The investigation of different levels of vitamin A and its effects on animal performance, carcass traits, and the conversion rate of external fat color in cull-cows.

Thesis

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By

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Abstract

Cull cows represent a significant percentage of the revenue received from the U.S. beef industry, however, cull cows are often heavily price discounted at time of slaughter due to decreased body condition scores, carcass yield and quality and increased yellow fat color as a result of a prolonged high vitamin A diet. This study's objective is to evaluate different feeding strategies and their effects on body condition score, external fat color, carcass yield and quality traits in cull cows. The central hypothesis is feeding a high energy diet, with low levels of Vitamin A, for 56 days will improve animal performance, carcass yield and quality traits in addition to capturing the point (rate) of the conversion of yellow to white external fat.

In the present study 86 Angus crossbreed cows, culled from two Ohio State University farms were utilized. Cows were fed either low vitamin A diet (LVA) consisting of whole shelled corn, soybean hulls, soybean meal and a mineral-vitamin supplement or a high vitamin A diet (HVA) diet, formulated using whole shelled corn, fescue hay, DDGS and a mineral-vitamin supplement for 56 days. During the 56 day feeding period, weights, body condition scores, and subcutaneous adipose samples were collected every 14 days. On days 56, cattle were slaughtered; 48 hours postmortem carcass characteristics and objective color scores were recorded and a sample of the *longissimus dorsi* lumborum was collected. Subcutaneous adipose tissue samples were

utilized to record subjective color scores and then ground to be analyzed via HPLC for beta-carotene concentration. The *longissimus dorsi* lumborum samples were sliced into 2.54cm steaks, one of which was utilized to perform WBSF testing, the other was ground and utilized for pH testing. After results were gathered, data was analyzed via a proc mixed model of SAS.

Feeding cull cows a low vitamin A diet resulted in significant differences in external carcass fat color ($P = 0.01$) as well as objective b* values ($P < 0.01$) on day 56. Subjective fat color scores were not significantly different on days 0 or 14, but were significantly different on days 28 ($P < 0.05$), 42 ($P < 0.05$) and 56 ($P < 0.01$). Additionally, 9-*cis*-beta-carotene concentrations ($P = 0.05$) on day 56 were significantly different between treatments. A trend was noticed for all-*trans*-beta-carotene concentration ($P = 0.10$) on day 56 as well. Cull cow weights were significantly higher when fed the low vitamin A diet starting on day 14 ($P < 0.01$), 28 ($p = 0.01$), and 42 ($P = 0.04$) and a trend was noticed on day 56 ($P = 0.09$)

Overall, cows fed the LVA treatment for 56 days exhibited decreased adipose yellowness and beta-carotene concentrations as well as increased live weights. However, increased time on feed in addition to alternative feed formulations may be needed to see an increase in the overall value of cull cows. Additional research should also be conducted taking into effect time of year as well as breed type.

Dedication

Dedicated to my parents:

Jay Parkinson and Lisa Arnold

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Chapter 1 - Introduction

Cattle production is one of the most important industries in the United States. According to the National Agricultural Statistics Service (NASS), in 2015, cattle production was ranked first in cash receipts. Cash receipts are used as a means of showing "revenues from the sale of agricultural commodities, program payments from government agencies, and payments from private crop and livestock insurance programs" (USDA, 2016). Beef cattle production in the United States is a complex system involving many facets, beginning with cow calf producers, and eventually ending with slaughter. Most of the beef in the United States originates from fed beef ranging in age from 14 to 18 months. However, cull cattle contribute a significant share to the overall beef production numbers, up to 19% of cattle slaughtered in the U.S. (Woerner, 2010). There are multiple reasons cows are sent to slaughter including not being bred, old age, physical defects, and producing inferior calves relative to the herd index. Traditionally, most producers will sell their culled cows during the fall, as most cows calve in the spring, are bred during the summer, and are evaluated for being pregnant during the fall. However, this results in an over-supply of cull cows during a short period of time, resulting in prices being lowest during this time of the year, with the vast majority of cull cows sold through auction barns, producers become price takers, resulting in a decrease in potential farm income. With the sale of cull cows contributing 20% of farm revenue, producers need to investigate alternative ways to improve cull cow value while not losing money. A few simple tactics include having healthy cows based on body condition scores; feeding of high energy diets; targeting a market cow class; and understanding the price index (an index of variations in prices of goods and services) (Boyles,2015).

Cull cows play a large role in the total annual revenues of cow calf producers; however, cull cows are significantly price discounted at slaughter due to advanced physiological age and their high prevalence of exhibiting yellow fat color (due to high levels of vitamin A precursors present in forage). Several studies have shown a correlation between a forage-based diet and advanced skeletal maturity on palatability, fat color and percent sellable product. These factors combined result in undervalued end products from cull cattle, with the majority of the carcass being ground. However, more and more cow slaughter facilities are selling whole muscle cuts to the food service industry resulting in increased revenues. Therefore, there is a need for information on how to improve palatability and whiteness of fat in the cull cow sector.

The central hypothesis is feeding a high energy diet, with low levels of Vitamin A, for 56 days will improve animal performance, carcass yield and quality traits in addition to capturing the point (rate) of the conversion of yellow to white external fat. This study's objective is to evaluate different feeding strategies and their effects on body condition score, external fat color, carcass yield and quality traits in cull cows. An understanding of the impact of differing levels of vitamin A on performance, carcass traits and external fat color may allow producers to more effectively feed cull cows to improve the market for meat from cull cows and maximize revenues.

Chapter 2 - Literature Review

2.1 Introduction

Cull cattle in the United States are the result of a substantial beef industry comprising many management styles and production systems. These differences in production result in vast differences in end products including final markets due to varying quality grades and subsequent fluctuations in pricing for consumers, due to vast differences in sensory attributes and demands.

Cull cattle are most purchased via live weight as opposed to being sold on a grid system, as is common in fed beef. Because of this an emphasis is placed on body condition score, an indication of a cow's relative fatness which will impact dressing percentage and quality grade. As body condition increases so too does quality grade, and to a point dressing percentage. Cattle more highly conditioned may be eligible for price premiums, unless they are excessively fat, as their carcasses are more likely to be fabricated into whole muscle cuts, commanding a premium over carcasses which are destined for ground meat, likely originating from underconditioned cattle.

Of major concern for packers marketing cull cows is external fat color, white versus yellow. When cows consume large amounts of forage high in provitamin A, an accumulation of these provitamin A carotenoids are stored in subcutaneous tissue, commonly known as external fat. Factors that play into the subcutaneous fat color include feed types and genetics which may serve to restrict, or promote, the accumulation of carotenoids in subcutaneous adipose tissue. Furthermore, the unique structure of adipose tissue makes it highly susceptible to changes in diet which effects end value of cull cows (Dunne, 2008).

The objective of this literature review is to provide an overview of the U.S. beef industry, specifically cull cows as well as factors affecting carotenoid concentration in beef adipose tissue. In addition, the literature review will provide insight into impacts of advanced maturity in cattle on carcass quality traits and subsequent palatability in beef.

2.2 Production Systems in the U.S.

Beef cattle production systems within the United States are characterized by a wide range of environments, animal phenotypes, management practices and nutritional inputs. However, most United States production systems are predominantly pastoral based, meaning that regardless of the system, calves are still born on grass and remain there until weaning and potentially much longer. The conventional beef production system in the United States is highly segmented. A multitude of operations are employed with cattle typically changing hands several times before being slaughtered (Figure 1). Operations would include seedstock operations, which raise bulls and females that are utilized by cow calf operations. Cow calf operations produce feeder calves; calves that will eventually end up in the food chain. Feeder calves are sold to one of several entities including stocker operations, backgrounding lots, and feedlots. All of these operations are responsible for raising and growing the feeder calves. Stocker operations and backgrounding lots grow the weaned feeder calves until the last few months of their lives at which point they will be sent to a feedlot to be fed a high concentrate diet. At approximately 14 to 18 months of age the cattle are ready to be harvested (Drouillard, 2018).

Seedstock and cow calf operations are spread throughout all fifty states with approximately 55% being concentrated within the central region of the continental United States. Approximately 20% of the national herd is found in the western region, 20% in the southern region and the remaining 5% being found in the northeastern United States, Alaska, and Hawaii. In contrast to the broad range seen in the disbursement of cow herds in the United States, the majority of feedlot production, over 72%, is concentrated within a five-state range including Nebraska, Texas, Kansas, Iowa and Colorado (Drouillard, 2018).

In the United States there are three main production methods used in the beef industry; conventional, grass fed and organic. The first, and by far most common production method is conventional. In this method cattle are finished on a high concentrate grain-based diet, this helps to improve intramuscular fat content in the beef. Furthermore, it is a cheap and efficient way to produce beef, resulting in a moderately priced end product (Funnell, 2019). Grass fed production on the other hand relies solely on grass and hay to feed cattle. This results in an increased time to finish animals which in turn leads to higher prices. Grass fed beef has seen an increase in demand over the last decade thanks to a shifting mindset by consumers and potential health benefits (Sitienei, 2018). The final production method, organic can take on the form of either of the other two methods, but with increased restrictions and oversight. Organic production refers to a strict set of rules that govern how the animal must be treated and eat; both grain fed and grass fed organic production are practiced (Organic).

While culling of cows can be due to a multitude of reasons the most common is because of being not bred or open. Many cow calf producers evaluate their herds for culling decisions in the fall as many producers breed their cows in the summer, evaluate for pregnancy in the fall and calve in the spring. Because of this timeline, there is an overabundance of cull cows being marketed in the fall resulting in rock bottom prices and producers becoming price takers as opposed to price makers (Boyles, 2015). For the year of 2019, cattle were cheapest during the month of September ($103.30 per hundred pounds) and highest during March (127.51 per hundred pounds) (Cook, 2020). By reevaluating the culling process and placing cows on feed before marketing producers may be able to capitalize on higher prices by selling cows when supply is low and demand is increased (Boyles,2015).

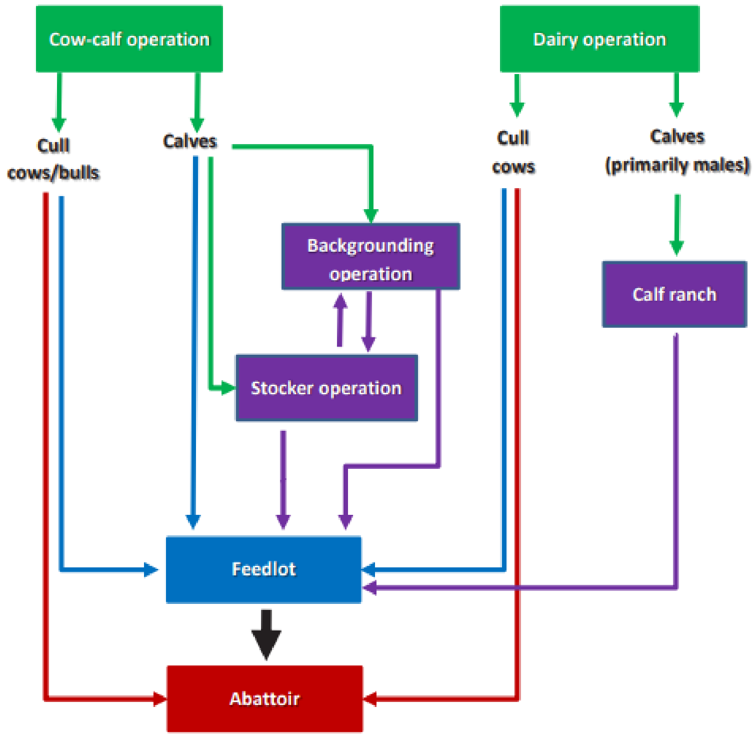

Figure 1. Flow of cattle through U.S. beef production chain

2.2.1 Conventional Production

In the United States the majority of beef production is classified as conventional. This means cattle are fed a high concentrate diet prior to slaughter as opposed to a grass-fed or organic diet. This high concentrate diet helps to increase intramuscular fat, marbling, which commands a premium for producers (Funnell, 2019).

After calves are weaned from cows, they are bound for one of two destinations, either as stocker calves or feeder calves. Stocker calves are weaned cattle that are placed on pasture to capitalize on linear growth before they receive a high concentrate ration. British breeds such as Angus, Shorthorns and Herefords are often placed in stocker situations as they require more time to build frame size before being placed in a feedlot; otherwise they may become overly conditioned before they have reached a proper weight. Feeder calves on the other hand are weaned cattle that are taken directly into a feedlot situation and are fed a high concentrate diet. Continental breeds such as Limousin, Charolais and Simmental are often utilized as feeder cattle as their large frames and fast growth rates will allow them to reach a proper frame score while also acquiring an appropriate amount of finish, subcutaneous fat, in a feedlot setting (Funnell, 2019). On average cattle spend five months on high concentrate diets, in a feedlot setting before being slaughtered at 14 to 18 months of age (Drouillard, 2018).

High energy diets fed to cattle in feedlots under conventional practices consist mostly of starchy grains including corn, barley, oats, and wheat as well as grain byproducts such as distillers' grains, soybean meal, corn screenings and wheat midlings. Because of the lack of fiber in concentrate diets, a source of roughage is often necessary to maintain proper rumen function. Hay, straw, and silage are all utilized to give the scratch factor that stimulates the rumen and keeps it functioning properly (Funnell, 2019).

Conventional beef amasses the majority of United States beef production because of its reputation with consumers. Beef cattle fed a concentrate diet can be harvested at young ages which ensures a tender product. Additionally, the feeding of high concentrate diets not only increases marbling within beef, adding flavor and juiciness, but provides a different flavor profile which many consumers find appealing, especially when compared to grass-fed beef. Furthermore, the conventional beef production system is able to provide a highly palatable product by resulting in tender, flavorful and juicy beef products at a more practical price point than other production systems (Drouillard, 2018).

2.2.2 Grass-fed Production

While approximately 95% of all beef produced in the United States falls under conventional production methods in which cattle are grain finished, other production systems do exist and are even growing in demand. One such production system is grass fed beef (Felix, 2019) This up and coming production system was responsible for $480 million in supermarket sales during 2019, representing a 15% year over year growth (grass-fed beef, 2019). The USDA defined grass-fed beef in 2007 as “livestock whose lifetime diet must consist only of grass and forage, with the exception of milk consumed before weaning.” Additionally the American Grass-fed Association lays out guidelines to follow in order to achieve a grass fed beef certification including: eating forage from pasture or stored sources, no grain in the diet, receive no hormones or added antibiotics in the feed, are humanely raised and handled and are born in the United States. While the majority of conventional beef systems in the United States are pastoral based anyways, the complete exclusion of grain from the diet is a selling point for some consumers. Additionally, increased demand can be attributed to a shift in consumer trends towards locally raised food stuffs as well as management practices perceived to be both more animal welfare and environmentally friendly in addition to perceived health benefits (Sitienei, 2018).

2.2.2.1. Health Benefits of Conventional vs. Grass Fed

Cardiovascular disease, caused by abnormal blood lipid levels, is a leading cause of mortality in the United States. To combat this, health professionals have suggested lowering saturated and *trans*-fatty acids as well as cholesterol in the diet while increasing consumption of omega-3 fatty acids and conjugated linoleic acids. According to Crandell et al., 2018 The feeding of a grass-based diet to cattle has been shown to decrease "bad" fats and increase "good" fats in beef (Crandall, 2018). Conversely, a paper published by Smith et al, 2009 shows that grass feeding cattle decreases overall marbling and increases saturated fatty acids ("bad" fats) by milligram amounts while decreasing mono unsaturated fatty acids ("good" fats) by gram amounts, meaning that grass fed cattle may in fact be less healthy to consume than grain fed cattle (Smith, 2009). Furthermore, changing the fatty acid profile of beef also affects palatability of the final product (Crandall, 2018). In a flavor panel conducted by Duckett in 2014, all respondents reported that beef from grass-fed cattle lacked the unique "beefy" flavor of conventional beef (Duckett et al., 2014). Furthermore, in a study of 484 consumers, only 9.7% indicated that they were extremely satisfied with the grass-fed beef that they had consumed. Reasons for dissatisfaction included price, appearance, aroma, tenderness, and flavor. The main reason that these consumers purchased and consumed grass-fed beef were primarily attributed to the perceived health benefits followed by a desire to live a healthy lifestyle and concern for the humane treatment of animals (Crandall, 2018).

2.2.3 Organic Production

Another popular production practice in the United States is organic farming. In 2002, the United States Department of Agriculture (USDA) established rules governing organic certification programs and defined organic as "agricultural products that have been grown and processed according to specific standards of various state and private certification organizations." The USDA mandates that organically raised beef must be raised using organic management practices and be kept separate from conventionally raised counterparts; growth hormones and subtherapeutic antibiotic use is prohibited; animals must be fed 100% organically raised feedstuffs; and must have access to pasture. Organic beef production can take two forms; grain fed and grass-fed production. The former relies on organically produced grain, hay, and supplements to finish beef for market while the later relies strictly on organic grass and hay to finish cattle (Organic).

Because of the increased costs associated with organic farming, including higher production costs, marketing and an increased risk, the price of organically produced beef is significantly higher than its conventionally raised counterparts. In The first quarter of 2017 organic beef averaged $7.97 per pound, a 67% premium over conventional beef (Organic). Even with the steep prices, demand for organically raised beef products continues to grow, seeing double digit growth nearly every year since 1990 and now accounts for 4% of total U.S. food sales (Maguire, 2019). While the USDA does not maintain official records on organic beef sales, the Organic Trade Association estimated that in 2016 the sale of organic meat and poultry jumped by 17% and would reach total sales in excess of $1 billion in 2017. That being said, the sourcing of organic feedstuffs is a major hindrance of organic beef production within the United States (Drouillard, 2018).

2.3 Grid Pricing System

An estimated 63% of beef carcasses are purchased on a grid system, meaning quality grades and yield are assessed for each carcass and an individual price is assigned (Inspection & Grading, 2019). According to West Texas A&M Meat Scientist Ty Lawrence, in some parts of the country up to 90% of cattle are purchased on such a system (Bunting, 2015). Grid prices are determined by large scale packing plants and point of evaluation when accessing a dollar value of a beef carcasses begins by evaluating the Longissimus Dorsi at the 12th and 13th rib interface and is relayed in terms of quality grades as well as yield grades.

2.3.1 Quality Grades

Quality grades are used to estimate consumer eating experience accounting for palatability factors such as tenderness, juiciness, and flavor. Quality grades of prime, choice, select or standard apply to carcasses under 42 months of age, however, carcasses that show advanced maturity, such as cull cows, are only eligible for quality grades of Commercial, Utility, Cutter, and Canner (Figure 2). The current quality grade system is designed to reward beef carcasses for the amount of marbling and age of animal at time of slaughter. A beef animal younger than thirty months of age exhibiting a minimum of four percent marbling is often rewarded with a premium. In contrast, a beef animal revealing signs of advanced maturity, forty-two months of age or older, will be penalized by applying a discount per one hundred pounds. According to the USDA carcasses that grade commercial are often sold as ungraded or “store brand” meat while carcasses that grade utility, cutter, and canner are more often utilized for ground beef and processed products.

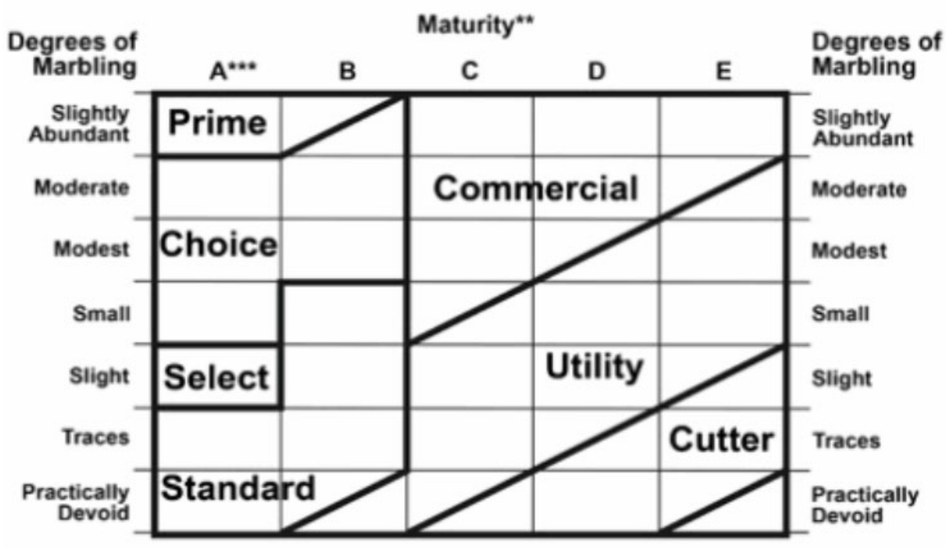

Figure 2. USDA quality grades determined by marbling score and maturity

In the United States cull cows fall into the nonfed beef category. This includes cows and bulls which are not eligible for the USDA quality grades of prime, choice, select or standard. Instead the USDA qualifies nonfed beef as commercial, utility, cutter, or canner; just as with fed beef these grades are based off maturity and marbling. That being said, most packers do not utilize the nonfed beef grading system and instead break cull cows up into three categories: white cows, boners and breakers, and cutters and canners. White cows refer to the highest quality cows, which have a significant amount of white external fat on the carcass; this is a result of being fed a high concentrate diet prior to slaughter. Breakers and boners are slightly leaner than white cows, but still exhibit good muscling and marbling. Cutters and canners have little to no external fat nor marbling and also lack the muscle present in the other two categories. These categories, unlike the USDA grades, consider marbling as well as lean percentage, commonly referred to as percentage of boneless, closely trimmed retail cuts (Blevins, 2009).

2.3.1.1 Age

When determining beef quality grades, maturity at time of harvest, along with marbling plays a large role in the overall quality grade. In the United States both dentition and skeletal maturity are utilized to determine approximate age of the animal at time of slaughter and is relayed in terms of maturity grades, ranging from A (an animal less than 30 months of age) to E (an animal over 96 months of age).

In the absence of birth records, dentition, or an animal's dental age based on number of erupted incisors, is one of the most accurate methods of determining chronological age. Cattle have three types of teeth: incisors, premolars and molars. The incisors are found in the rostral part of the mouth, and are only present on the mandible or lower jaw, premolars and molars, also known as cheek teeth are present in the caudal part of the mouth on both the mandible and maxilla. The incisors are the main teeth of interest when approximating age of beef carcasses; A maturity carcasses present two or fewer permanent incisors, indicating that they are younger than 30 months of age (Using Dentition).

In addition to dentition, skeletal ossification of cartilage is used to determine physiological age. As cattle age their cartilage begins to ossify, or turn to bone. In Bos Taurus cattle breeds (breeds such as Angus, Shorthorn and Hereford) ossification starts at the back of the animal. However, in Bos Indicus breeds of cattle (Brahma and other "humped" cattle) ossification occurs in the reverse order, meaning these breeds cartilage ossifies at the head and progresses back towards the tail of the animal as it ages. The spinal process is the area of interest when determining percent ossification and subsequently approximate physiological age. The spinal process consists of five sections: the coccygeal, sacral, lumbar, thoracic and cervical vertebrae. During grading, trained evaluators will assess the amount of ossification of the thoracic buttons at the 12^{th} and 13^{th} rib interface, where the carcass is ribbed for quality grading. An A maturity carcass will present less than ten percent ossification, B maturity less than thirty-five percent ossification, C maturity less than seventy percent ossification, D maturity less than ninety percent ossification, and E maturity greater than ninety percent ossification; each maturity level is assessed on a 00 – 100 scale (Beef Quality).

Carcasses that are less than 30 months of age according to dentition and that show skeletal ossification less than D00 are deemed as A maturity, excluding any quality defects such as dark cutting carcasses. Therefore, these animals are eligible for USDA quality grades of Prime, Choice, Select and Standard. Conversely, carcasses deemed to be less than 30 months of age according to dentition, but with ossification greater than D00 are only eligible for USDA quality grades of Commercial, Utility, Cutter and Canner. If a carcass is determined to be over 30 months of age according to dentition then this rule no longer applies; maturity is assessed using ossification percentages. This is important in estimating consumer eating experience; as an animal ages overall palatability decrease (Officials Handbook, 2019).

Age of animals at time of slaughter is not only important in determining pricing and consumer eating experience, but also plays a role in food safety and determining risk factors for bovine spongiform encephalopathy (BSE), commonly referred to as mad cow disease (All About BSE). BSE is a progressive neurologic disease in cattle, meaning it affects cattle's brain and spinal cord and worsens as the disease progresses. BSE is caused by abnormal prions, which arise from consumption of animal biproducts already contaminated with BSE (All About BSE). The incubation time is anywhere from four to six years, during which the cow shows no symptoms. As symptoms start to occur, cows become uncoordinated, have trouble walking and getting up, and become nervous and violent before eventually dying. Because of the increased age of cattle exhibiting BSE, an age of 30 months has been established as the point at which specific risk materials (including the brain and spinal column) must be removed from cattle before sale and consumption (All About BSE).

2.3.2 Yield Grades

When marketing cull cows an emphasis is often placed on yield and dressing percentage as opposed to quality and cows are often purchased based on live body condition scores (Inspection & Grading, 2019). Yield grades ranging from 1 to 5 determine the amount of useable lean meat, or sellable product on a carcass. A yield grade of 1 represents a lean and heavily muscled carcass and 5 excessive fat and light muscling. As yield grade increases, so to does fat percentage of a carcass, meaning that while sellable product is decreased, quality grade should be increased. Therefore, it is important for producers to balance a need for a high percentage of sellable product as well as a desire for increased quality grades. Yield grades are assessed by determining backfat thickness, ribeye size, kidney, pelvic, and heart fat percentage, and hot carcass weight of beef carcasses and are reported in tenths (Beef Cattle Grading).

According to the 2016 National Beef Quality Audit the average yield grade was 3.1, an increase from 2.9 during the 2011 quality audit. This increase in yield grade is the result of an increase in hot carcass weight, backfat thickness and ribeye area in addition to an increase in quality grade. The frequency of yield grades 3, 4 and 5 also increased from 2011 to 2016 with the largest percentage being yield grade 3 at 29.9% (Beef Quality Assurance, 2016). The 2017 cow and bull audit, a part of the National Beef Quality Audit, also showed a large increase in yield grades of cows, from 2.6 in 2007 to 3.1 in 2017 (National Cow/Bull Audit, 2017).

2.4 Body Condition Scores

Body condition scores (BCS) are a visual number system ranging from 1 (extremely thin) to 9 (very obese) used to describe the relative fatness or body condition of a cow (Rasby et.al. 2007). Figure 3 shows examples of body condition scores of 1, 5 and 9, respectively. Cattle store energy in the form of fat that functions as an insulator from severe cold weather conditions and as a protector of internal organs. Body condition scores play a role in determining value at marketing and can be useful in culling decisions due to their correlation to reproductive and productive efficiency. The main reason for using this subjective scale is the ease and low cost of implementation. With some practice and a little training, producers can consistently call BCS scores within their own herds and use this as a tool for culling (Broring, N., et al.).

2.4.1 Optimal Body Condition

Because BCS is a visual representation of fatness of an animal it is no surprise that carcass weight increases linearly with BCS scores. Furthermore, BCS scores of 4, 5 and 6 while optimizing potential reproductive benefits also optimizes economic benefits for both the producer and beef packers when selling cull cows (Apple, 1999). In a study conducted by J.K. Apple in 1999, The highest total carcass and live animal values were attributed to BCS 6 cull cows. Because of this, the slaughter cow industry separates cattle into end use categories, grouped together by BCS scores. Poorly conditioned cows (BCS of 1, 2, or 3) are termed boners, intermediately conditioned cows (BCS of 4, 5, or 6) are termed boning utility, and fat cows (BCS of 7, 8, or 9) are termed breakers or sometimes breaking utility. Because of increased demand from the food service industry more and more whole muscle cuts are being salvaged from cull cattle in every category. However, those cows with BCS of 1, 2, or 3 are most commonly utilized for ground products, meaning their carcasses will command the least money (Apple et al., 1999).

Figure 3. Examples of BCS of 1(left); 5 (middle); and 9 (right)

2.5 Premiums and Discounts

Cattle in the United States are valued differently depending on how they are purchased, and their potential end uses. A majority of the fed beef in the US today is bought on a grid system meaning yield and quality are assessed postmortem and a price for each carcass is assigned. In the case of cull cows and other nonfed beef, prices are typically assigned to the live animal based on body condition score. However, postmortem, carcasses may be assigned a premium or a discount. Premiums are increases in value to a carcass base price assigned to carcasses due to desirable traits. For nonfed beef a common premium is the white-cow program; this is assigned to carcasses with white external fat. Discounts on the other hand are deducted from the price of the carcass for negative characteristics. Cull cows are regularly discounted as their advanced age makes them more susceptible to negative carcass characteristics. These can include advanced maturity, yellow fat, light carcass weights, and bruises.

2.5.1 White Cow Program

Cattle fed a high-energy diet for an extended period often result in external fat white in color, a brighter cherry red colored lean, greater levels of marbling, and improved palatability. In contrast, cattle fed a low-energy diet, primarily consisting of forage, produce lean light muscled carcasses, yellow in external fat color, lower levels of marbling, and darker colored lean. As a result, most packers do not use a premium system based on quality grades, instead they utilize a program referred to as "White-Cow" program. The white-cow program involves applying a premium to cows carrying white fat, simply for its desirable appearance, allowing it to be sold to consumers in a fresh form. On April 02, 2020 carcasses applicable for the white cow program averaged $137.18 per hundred pounds, a nearly $3.00 increase compared to any other nonfed beef category (Daily Prior Day Direct Cow and Bull Negotiated Report). During the 2016 cow and bull audit yellow external fat accounted for discounts of -$12.47 per hundred pounds

(NCBA, 2017). Such a hefty discount can be attributed to the fact that most consumers view yellow fat as being caused by spoilage, rather than understanding it is related to the vitamin A precursors in the fat being from a high forage diet (Beef Cattle Extension, 2019).

2.5.2 Beef Quality Assurance

The introduction of Beef Quality Assurance (BQA) has brought about increased awareness of animal welfare and improved management and subsequent meat quality of cattle, especially in the fed beef sector. These changes have trickled down to the nonfed beef sector as well, but more slowly. Significant progress was shown in adherence to BQA practices for cows and bulls between the 1999 and 2007 cow and bull audits. However due to the increased chance of negative quality attributes in older cull animals, special care should be taken when working with nonfed beef animals to minimize negative consequences, discounts. Bowling et al. (2008) summarized the most common problems in the nonfed beef sector that need to be addressed through improved BQA practices. These include food safety, animal welfare and handling, poor condition and nutrition, antibiotic residues, bruises, hide damage, lameness and soundness issues, condemnation rates and downer cattle, and injection site lesions (Blevins, 2009).

Since 2018, some large scale beef packers began to require BQA certification as a requirement for someone wanting to sell their cattle. Tyson Foods was the first to implement this change. As of January 2020, Transportation Quality Assurance became mandatory by some packers in the United States holding drivers and handlers of beef cattle accountable.

2.5.3 Bruises

During the 2016 Cow and Bull Quality Audit 4,262 cow carcasses were evaluated for bruising by trained personal. Results of this audit concluded that 64.1% of all cow carcasses had bruising. While most of these cases were listed as minimal, meaning less than one pound of surface trim was conducted nearly 50% of the bruises still fell within the major and critical ranges meaning greater than one pound of surface trim occurred. Additionally, 1.4% of the bruises were listed as extreme, indicating that an entire primal was lost. The greatest percentage of these bruises occurred in the rounds and sirloins of cow carcasses; areas of great importance and value when trying to market whole muscle cuts. Overall, bruises resulted in lost value of -$3.41 per hundred pounds for the beef industry (NCBA, 2017).

2.5.4 Other Discounts

Other major discounts seen during the 2016 cow and bull audit included injection-site lesions, dark cutters, and inadequate muscling. Together these discounts accounted for a loss of -$33.04 per hundred pounds with the largest percentage of that contributed to inadequate muscling. Overall, lost income from quality defects leading to discounts have increased substantially from the first quality audit conducted in 1994 to the 2016 audit. This steep increase can be attributed to the increase in value for virtually all products fabricated from cows and bulls (NCBS, 2017).

Of special concern in the nonfed beef industry are dark cutting carcasses. A dark cutter refers to a carcass whose meat fails to turn the normal bright cherry red color associated with beef. Instead it is dark red, even purplish in color. It is most often associated with preslaughter stress which leads to a glycogen depletion. Glycogen is a carbohydrate energy source used by muscle, and when depleted normal postmortem anaerobic metabolism cannot occur. This leads to an increased pH compared to normal meat which subsequently causes myoglobin and water to be held in the meat leading to the characteristic dark color (McKinnon, 1998). For the week of March 30, 2020 an average discount of $33.93 per hundred weight was applied to carcasses exhibiting dark cutting characteristics (Premiums and Discounts).

2.6 The Effects of Covid-19 on Cattle Prices

Covid-19, officially SARS-CoV-2, is a member of the coronavirus family which is common in many animal species and people alike. It is a betacoronavirus, similar to SARS and MERS all three of which originated in bats. The Covid-19 outbreak began in China at the end of 2019 and has spread throughout the world ever since, officially being declared a pandemic on March 11, 2020 (Covid-19). As of June 24th, 2020, there were 2,336,615 confirmed cases of Covid-19 in the United States and 121,117 deaths due to the virus (Cases and Deaths in the U.S., 2020). Meat and poultry packing plants have been a hotspot of Covid-19 infection, not because of transmission through the meat products, but because of the nature of the work; close distance between workers on lines, for extended periods of time, the potential sharing of tools and surfaces, and because of the large workforce the increased possibility of ridesharing all play a part in spreading the virus (Worker Safety and Support, 2020).

These rampant outbreaks of Covid-19 in the meat packing sector lead to slowdowns in efficiency and production by mid-April 2020. Derrell Peel, an extension economist at Oklahoma State University, explained that “The U.S. meat industry faces unprecedented threats as COVID-19 sweeps through labor forces at meat processing facilities nationwide.” Because of this decrease in production the beef industry in the United States has been sluggish. Feedlots have been forced to slow fed cattle finishing and have switched instead to maintenance diets to hold animals that cannot be shipped to slaughter. Cull cows and bulls have been similarly affected by the outbreak, causing most to be maintained on drylots or turned back to pasture to await reopening of plants back to full capacity. Luckily, cattle, unlike pork and poultry have greater flexibility in timing and many animals are being held on pasture. However, the increased demand for hook space in packing plants has led to a decline in prices for producers (Wes Ishmael, 2020). According to Glynn Tonsor, a research and extension agricultural economics professor and extension livestock market specialist with Kansas State University, cattle prices have fallen by 26% from $127.96 per hundredweight in January 2020 to $94.28 per hundredweight in April 2020 in response to slowdowns and closures from Covid-19 (Livestock Prices Drop). The total impact of the coronavirus on the beef industry as of April 2020 was estimated to be a loss of nearly $13.6 billion (Economic Damages).

Additionally, Kenny Burdine, a food and agriculture economist at the University of Kentucky stated that cattle prices, including cull cow and bull prices, are swinging up and down amid the coronavirus outbreak. He stated, “I can tell you what’s going on right now, but by next week, things could be very different.” That being said the pandemic has affected those cattle closest to slaughter including fed beef, cull cows and bulls meaning that prices have not been good for producers looking to market their culled animals;

prices for cull cows have dropped nearly $17.00 per hundredweight from March 2020 to April 2020, with futures still being very uncertain (Nielson, 2020).

2.7 Sensory Attributes

Pricing of cattle is all based on the acceptability and palatability if the end product. As cattle age, palatability decreases which negatively impacts the consumers eating experience. Palatability is defined by tenderness, flavor, and juiciness. Several studies have shown a negative linear trend in tenderness and flavor with increased age (Romans, et al., 1965; Walter, et al., 1968; Berry et al., 1974). Studies repeatedly explain that the amount of heat-soluble collagen in beef decreases as animals age, causing toughening (Goll, 1964; Hillet. Al., 1966; and Herring et.al. 1974). When compared to grain fed cattle, cows are often lean, light muscled, and low in marbling; therefore, meat products originating from cow carcasses result in lower juiciness levels as well as greater toughness. As a result, much of a cow carcass ends up as ground-beef products, usually blended with fat trimmings from grain fed beef carcasses and seasonings.

Even though the majority of cow carcasses are destined as ground beef products, auditors involved in the 2007 Cow/Bull audit reported that all facilities audited in the study were selling whole muscle cuts such as the rib, loin, round, and chuck primarily destined for foodservice application (NCBA, 2007). In non-tabular form, 51% of a cow was marketed as wholesale cuts intended as steaks and roasts. This would be an incentive for beef producers to improve yield and quality characteristics in cull-cows.

Studies have shown that feeding mature cull cattle prior to slaughter increases palatability of whole muscle cuts, resulting in increased consumer appeal and the possibility of greater profits for both producers and processors. In a study conducted by Gredell et al. (2018) cattle being identified as mature fed were more acceptable in almost every sensory category. Mature fed carcasses were perceived to be more tender than mature unfed carcasses and had lower Warner Bratzler Shear Force values than mature unfed carcasses. In this study Mature fed carcasses were consistently more tender than mature unfed carcasses in both treatment groups (USDA slight and USDA traces/practically devoid). The slight mature fed carcasses had a tenderness score of 67.52 while the mature unfed carcasses had a score of 58.66 as evaluated by a trained sensory panel. The traces/practically devoid treatment group had tenderness scores of 61.24 and 56.01 respectively for mature fed and mature unfed carcasses. There were no significant differences for WBSF between mature fed cattle and young fed cattle; the former had an average WBSF of 3.24Kg and 3.47Kg depending on treatment group while the later had and average WBSF of 3.25Kg and 3.96Kg. Both of these differed significantly from the mature unfed group with average WBSF values of 4.34Kg and 4.59Kg. Additionally, no differences in off flavor intensity were discovered between mature cattle and young fed beef. This data provides strong support for the feeding of cull cattle to increase sensory attributes and increase profits for an undervalued sector of the beef industry (Gredell, 2018).

2.8 End uses of Cull Cow Meat

While some cull cows are still destined for ground beef production, in an attempt to boost profits, slaughter plants are now fabricating primal and sub primal cuts from cull cows in the boning utility, breaking utility and commercial cow groups. Many of these cuts are coming from the round, loin and rib including sirloins, ribeye's, and tenderloins. Outlets such as fast-food venues, airlines, family restaurants and even grocery stores are beginning to purchase nonfed beef cuts to fill their beef needs while maintaining a reasonable price (Blevins, 2009)

According to the Western Producer, up to 40% of a cull cow carcass is destined for whole muscle cuts. Many of these cuts will come from the middle meats, the loin and rib where sirloin, strip and ribeye steaks come from. However, a significant amount of whole muscle cuts are being utilized from the round and the brisket. These cuts are often destined for further processing into items such as deli meats. In fact, some of these cuts from the round can be easier to market from nonfed beef than from the fed beef industry; although they may be tougher, they are a leaner product, perfect for further processing (Duckworth, 2015).

It is likely that the demand for beef from cull cattle will continue to increase. According to the Ag Web Farm Journal the United States cow herd was estimated to be 31.3 million head in January of 2020 (peel, 2020). This is down from the 33.6 million head herd in the U.S. in the year 2000 (Insights, 2020). Additionally, the price of beef has increased by approximately 20% over the past 20 years. With the national herd size down by over 2 million head and the steady increase in price of beef over the past 20 years cull cows are more valuable now than ever. They are going to continue to be an integral source of moderately priced beef in the United States and worldwide (ERS Charts of Note).

2.9 Genetics

Genes are made up of individual DNA bases and are the basic functional units of heredity. They serve as instructions for the body, some of which regulate the production of proteins and range in size from several hundred to several million DNA bases. Genes are present in sets of two, one copy inherited from each parent and while many genes are the same across an entire population, a small subset can present slight variations which eventually lead to differences in phenotypes (What is a gene?, 2019).

2.9.1 beta-carotene-15',15'-oxygenase in Cattle

beta-carotene-15',15'-oxygenas, or *BCO1*, is responsible for the cleavage of beta-carotene at its central double bond to create two molecules of all-trans-retinal, the aldehyde form of vitamin A (UniProt). Uptake of beta-carotene occurs in in the small intestine, and cleavage by *BCO1* is carried out in intestinal enterocytes after which the retynl esters are stored in the liver and adipose tissue (Lyn). Alterations in this gene in mice and humans has led to increased beat-carotene concentration in fat deposits, resulting in increased yellow color scores on affected subjects (Harrison, 2018). Johannes von Lintig found that *BCO1* deficiency stopped all production of vitamin A from dietary beta-carotene in mice (Harrison, 2018). Additionally, Lindqvist et al. found that a single genotype polymorphism (SNPs) in the *BCO1* gene resulted in carotenemia, an orange skin color due to excess beta-carotene being stored in subcutaneous fat, of human patients. This is due to the SNPs negative influence on the ability of *BCO1* to cleave dietary beat-carotene and produce vitamin A. Therefore a mutation in the *BCO1* in cattle would likely result in greatly increased beat-carotene concentrations in adipose tissue of affected animals, leading to increased visual color scores (Harrison, 2018).

2.9.2 beta-carotene-9',10'-oxygenase in Cattle

Genes in certain breeds of cattle, such as Jersey cattle, can cause cull cows to have varying degrees of yellowness in subcutaneous adipose tissue, meaning they are more susceptible to beta-carotene buildup. One such gene that varies between cattle is the beta-carotene-9',10'-oxygenase or *BCO2* (Tian, 2010). This gene plays a critical role in the eccentric cleavage of beta-carotene and therefore is involved in the control of adipose color in cattle (Tian, 2010). The *BCO2* cleaves beta-carotene at the 9-',- 10-' double bond creating beta-ionone and beta-apo-10'-carotenal as byproducts. Beta-apo-10'-carotenal can be further metabolized to produce vitamin A (Tian, 2010). Tian et al.,(2019) found that a single nucleotide base change results in a tryptophan insertion, causing significant changes in the subcutaneous adipose tissue color of affected animals (Tian, 2010). Therefore, while feeding cull cows may have an effect on converting yellow subcutaneous fat to white, breed and genetic differences play a large role in carcass quality from not only an adipose tissue standpoint, but in terms of all other carcass quality characteristics as well (Tian, 2010).

Additionally, studies conducted in cattle, sheep, chickens, and mice have shown that *BCO2* mutations cause an imbalance leading to hepatic fat and carotenoid accumulation in the mitochondria (where BCO2 is localized) which impairs respiration. The buildup of carotenoids in hepatic mitochondria was shown to subsequently reduce ADP-dependent respiration rates and is associated with cell signaling pathways related to oxidative stress. Thus, Wu et al., 2016, have suggested that the BCO2 gene is responsible for regulating and preventing harmful effects caused by excess carotenoids, including oxidative stress, macular degeneration, and anemia and hepatic steatosis (Wu, 2016).

2.10 Feed Types

Feeding a high concentrate diet results in improved final weight, dressing percentage, quality grade, and muscle mass in cull cows. However, a common practice in many cow calf operations is to feed a low energy diet, consisting mainly of forages to cows. This results in culled cows being light muscled with little external fat and therefore small in size. Subsequently this small size resulting from a forage-based diet leads to decreased sellable product.

While age, gender, and breed of cattle are internal contributors to external fat color in beef carcasses, Dunne et al. (2008) indicated that diet was the most important external factor that was greatly dependent on duration of feeding. “Cattle produced under extensive grass-based production systems generally have carcass fat which is more yellow than their intensively-reared, concentrate-fed counterparts this is caused by carotenoids from green forage” (Dunne, 2008).

2.10.1 Feedlot Diets

The feeding of a high concentrate diet, such as that found in a fed beef feedlot, has been shown to improve yield and quality characteristics as well as fat color in culled cows. A typical feedlot diet consists of approximately 86% grain, 10% roughage and 4% vitamin and mineral additives (Forster, 2011). While types and sources of grain vary throughout the country corn, barley, oats, and wheat as well as grain byproducts such as distillers' grains, soybean meal, corn screenings and wheat midlings are commonly used (Funnell, 2019). All of these grains and grain byproducts are lower in vitamin A precursors than forage, while providing an increased plain of nutrition. The reduced vitamin A content specifically increases intramuscular fat, while other dietary elements increase subcutaneous fat, and muscle mass (Pickworth et al., 2012)

2.10.2 Volatile Fatty Acids

The reason for the use of a high-energy diet to increase marbling is the type of energy substrate that intramuscular fat cells absorb and utilize. A study conducted by Smith and Crouse (1984) showed that acetate provides 70 to 80% of the acetyl units for back fat, but only 10 to 25% of the acetyl units for intramuscular fat (marbling). Also, propionate provides 50 to 70% of the acetyl units for intramuscular fat, but only 1 to 10% of the acetyl units for subcutaneous fat. The remaining 20-40% of acetyl units for the intramuscular fat come from glucose absorbed in the small intestine (Smith and Crouse, 1984).The reason that these parameters are related to the animal's diet is that the major volatile fatty acid (VFA) produced by the rumen microorganisms are acetate, propionate, and butyrate. These VFA's are the main products of the digestion of feed by bacteria in the rumen and serve as the main precursors for both glucose and fat in ruminants. On a forage-based diet, the proportion of VFA would approximate 65-70% acetate, 15-25% propionate, and 5-10% butyrate. Feeding diets high in readily fermentable carbohydrates (starch) increases the proportion of the propionate produced through ruminal fermentation, and results in VFA proportions of approximately 50-60% acetate, 35-45% propionate, and 5-10% butyrate (Smith and Crouse, 1984).

2.10.3 Carotenoids in Common Feedstuffs

Pickworth et al. (2012) quantified provitamin A compounds in common cattle feedstuffs collected from across the country in an attempt to better understand vitamin A supplementation requirements for beef cattle. The study looked at 18 common feedstuffs including: alfalfa hay, fescue hay, orchard grass hay, fescue pasture, wheat and rye grass hay, wheat straw, whole shell corn, steam flaked corn, cracked corn, high moisture corn, soybean meal, soybean hulls, wet distillers grains, dry distillers grains, corn syrup, and corn gluten meal. Results from this study indicated that fresh fescue pasture contained by far the highest amount of b-carotene at 9.9 mg/100g DM followed by corn silage at 1.7 mg/100g DM. Dried forages, while still containing significant levels of provitamin A had significantly less than fresh pasture sources; alfalfa, fescue and orchard grass hay contained 0.73 mg/100g DM, 0.73 mg/100g DM and 0.77 mg/100g DM, respectively. In contrast to hay, wheat straw only contained 0.015 mg/100g Dm. Wet distillers grains contained 0.17 mg/100g DM whereas dried distillers' grains contained 0.096 mg/100g DM. All corn sampled (whole shell, steam flaked, cracked and high moisture) ranged from 0.030 mg/100g DM to 0.072 mg/100g DM. Soybean meal and soybean hulls contained 0.013 mg/100g DM and 0.009 mg/100g DM, respectively. Results of this study point to feed sources such as corn, soybean meal and hulls, and wheat straw as potential feedstuffs of interest when formulating a diet low in vitamin A (Pickworth et al., 2012).

2.11 Vitamin A

Vitamin A is an important fat soluble nutrient responsible for the maintenance of healthy vision, growth, cell division and reproduction in cattle and people alike. Essential vitamins are compounds that must be obtained from the diet for proper health and growth (Beta-Carotene, 2019). In cattle especially, vitamin A is responsible for maintaining gut health, ensuring adequate spermatogenesis in bulls, good conception rates in cows, and proper growth of calves (Stalker, 2015). Deficiencies of vitamin A lead to loss of appetite, reduced feed efficiency and swelling of limbs in affected animals. However, this is not typically a problem in cull cows, as forages are a great source of vitamin A precursors such as beta-carotene (Stalker, 2015).

2.11.1 Carotenoids

Carotenoids, including beta-carotene, are isoprenoid compounds that contain up to 15 conjugated double bonds and are synthesized by plants, fungi, and bacteria. There are approximately 1,200 known carotenoids (Carotenoid Database). Ten of which are present in significant amounts in plasma, the liver and adipose tissue (Lintig, 2012). Two categories of carotenoids are carotenes and xanthophylls. Carotenes, such as alpha- and beta- carotene, are nonoxygenated, whereas xanthophylls, such as beta-cryptoxanthin and lutein, are oxygenated. Both classes absorb violet and blue green light, reflecting back red, orange, and yellow hues (Koon, 2018).

Beta-carotene is arguably the best natural source of provitamin A because when cleaved, it produces two molecules of vitamin A. In contrast, other provitamin A carotenoids (e.g., beta-cryptoxanthin, alpha-carotene) only provide one molecule of vitamin A. Beta-carotene is found as a pigment in green plants, which makes up a significant portion of a cow's diet, and can be easily converted into vitamin A in the ruminant (Stalker, 2015). Carotenoids serve two important functions – as an antioxidant and blue light filter to maintain eyesight (Lintig, 2012). When consumed regularly, beta-carotene and other select carotenoids impart a yellow pigmentation to adipose tissue (Morgan, 1969). However, evidence in cattle has shown that beta-carotene is the main pigment responsible for causing the yellow appearance in fat (Morgan, 1969).

2.11.2 Provitamin A to Vitamin A

Once absorbed, provitamin A, carotenoids, are converted into retinal via beta-carotene-15,15'-oxygenase 1 (BCO1) (Lindqvist, 2004). Retinal (the aldehyde form of vitamin A) can then either be reduced to retinol (the hydroxyl form of vitamin A) or oxidized into retinoic acid (the carboxylic form of vitamin A) (Harrison, 2018). Once converted, vitamin A is stored as retinyl esters primarily in the liver but also in adipose tissue (up to 20% of total vitamin A concentration in cattle) (Pickworth, 2009). Work by McGillivray et al. (1951) in sheep, showed that the microflora present in the rumen had little effect on decreasing carotenoid concentration after consumption, stating that carotenoid concentration in trial pastures and the abomasum were very similar. McGillivray suggests that absorption of beta-carotene may occur mostly in the small intestine, followed by degradation of remaining carotenoids in the colon and rectum. Interestingly though, all sheep in the study excreted more carotenoids than ingested and this increase in carotenoids was noted in the ileum and caecum. They attributed this increase to either a partial degradation of lignin, a failure in their extraction method, or the production of carotenes by microflora in these regions (McGillivray, 1951).

2.11.3 Vitamin A and Consumer Appeal

Gorocica et al. (2007) reported reduced intramuscular fat (marbling) in beef cattle with increased provitamin A and vitamin A consumption. Reduced marbling would therefore be expected to be observed in cull cows fed a forage-based diet high in provitamin A, subsequently reducing palatability. The yellow color of the external fat would also result in a discount in carcass price, simply for its appearance (Figure 4). Therefore, feeding grain to cows for a relatively short period of time prior to slaughter may improve the color of both fat and lean, and enhance the size and shape of whole-muscle cuts. Many studies suggest that feeding a high energy diet for 56 –105 days can increase fat deposition and red meat yield due to protein synthesis.

Figure 4. Carcasses representing cow and fed beef illustrating yellow versus white fat

2.12 Adipose Tissue

Adipose tissue, commonly known as subcutaneous fat or external fat, consists of loose connective tissue composed of adipocytes. Its main role is to store energy, while also providing cushion and insulation to the body. A significant amount of fat deposits subcutaneously (below the skin), however, significant amounts also accumulate around internal organs, between muscles, and even intramuscularly (Adipose tissue).

2.12.1 Fat Deposition

In cattle (ruminants) the order of fat deposition begins with mesenteric (around the intestine) and perinephric (internal fat or kidney, pelvic and heart fat - KPH), intermuscular (seam fat), subcutaneous (external fat) and intramuscular (marbling) (Smith, S. B 2009). During times of stress, however, the utilization of fat deposits occurs in the opposite order; intramuscular fat deposits are the first to be utilized (Smith, S. B 2009).

2.12.2 Intramuscular Fat

Because marbling is the major driver of beef quality and subsequent beef prices in the United States, the accumulation of intramuscular fat deposits is of great importance to both the fed and nonfed beef industries. Intramuscular fat is unique in that it is deposited within perimysial connective tissue alongside myofibers. Furthermore, it has been well documented that glucose provides a large proportion of acytl units to fatty acid biosynthesis in intramuscular fat. Therefore, it is no surprise that the feeding of a grain-based diet stimulates adipogenesis whereas a forage-based diet suppresses the development of adipose tissue (Smith, S. B 2009).

2.12.2.1 Effects of Vitamin A on Intramuscular Fat

A diet high in provitamin A and vitamin A, has also been shown to suppress adipocyte differentiation in both mice and cattle due to its repressive action on peroxisome proliferator-activated receptor gamma (PPAR-γ) (Castillo, G. 1999). Retinoic acid is an agonist of the retinoid X receptor (RXR), which when bound heterodimerizes with PPAR-γ to promote the transcription of genes involved in adipogenesis (Castillo, G. 1999). Therefore, it is believed that the main effects of vitamin A in the diet is the suppression of adipocyte differentiation which negatively correlates with marbling scores in cattle. It is a common practice in Japan, and an increased area of study in the United States to feed vitamin A deficient diets to fed beef to increase marbling scores. This practice also includes restriction of dietary provitamin A, which accumulates in the liver, blood, and adipose tissue of cattle when fed at high levels (Smith, S. B 2009). Research conducted by Gorocica-Buenfil et al., (2007) showed that serum retinol levels decreased significantly in angus cross steers fed low provitamin A and vitamin A diets compared to those fed a high vitamin A diet for 112 days. However, this trend was not seen on day 145 when the steers were harvested, indicating that an increasing length of time on a vitamin A restricted diet may have a diminishing effect. On day 145 there was a significant difference (p=0.02) between the low and high vitamin A treatments on marbling. Interestingly, cell number and size did not significantly differ in the intramuscular fat deposits between treatments (Gorocica-Buenfil, 2007).

2.12.3 Beef Adipose Color Scores

The American Meat Science Association (AMSA) provides a standardized color score for beef adipose tissue color for use in trained and consumer surveys. The AMSA describes fat color as: 1 – white, 2 – creamy white, 3 – slightly yellow, 4 – moderately yellow, 5 – yellow. Carcasses of main concern fall within the 3-5 range indicating high levels of b-carotene buildup in fat. However, there is not a standardized pictorial guide as of yet to compare fat samples too. Therefore, determination of color scores and subsequent application of premiums and discounts to carcasses is up to the discretion of graders at individual plants and varies widely between plants (Hunt, M. 2012).

2.13 Conclusion

To improve cull cow meat characteristics some practices might need to be followed in order to increase muscularity and fat deposition as well as decrease yellow fat color. To improve muscularity and fat deposition high energy and high protein diets need to be fed. Previous studies (Gorocica-Buenfil et al., 2007; Pickworth et al, 2011; Pickworth et al. 2012) have shown a decrease in subcutaneous fat retinol concentrations in Angus cross steers when fed a low vitamin A diet. However, we are not aware of any study that has formulated diets for cull cows, with a special interest in converting yellow to white fat. The capturing of the exact point when fat yellow in color begins to convert to white fat, correlated with feed type and time on feed, is nonexistent.

Chapter 3 - Materials and Methods

3.1 Animal Selection

Cull-cows used for this study were selected by the managing team at two Ohio Agricultural Research and Development Center (OARDC) beef facilities. Cows were checked every October for pregnancy, those that were culled were utilized in the current study.

3.2 Animals and Feed

Eighty-six Angus crossbreed cull cows were used in two consecutive years with a feeding time of 56 d per year under a clean bunk management (IACUC protocol # 2017A00000083). Cows were blocked by body condition score then divided into two feed treatments: 1-low vitamin A concentration (LVA) and 2 -high vitamin A concentration (HVA). The LVA diet was formulated using whole shelled corn, soybean hulls, soybean meal and a mineral-vitamin supplement. The HVA diet was formulated using whole shelled corn, fescue hay, DDGS and a mineral-vitamin supplement. Ingredients chosen were determined by Vitamin A levels. Soybean hulls were used as a forage source that contains vitamin A equivalents of 44 UI/Kg of dry matter (DM), compared to fescue hay, the forage source of the HVA that contains 2900 UI/Kg of DM. As a protein source soybean meal has a vitamin A precursor concentration of 59 UI/Kg of DM, compared with 800 UI/Kg of DM in the DDGS (Pickworth et al., 2012).

3.3 Cow Evaluation Factors

Cows were weighed at the start of the trial, day zero (0), as well as on days 14, 28, 42 and 56. On days 0, 14, 28, 42 and 56 a subcutaneous fat biopsy on the rump was conducted. The subcutaneous adipose tissue biopsy was used to evaluate color using a yellow color scoring system.

3.3.1 Weight and Body Condition Score

On days 0, 14, 28, 42 and 56 cows were weighed prior to fat biopsy's being conducted. Cows were weighed prior to feeding without restriction to feed and water. Body condition scores were also recorded, prior to weight and fat biopsy being conducted, after cows were released from the chute. Body condition was recorded on a 1 – 9 scale, with 1 being extremely thin and 9 being obese.

3.3.2 Fat Biopsy

On biopsy days 0, 14, 28, 42 and 56 an area of 5x5 centimeters was designated close to the rump area by the base of the tail and shaved. Alternating sides of the animal were used. The area was scrubbed, then 5ml of lidocaine was used locally. Once the area lost sensitivity, a 5 centimeter cut with a sterile scalpel was made to remove the subcutaneous adipose tissue for color evaluation, a 2x2x2 centimeter sample of adipose was removed. Upon removal of external fat, fat samples were placed in a plastic bag under refrigerated conditions (dry ice) and transported back to the Department of Animal Sciences at The Ohio State University. Biopsies were conducted by a veterinarian.

3.3.3 Color Visual Evaluation

During transport, fat samples were given time to harden, to help with the onset of fat color. Visual evaluation of fat color was conducted by Animal Science personnel who used a 1 to 5 number scale published by the American Meat Science Association (AMSA, 2012). Fat color scale ranged from 1 –5; color descriptors include: 1-white; 2 –creamy white; 3 –slightly yellow; 4 –moderately yellow; and 5 –yellow.

3.3.4 Beef Carcass Evaluation and Analysis

Upon day 56, cows were sent to one of three locations for slaughter. Upon forty-eight hours postmortem, carcasses were evaluated for: yield (external fat, ribeye size, internal fat percent; and hot carcass weight) and quality grades (marbling score and skeletal maturity) evaluated at the $12^{th}/13^{th}$ rib interface by trained Ohio State personnel; USDA Marbling cards were used as a point of reference for marbling scores. In addition, an objective color score of external fat was recorded using a colorimeter for L-values (lightness), a* (redness), and b* (yellowness), calibrated against a white tile (Konica Minolta Colorimeter CR-410, 50mm aperture, D65 illuminant; Minolta Company, Ramsey, NJ). Additionally, 10.16cm beef striploin samples were removed from carcasses, vacuum packaged and stored at -80º C for further analysis.

3.4 Muscle Analysis

Beef strip loins were sliced into 2.54cm slices for the following analysis: muscle pH and warner-Bratzler shear force. The main area of interest in analysis was the *longissimus dorsi* lumborum.

3.4.1 Muscle pH

Meat samples were first frozen in liquid nitrogen and then ground into a fine powder before two aliquots of 100mg apiece were placed in 1.5ml plastic tubes. Muscle pH was then performed according Bendall's *Postmortem Changes in Muscle*. The two 100mg aliquots of powdered muscle sample were homogenized it into an ice-cold measurement buffer (5 mM iodoacetic acid and 150 mMKCl (pH 7.0)) at a 1:8 ratio. The muscle and buffer mixtures were warmed to 25º C, centrifuged, and measured with a pH probe (Bendall, 1973). Samples were measured in duplicate.

3.4.2 Warner-Bratzler Shear Force–Tenderness

Tenderness of excised strip steaks was measured using Warner Bratzler Shear Force testing in accordance with a protocol from Caine et al. (2003). One 2.54 cm steak from each carcass was thawed to 4º C overnight before being cooked to an internal temperature of 71º C using a clamshell grill. Temperature was measured using a thermocouple placed in the geometric center of each steak. After cooling steaks back down to 4º C overnight six cores, taken parallel to muscle fibers, were taken from each steak. Cores were sheared once, perpendicular to muscle fibers, using a TAXT-plus machine (TA. XT plus Connect, Texture Technologies, Hamilton, MA) with a Warner Bratzler shear blade to determine peak force and toughness. Shear force was measured six times and averaged for each beef strip steak to determine an average tenderness (Caine et al. 2003).

3.5 Carotenoid Analysis

Carotenoid analysis was conducted by powdering frozen adipose (200mg) in liquid nitrogen before mixing with 0.5mL methanol, 5mL hexane and 5mL of a 0.1% ethanolic sodium hydroxide solution. Samples were continuously stirred at 4 °C one hour, then 5mL of distilled water was added and the vial vortexed to induce phase separation. The resulting supernatant was pipetted off and dried under nitrogen gas. Samples were stored dry at -80º C prior to high performance liquid chromatography-photodiode array (HPLC-PDA) analysis.

Samples were analyzed using an HPLC (Waters 2996, Waters Corporation, Milford, MA) equipped with a Waters 2996 PDA, using a C-30 column (150 x 4.6mm, 3um particle size, YMC America, Allentown, PA). Samples were redissolved with 100uL of MTBE and 100uL of methanol, and vortexed for five seconds before being filtered through a nylon syringe filter (0.22 µm pore size). A gradient elution method was employed using solvent A (MeOH:H_20, 80:20, *v/v*) with 0.1% aq. formic acid and Solvent B (MTBE: MeOH: H_20, 78:20:2, *v/v*) with 0.1% aq. formic acid added. The gradient was as follows: beginning at 5% B, increasing to 95% B over 10 min, holding at 95% B for 6 min, and returning and holding at 5% B over 4 min. The flow rate was 1.30 mL/min, column temperature 40º C and injection volume was 20µL. Quantification was performed using an external calibration curve, generated with authentic *beta*-carotene standard, and comparing relative peak areas of the curve to those in the samples to determine µg *beta*-carotene/100 g of adipose tissue.

3.6 Statistical Analysis

Data was analyzed as a complete block design, using the PROC MIXED of SAS (9.4). The model included dietary treatment and time that was used as the fixed variable, whereas block was a random variable. Means separation for interaction of treatment and time, was conducted using the SLICE option of SAS. Due to the initial effect of age and BCS, initial outcomes were used as co-variables. Data was analyzed using PROC MIXED. Differences between treatments showing significance was determined at $P \leq 0.05$, tendencies determined at $P \leq 0.10$.

Chapter 4 - Results and Discussion

4.1 Weight and Body Condition Score

Least square means of cull cow weights and body condition scores are presented in Figures 4.1 and 4.2 respectively. Weights of cull cows were significantly affected on days 14 ($P < 0.01$), 28 ($P = 0.01$), and 42 ($P = 0.04$) and a trend was noticed on day 56 ($P = 0.09$) with cows in the HVA treatment weighing more. Body condition scores (BCS), however, were not significantly affected on days 14, 28 or 42; BCS was not assessed on day 56 prior to slaughter. These findings conflict with results found in previous studies (Gorocica-Buenfil et al. 2008; Pickworth et al. 2011; Pickworth et al. 2012) which noted no significant differences in growing weight of Angus-based steers fed treatments consisting of low and high vitamin A diets. This could be a result of differences in diet formulations, in each of the above studies base diets for all treatments were the same, with the difference being supplemental vitamin A. Conversely in this trial differences in provitamin A concentration was due to completely different diet formulations between treatments. Additionally, age of animals, sex of animals and time on feed between the above mentioned studies and the current study were notably different.

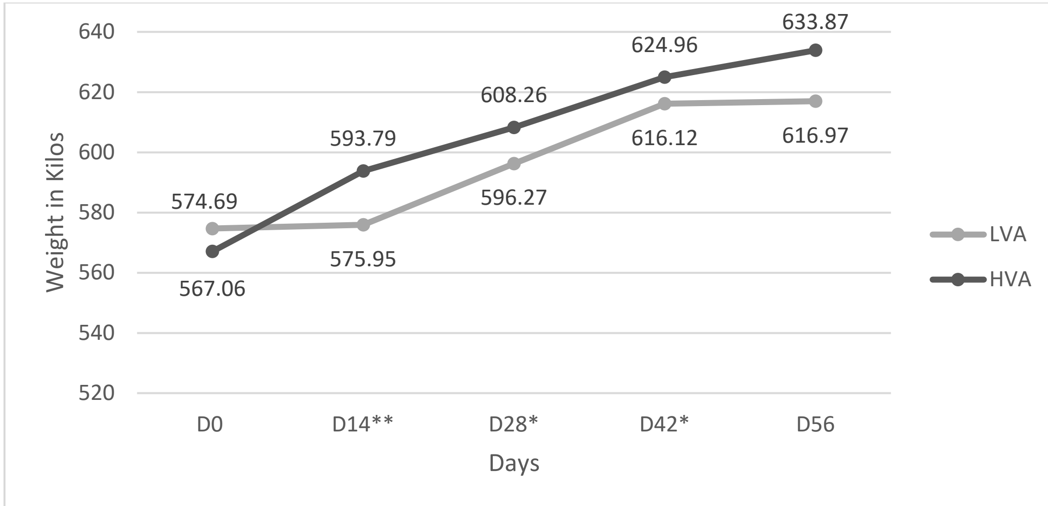

Figure 5. Least-square means on the effect of days on feed on weight (kg) of cull cows. Days with * indicate significance ($p \leq 0.05$), days with ** indicate $p \leq 0.01$

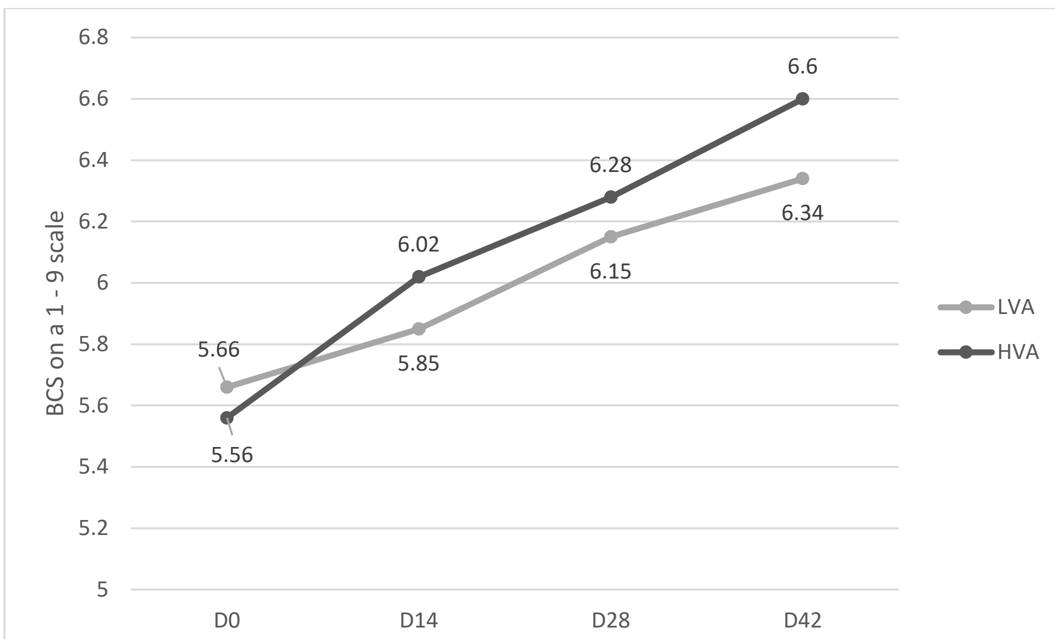

Figure 6. Least-square means on the effect of days on feed on body condition score of cull cows. Days with * indicate significance ($p \leq 0.05$), days with ** indicate $p \leq 0.01$

4.2 Carcass Characteristics

Least square means of carcass characteristics is presented in table 1. Carcass characteristics were not significantly affected by treatment. However, external fat color exhibited a treatment difference (P = 0.01), with the LVA treatment presenting less overall yellowness, (2.22 vs. 2.58). While these values are significantly different, in practice the difference in color scores of 2.22 and 2.58 would scarcely be noticeable to the human eye. This result means a potential increase in feed time may be needed to note visual differences between treatments. This finding supports previous studies (Goracica-Buenfil et al. 2008; Pickworth et al. 2011) reporting backfat, ribeye area, hot carcass weight, marbling score and quality grade were not significantly affected by low and high vitamin A diets when fed to Angus-based steers. Pickworth et al. 2012, however, found that vitamin A supplementation fed to Angus-crossbreed steers for 184 days significantly affected hot carcass weight, marbling score and quality grade. Goracica-Buenfil et al. 2007 noted no significant differences between backfat, ribeye area, or hot carcass weight, but did find differences in marbling score and quality grade between Angus-cross steers fed high and low vitamin A concentrations. Additionally, Goracica-Buenfil et al. 2007 noted no significant differences in carcass traits between Holstein steers on a vitamin A restricted diet for 112 or 243 days. These many conflicting finds could be attributed to differences in genetics, sex, and age of animals used in each study.

Table 1. Least square means of carcass data and quality traits of cow carcasses

Item	Treatment LVA	HVA	SEM[1]	P-value[2]
PYG[3]	2.97	2.89	0.085	0.34
Backfat (cm)	1.02	0.93	0.09	0.32
Ribeye Area (cm^2)	80.67	78.84	1.82	0.32
Hot Carcass Weight (kg)	337.65	329.08	8.38	0.31
Skeletal Maturity[4]	434.38	423.54	29.23	0.71
Lean Maturity[5]	182.62	179.06	4.44	0.42
Overall Maturity[6]	367.01	355.25	22.72	0.61
Marbling[7]	410.25	404.69	16.34	0.73
Quality Grade[8]	2.04	2.06	0.27	0.94
External Fat Color[9]	2.22	2.58	0.14	0.01

[1]SEM: Standard error of the mean
[2]P-value: Significance determined at P-value ≤0.05, tendencies determined at P-value ≤0.10
[3]Preliminary Yield Grade
[4]Skeletal Maturity: A (30 mo.): 100 – 199, B (31 – 41 mo.): 200 – 299, c (42 – 71 mo.): 300 – 399, D (72 – 95 mo.): 400 – 499, E (>96mo.) 500 - 599
[5]Lean Maturity (100 – 590)
[6]Overall Maturity (100 – 590)
[7]Marbling Score: Practically Devoid: 100 – 199, Traces: 200 – 299, Slight: 300 – 399, Small: 400 – 499, Modest / Moderate: 500 – 599, Slightly Abundant: 600 – 699, Moderately Abundant: 700 – 799, Abundant: 800 - 899
[8]Quality Grade: Cutter: 0.00 – 0.99, Utility: 1.00 – 1.99, Commercial: 2.00 – 2.99, Standard: 3.00 – 3.99, Select: 4.00 – 4.99, Low Choice: 5.00 – 5.99, Top Choice: 6.00 – 6.99, Prime: 7.00 – 7.998
[9]External (subcutaneous) Fat Color: 1 -white; 2 –creamy white; 3 –slightly yellow; 4 –moderately yellow; and 5 –yellow

4.3 Subjective Fat Biopsy Color Score

Least square means of subjective fat color scores is presented in figure 4.3. Subjective color scores were based on the American Meat Science Associations 1-5 fat color scoring scale. Fat color scores did not differ significantly between treatments on day 0 (P = 0.58) or day 14 (P = 0.13), however, a time by treatment difference was observed on days 28 (P = 0.05), 42 (P = 0.02) and 56 (P = 0.01). On D56 subjective color scores of fat samples increased for both the HVA and LVA treatments compared to day 42. HVA treatment had a score of 2.42, while the LVA treatment had a score of 2.12. The increase seen in both treatments color scores seen between D42 and D56 could be result of difference in sample collection seen between slaughter locations. As a result, color scores for D56 are not provided in figure 7.

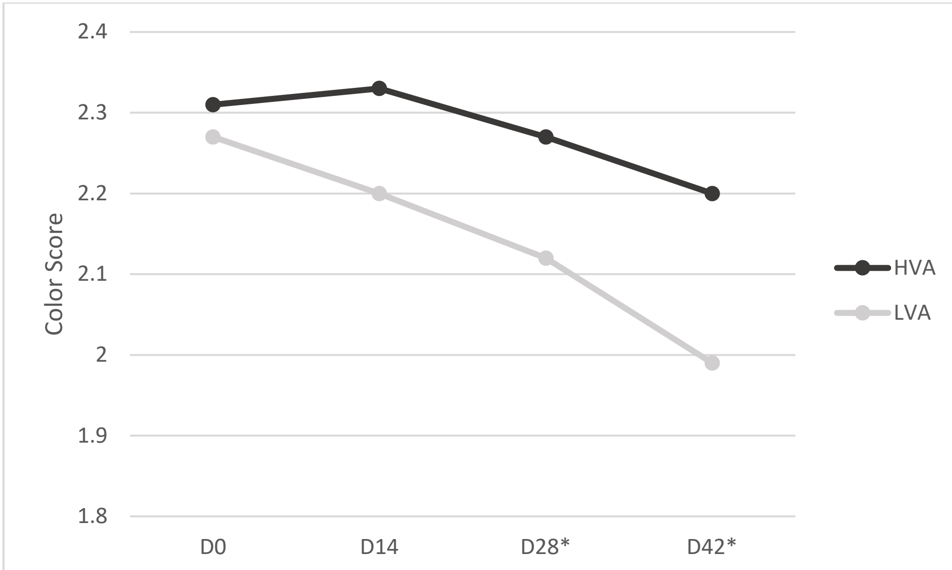

Figure 7. Least-square means of subjective fat color scores of cull cows. Days with * indicate significance (p ≤ 0.05), days with ** indicate p ≤ 0.01

4.4 Objective Fat Color Score

Least square means of objective color scores are presented in table 2. L*, representing lightness color value ranging from 0 - 100 as well as a* representing red and green color values were not significant. B*, which represents blue and yellow color values was significantly different between the treatment groups (P = 0.0002). This corresponds with the subjective fat biopsy visual color scores presented in table 4.3 which showed significant differences between treatments at days 28, 42 and 56. A study conducted by Rohrle et al. (2011) noted that crossbreed heifers fed a purely concentrate diet (low in provitamin A) were significantly less yellow (P < 0.05) compared to crossbreed heifers fed a pasture, silage and pasture, or silage, pasture, and concentrate mix diet. Cattle in that study also had lighter subcutaneous adipose tissue when fed strictly concentrate (Rohrle, 2011). The disagreement between these to studies in terms of lightness could potential be correlated to factors such as age, genetics and diet formulation.

Table 2. Least-square means of objective subcutaneous fat color scores of cow carcasses

	Treatment			
Item	LVA	HVA	SEM[1]	P-value[2]
L*[3]	73.50	73.24	0.78	0.74
a*[4]	10.30	10.08	0.39	0.59
b*[5]	17.23	19.96	0.69	<0.01

[1]SEM: Standard error of the mean
[2]P-value: Significance determined at P-value ≤0.05, tendencies determined at P-value ≤0.10
[3]L*: Lightness
[4]a*: Redness
[5]b*: Yellowness

4.5 Warner Bratzler Shear Force, peak force, and pH

Table 3 shows least square means for pH, Warner Bratzler Shear Force (WBSF) and peak force of *longissimus dorsi* lumborum samples. No significant differences were noted between the low and high vitamin A diets for WBSF (P = 0.92), peak force (P = 0.70) or pH (P = 0.32).

Table 3. Least-square means of Warner Bratzler Shear Force, peak force, and muscle pH of longissimus lumborum muscle samples from cow carcasses

	Treatment			
Item	LVA	HVA	SEM[1]	P-Value[2]
WBSF[3], kg	4.78	4.81	0.26	0.92
Peak Force[4], kg*sec	11.95	12.18	0.60	0.70
pH	5.60	5.55	0.06	0.32

[1]SEM: Standard error of the mean
[2]P-value: Significance determined at P-value ≤0.05, tendencies determined at P-value ≤0.10
[3]WBSF: Warner Bratzler Shear Force, Kg
[4]Peak Force: Area under the curve, Kg*sec

4.6 Carotenoid Concentration

Table 3 shows the least square means of both all-*trans*- and 9-*cis*-beta-carotene in subcutaneous adipose samples collected on D0 and D56. No significant differences were noted between the LVA or HVA treatments on D0 for either all-*trans*-beta-carotene ($P = 0.37$) or 9-*cis*-beta-carotene ($P = 0.42$). On D56 a significant difference was seen between LVA and HVA for 9-*cis*-beta-carotene ($P = 0.05$) and a trend was noticed for all-*trans*-beta-carotene ($P = 0.10$). These results support a previous study (Rohrle, et al. 2011), which found significantly less ($P < 0.05$) beta-carotene in subcutaneous fat samples of Charolais X Limousin cross heifers for when feeding a treatment of barley based concentrate (0.09 µg/g) versus treatments consisting of pasture (0.54 µg/g), silage and pasture (0.49 µg/g), and silage, pasture and concentrate (0.49 µg/g) for 11 months. While Rohrle, et al. showed significantly less beta-carotene when heifers were being fed concentrate versus a silage or pasture diet and this study only identified a trend in all-*trans*-beta-carotene and significance in 9-*cis*-beta-carotene, this could be due to the duration of the study; 11 months versus 56 days.

Table 4. Least Square Means of *Beta* – Carotene concentration in subcutaneous fat from cow carcasses

	Treatment			
Item	LVA	HVA	SEM[1]	P – Value[2]
D0 all-*trans*-*beta*-carotene (µg/g)	0.355	0.400	0.05	0.37
D56 all-*trans*-*beta*-carotene (µg/g)	0.200	0.242	0.03	0.10
D0 9-*cis*-*beta*- carotene (µg/g)	0.040	0.043	0.01	0.42
D56 9-*cis*-*beta*- carotene (µg/g)	0.013	0.020	<0.01	0.05

[1]SEM: Standard error of the mean
[2]P-value: Significance determined at P-value ≤0.05, tendencies determined at P-value ≤0.10

Chapter 5 - Conclusions and Future Directions

The present study outlined the effects of two feeding treatments in cull cows and its effects on cow weights and body condition scores, carcass characteristics, subjective and objective subcutaneous fat color scores, tenderness, pH and beta-carotene concentration. The feeding of a low vitamin A diet resulted in significant differences in cull cow weights, external carcass fat color scores, subjective and objective subcutaneous adipose color scores, and 9-*cis*-beta-carotene concentrations in subcutaneous fat samples collected on day 56 of the study, as well as a statistical trend in all-*trans*-beta-carotene concentration on day 56.

Overall the study did support the feeding of a low vitamin A diet for 56 days, from a statistical standpoint. However, when looking at the results of the LVA and HVA treatments, from an industry standpoint the differences seen in this study may not be adequate enough to support feeding cull cows a specialized low vitamin A diet.

Future research should be done to investigate the effects of other low vitamin A diets and prolonged time on subcutaneous adipose subjective and objective color scores as well as beta-carotene in subcutaneous adipose tissue. Additional research should also be conducted to investigate the effect of time of year as well as breed type of cows.

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