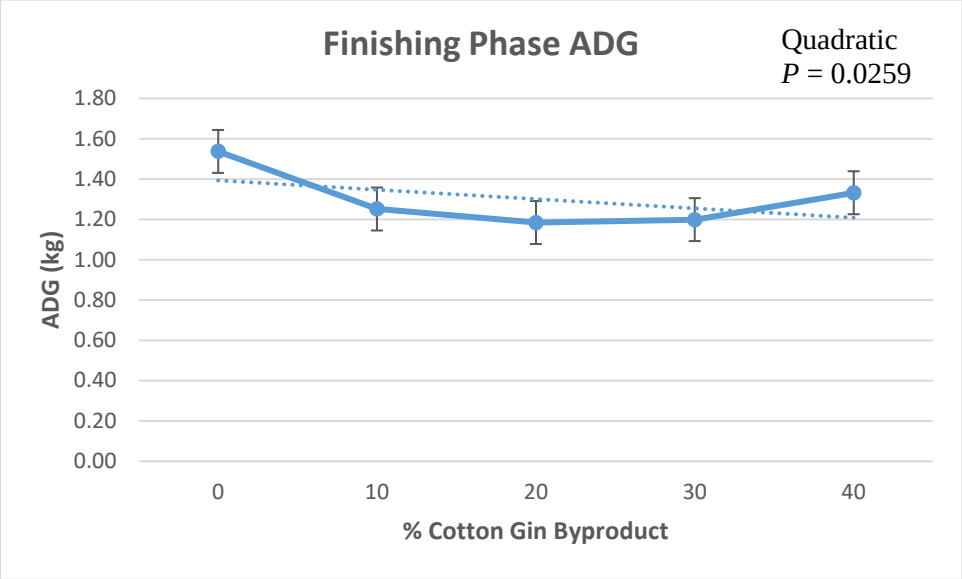

Figure 6. Finishing Phase Feed Efficiency in Experiment 1 (n = 49).

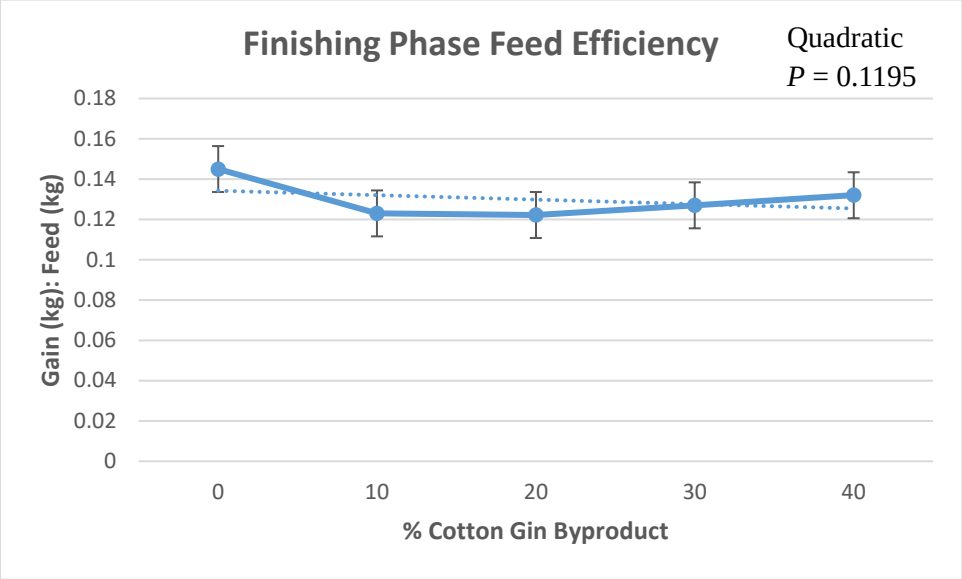

Figure 7. Overall Dry Matter Intake in Experiment 1 (n = 49).

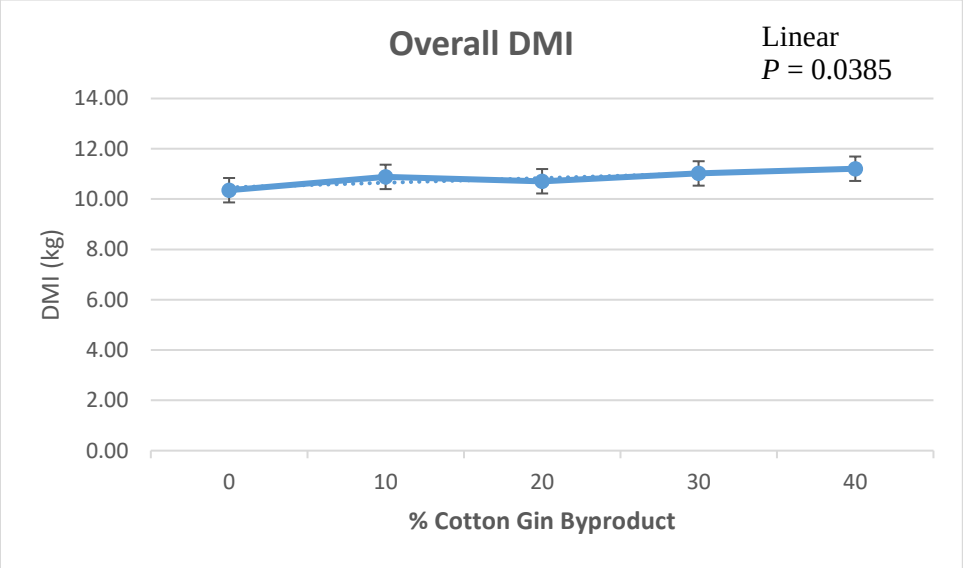

Figure 8. Overall Average Daily Gain in Experiment 1 (n = 49).

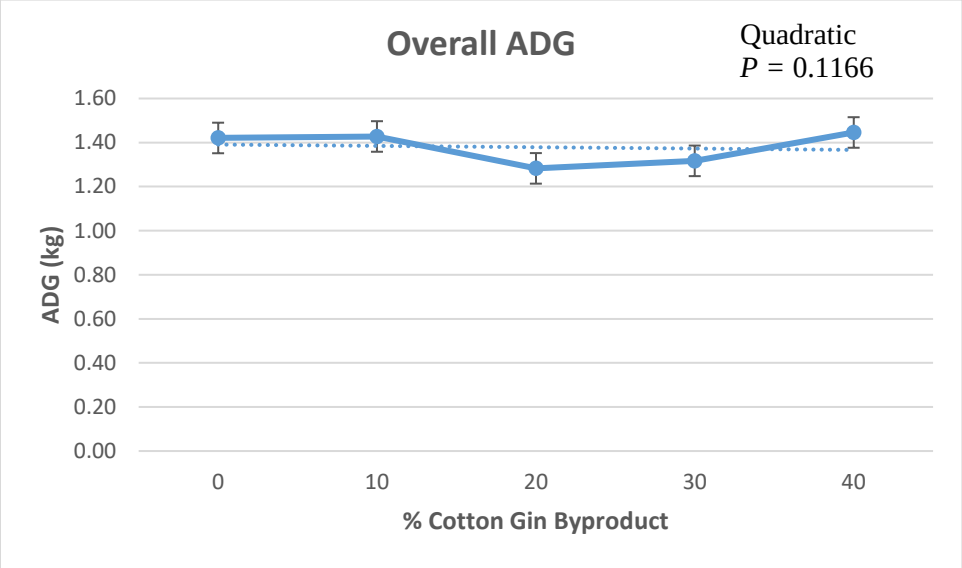

Figure 9. Overall Feed Conversion in Experiment 1 (n = 49).

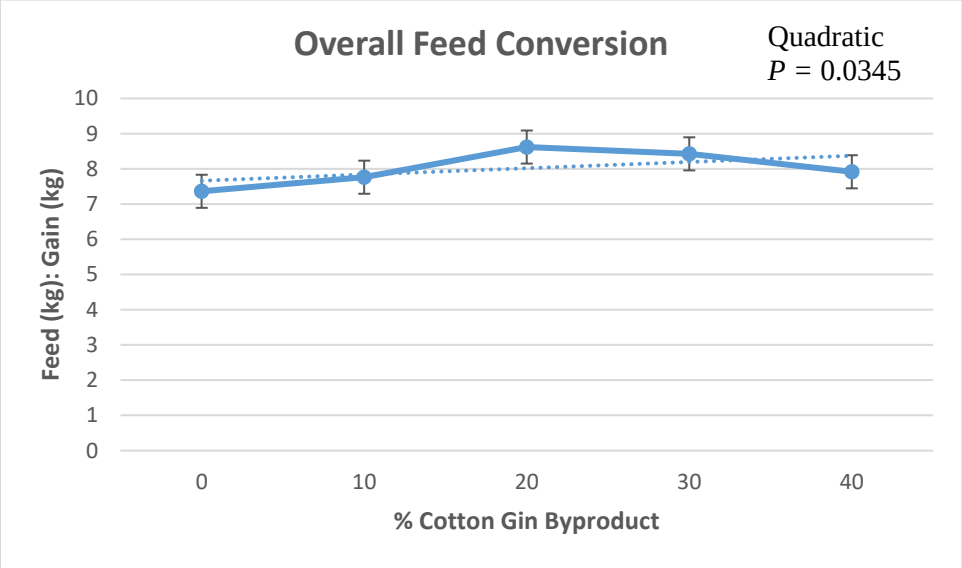

Figure 10. Overall Feed Efficiency in Experiment 1 (n = 49).

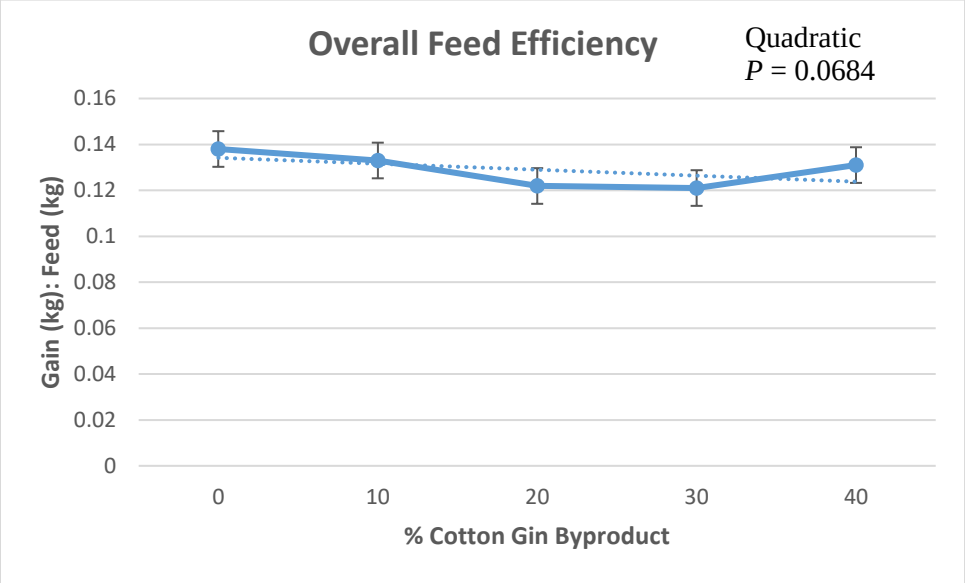

Figure 11. Blood urea nitrogen least squares means over time in experiment 1 (n = 50).

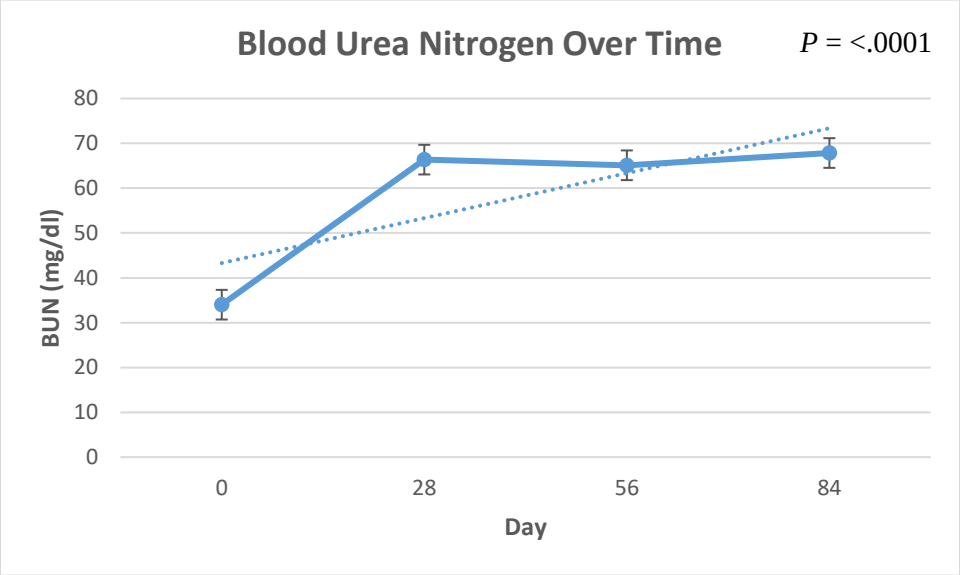

Figure 12. Growing Phase Dry Matter Intake in Experiment 2 (n = 73).

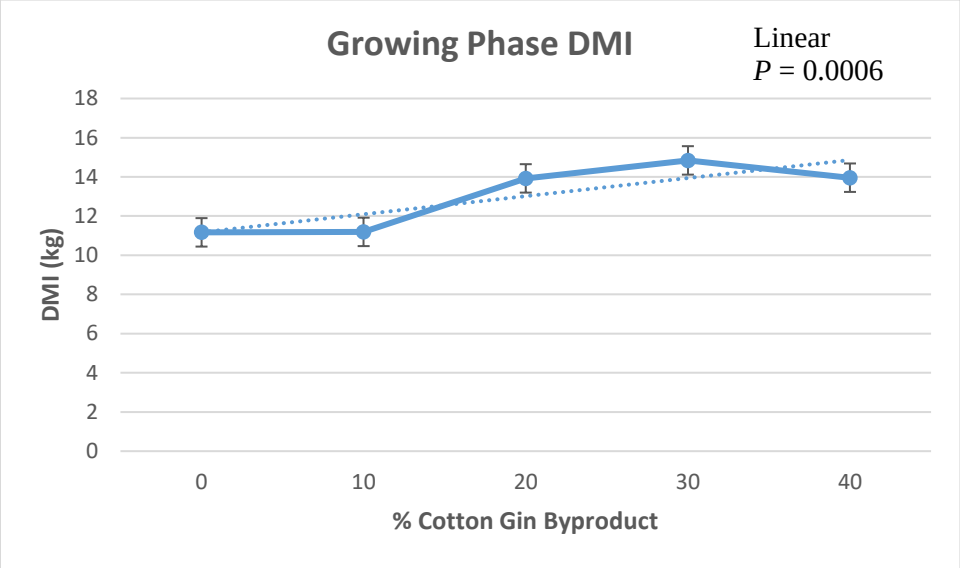

Figure 13. Growing Phase Average Daily Gain in Experiment 2 (n = 73).

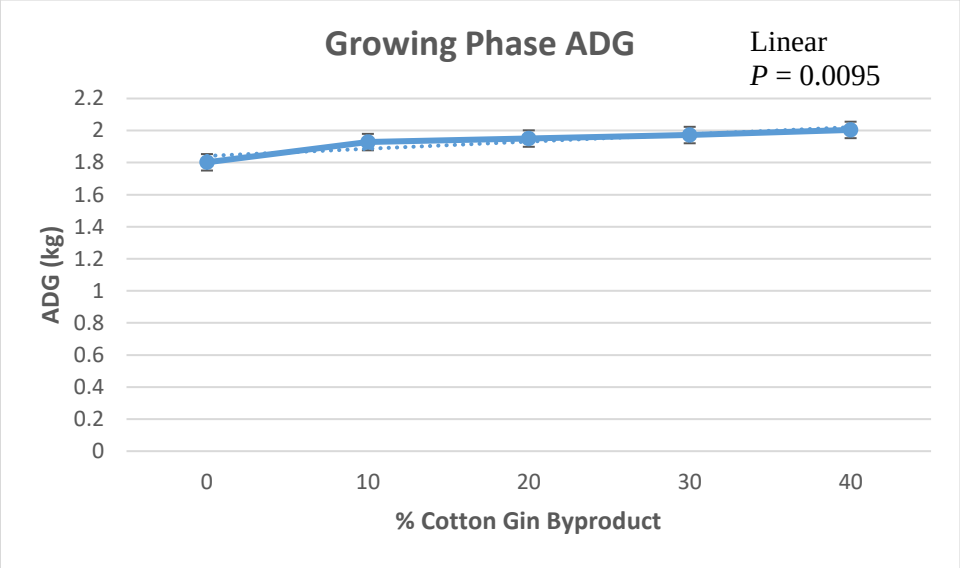

Figure 14. Growing Phase Feed Conversion in Experiment 2 (n = 73).

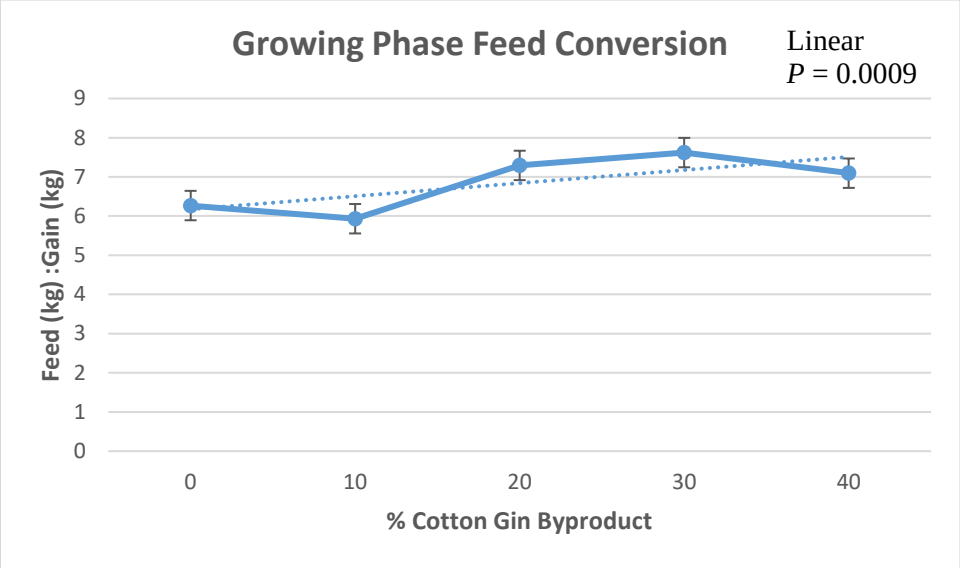

Figure 15. Growing Phase Feed Efficiency in Experiment 2 (n = 73).

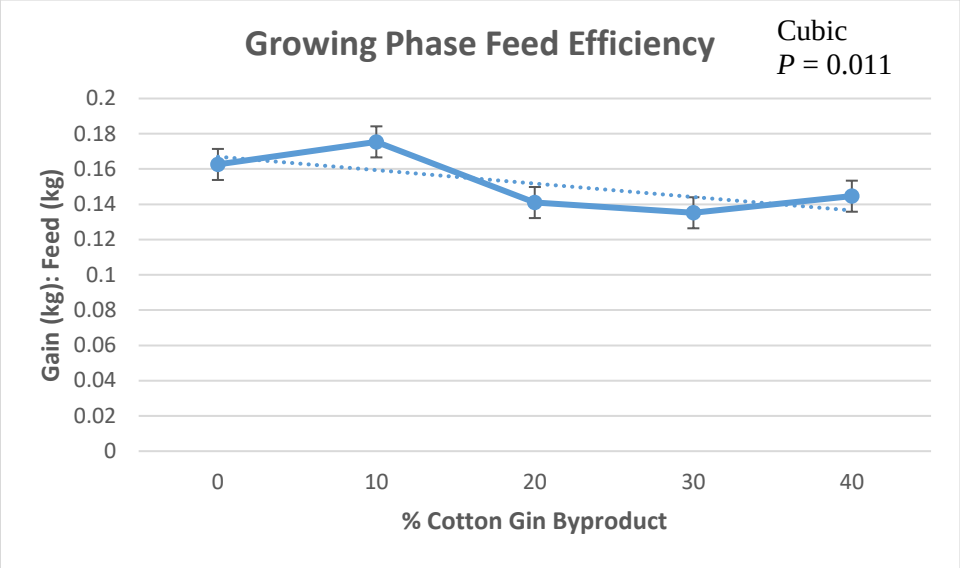

Figure 16. Finishing Phase Dry Matter Intake in Experiment 2 (n = 72).

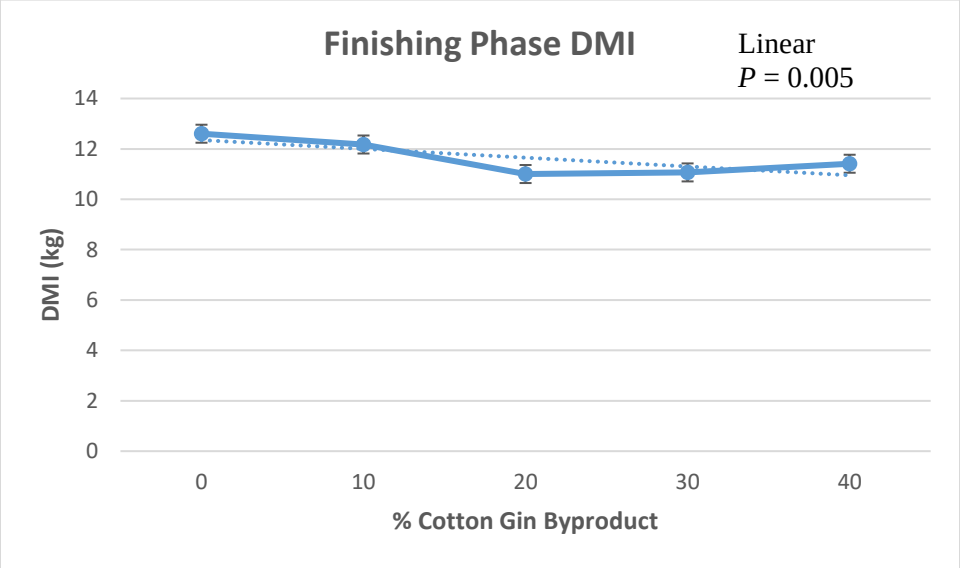

Figure 17. Finishing Phase Average Daily Gain in Experiment 2 (n = 72).

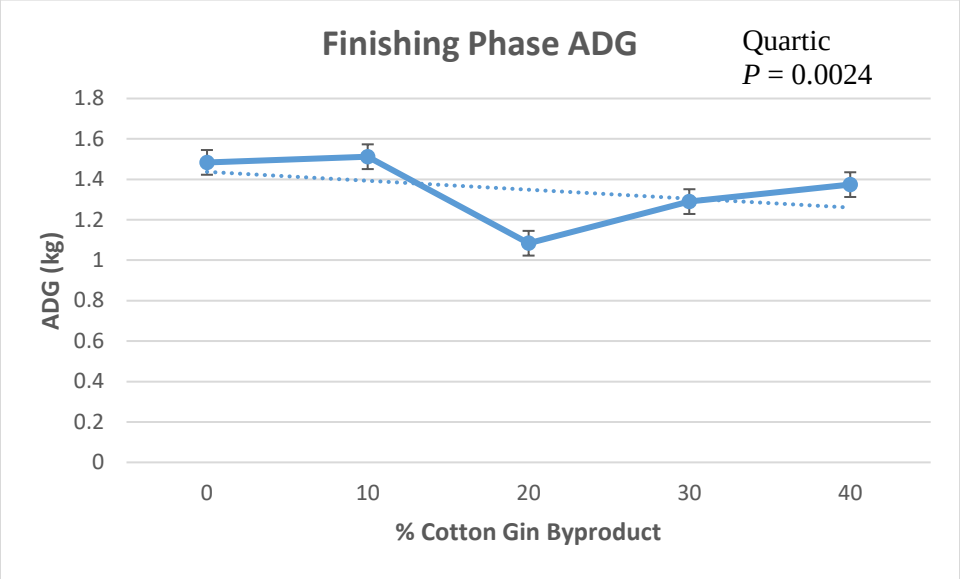

Figure 18. Finishing Phase Feed Conversion in Experiment 2 (n = 72).

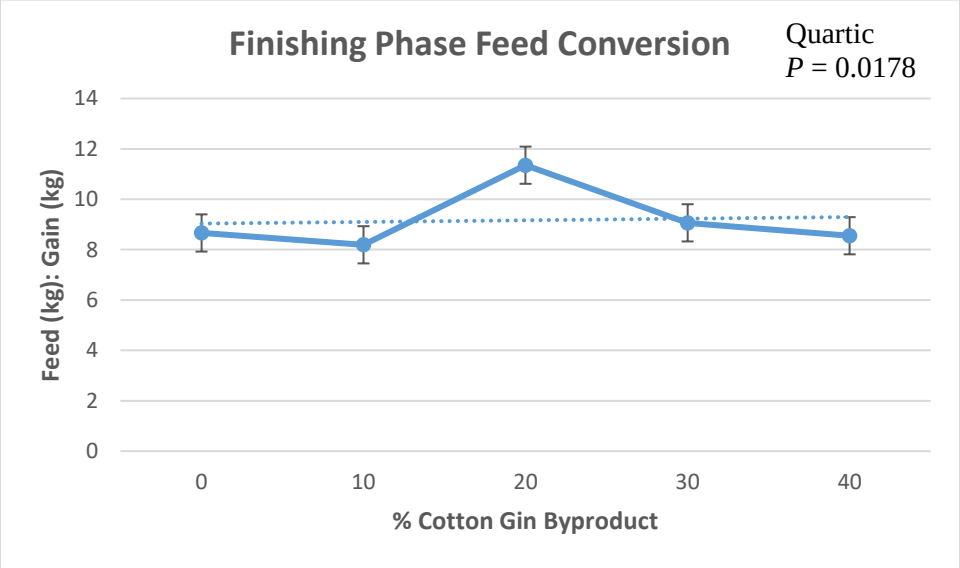

Figure 19. Finishing Phase Feed Efficiency in Experiment 2 (n = 72).

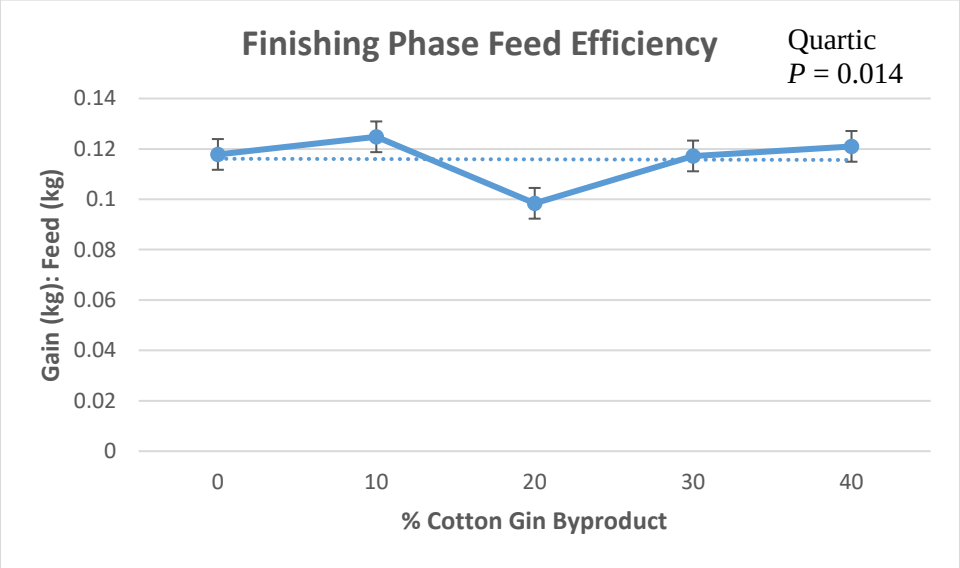

Figure 20. Overall Dry Matter Intake in Experiment 2 (n = 72).

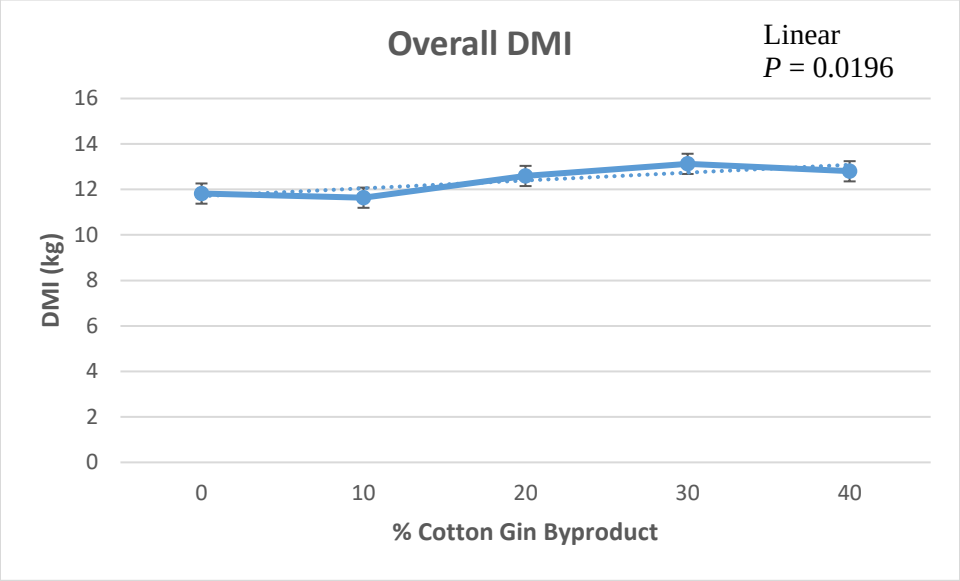

Figure 21. Overall Average Daily Gain in Experiment 2 (n = 72).

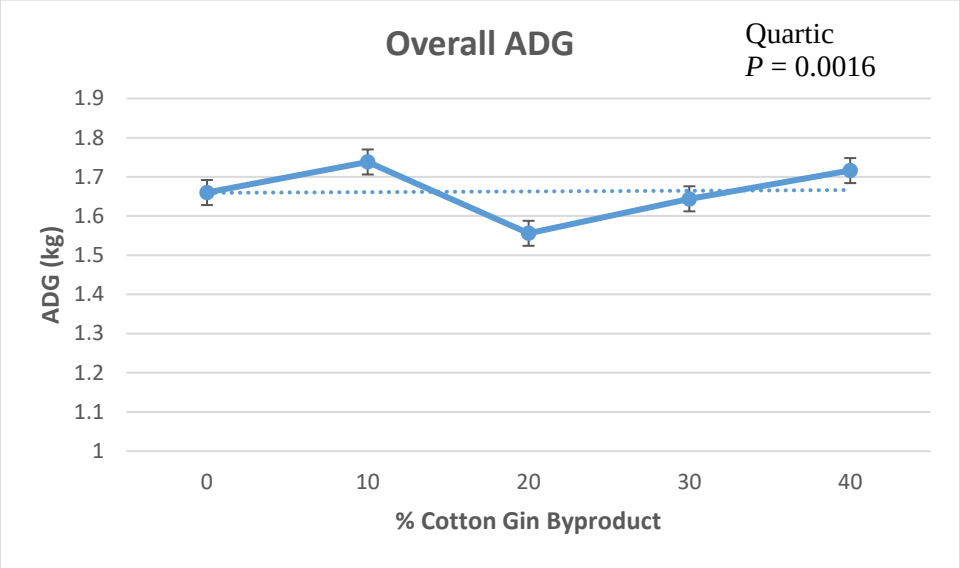

Figure 22. Overall Feed Conversion in Experiment 2 (n = 72).

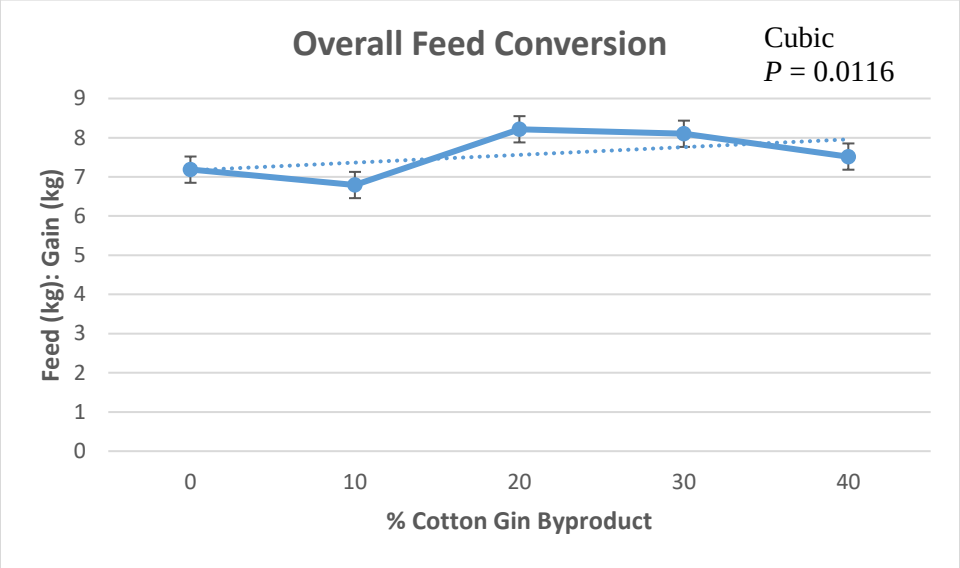

Figure 23. Overall Feed Efficiency in Experiment 2 (n = 72).

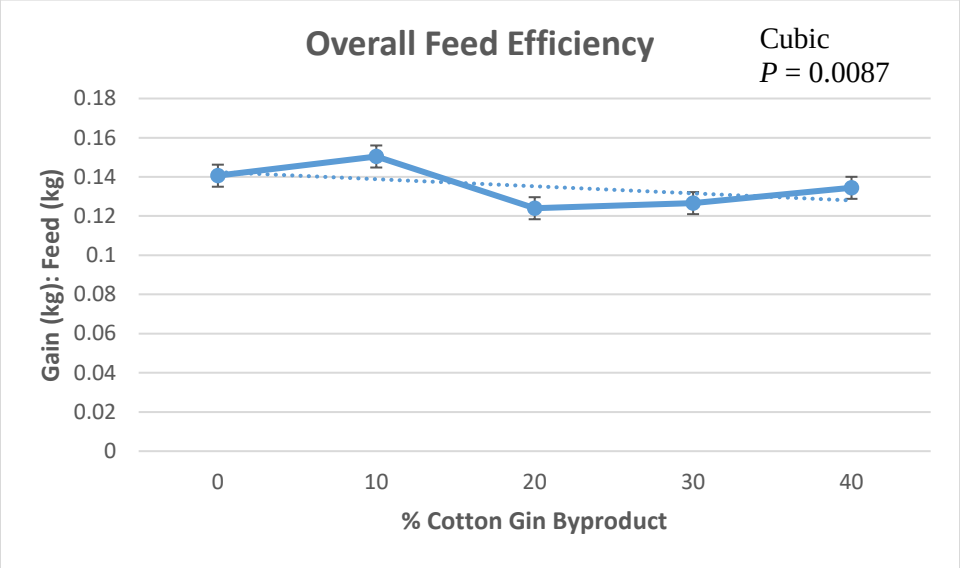

Figure 24. Blood urea nitrogen least squares means over time in experiment 2 (n = 73).

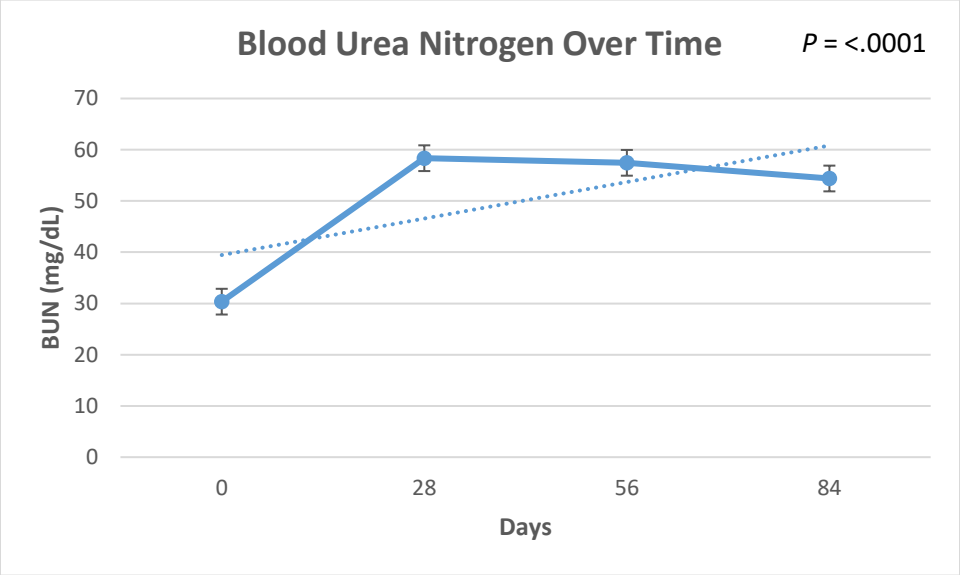

Figure 25. Carcass Marbling in Experiment 2 (n = 72).

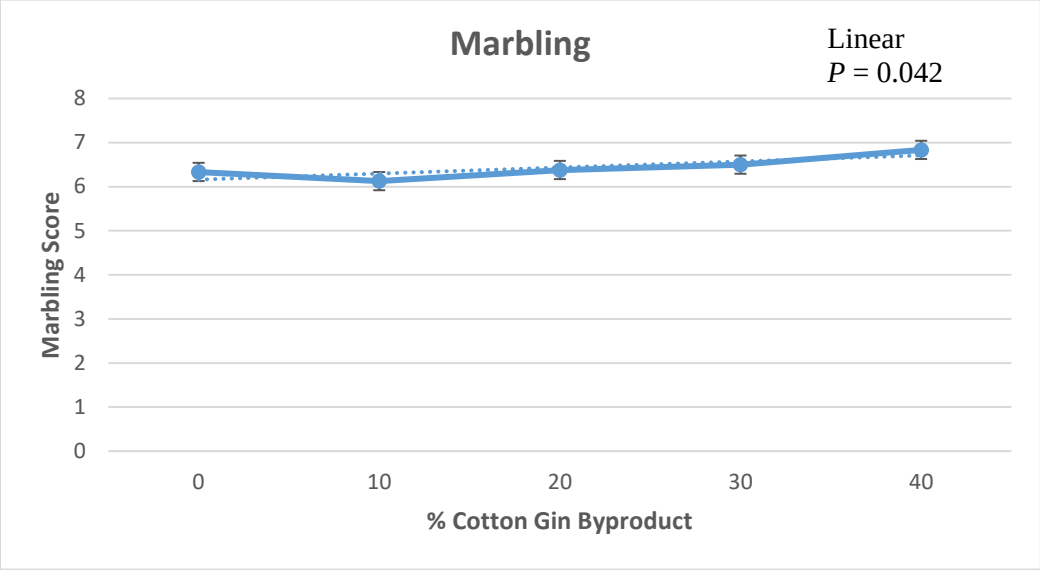

Figure 26. Carcass Quality Grade in Experiment 2 (n = 72).