

Environmental and Nutritional Effects on Beef

Tenderness

By:

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EXECUTIVE SUMMARY

Half-blood *Bos indicus*-influenced steers (n=92) raised at the Agricultural Research Center, Texas Agriculture Experiment Station in McGregor, Texas were used in a study to understand the impact of environment (south, east and central Texas) and nutrition (low versus high) immediately post-weaning and prior to feedlot feeding on the growth, composition and eating characteristics of beef. All groups were fed on high concentrate diets at the Agricultural Research Center, Texas Agriculture Experiment Station in McGregor, Texas. One group of steers was fed in the feedlot on a high concentrate diet immediately post-weaning and this group was defined as the **McGregor-Calf** fed group. A second group of steers (n=18) were fed hay ad lib and 5 lb per head per day of the Acu-Ration at the Agricultural Research Center, Texas Agriculture Experiment Station in McGregor, Texas, for approximately 5 months immediately post-weaning and then feedlot fed. This group was defined as the **McGregor-Low** treatment. A third group of steers (n=10) were fed on native pasture at the Agricultural Research Center, Texas Agricultural Experiment Station in Uvalde, TX. This treatment was to induce a low rate of gain on these steers in a Southern Texas climate. These steers were defined as the **Uvalde-Low** treatment. A fourth group of steers (n=16) were fed hay ad lib and 5 lb per head per day of Acu-Ration and then placed on rye grass pasture at the Agricultural Research Center, Texas Agriculture Experiment Station in Uvalde, Texas, for approximately 2.5 months immediately post-weaning to induce a higher rate of gain during prefinishing in a Southern Texas climate. After prefinishing these steers were feedlot fed. This group was defined as the **Uvalde-High** group. A fifth group of steers (n=8) were fed the same diet as the McGregor –Low steers until February 7, 2000 when

these steers were placed on mature rye (*Secale creale*) and TAM-90 (*Lolium multiflorum* L.) ryegrass grass pasture at the Agricultural Research Center, Texas Agriculture Experiment Station in Overton, Texas until May 22, 2000. This group of steers was fed on pastures with a high stocking rate to induce a lower rate of gain during prefinishing in an East Texas climate. During rye-grass feeding these steers were fed on a rotational grazing system. Rotational steers grazed on an 8-paddock system. All paddocks assigned to rotationally stocked treatments were grazed for two days with a 14 d rest period. This group was defined as the **Overton-Low, Rotational** group. A sixth group of steers (n=7) were fed the same diet as the McGregor –Low steers until February 7, 2000 then steers were placed on mature rye (*Secale creale*) and TAM-90 (*Lolium multiflorum* L.) ryegrass grass pasture at the Agricultural Research Center, Texas Agriculture Experiment Station in Overton, Texas until May 22, 2000. This group of steers was fed on pastures with a high stocking rate to induce a lower rate of gain during prefinishing in an East Texas climate. During rye-grass feeding these steers were fed on a continuous grazing system where steers constantly grazed a single pasture. This group was defined as the **Overton-Low, Continuous** group. A seventh group of steers (n=6) were fed on the same pastures as the Overton-Low, Rotational group, however, they were placed on pasture at a lower stocking rate to induce a higher rate of gain during prefinishing in an East Texas climate. This group of steers was defined as the **Overton-High, Rotational** group. An eighth group of steers (n=9) were fed on the same pastures as the Overton-Low, Continuous group, however, they were placed on pasture at a lower stocking rate to induce a higher rate of gain during prefinishing in an East Texas climate. This group of steers was defined as the **Overton-High, Continuous** group. All steers fed

at the Agricultural Research Center at Overton remained on pastures until May 22, 2000 when all steers were transported to the Agricultural Research Center, Texas Agriculture Experiment Station in McGregor, Texas for feedlot feeding.

Steers in the forage/environmental treatment groups, except the McGregor-Calf group, were managed on forage-based diets for approximately 5 months to simulate forage-based management systems typical in Texas beef production. All groups were fed a high concentrate feedlot diet at the Agricultural Research Center, Texas Agriculture Experiment Station in McGregor, Texas until reaching a visually assessed fat constant endpoint of 0.4 inches of external fat over the 12th rib within a pen treatment group.

Steers were slaughtered at Sam Kane Beef Processors in Corpus Christi, TX. All carcasses were electrically stimulated and carcass yield and quality grade characteristics were determined. The 9-10-11th rib was removed and dissected in to separable fat, lean and bone and then further processed to determine chemical lipid, moisture and protein. These measurements were used as indicators of carcass composition. Strip loins were removed from each carcass and used to determine trained meat descriptive attribute sensory evaluation for juiciness, tenderness and flavor. Steaks were also aged for 1, 7, 14, 21, 28 and 35 days and Warner-Bratzler shear force was determined. Chemical measurements related to meat tenderness, 24 hr. calpastatin, collagen solubility, chemical lipid and moisture, and sarcomere length, were determined.

Environment and nutritional treatments induced variation on half-blood *Bos indicus* steer live animal production characteristics that resulted in differences in live animal and carcass weights. The treatments resulted in carcasses that differed in yield grade and that had slight, but not significant, differences in marbling and quality grade. The major

impact of the environment and nutritional treatments had on carcass composition was that steers from treatments that resulted in lighter final carcass weights, the calf-fed, McGregor-Low, Uvalde-fed and Overton-High, Rotational, in general, had lighter ribs and lower muscle to bone ratios indicating that growth of muscle and bone were effected by treatment. Steers that had higher rates of gain tended to have more muscling and higher muscle to bone ratios. Higher muscle to bone ratios are an advantage in that carcasses with high amounts of lean in relation to the amount of bone produce more saleable product in relation to by-product. As bone is a by-product and has little value, production of a minimum amount of bone is desirable.

Meat palatability was impacted by environment and nutrition treatments, mainly by impacting juiciness and meat flavor attributes. Warner-Bratzler shear force values at 1 and 7 day of aging were higher or tougher than shear values after 14 days of aging. It is apparent that to reduce variation in tenderness and to improve eating quality in beef from *Bos indicus*-influenced steers that are managed in environments representative to south, east and central Texas, aging the meat at least 14 days is paramount.

This study showed that environment and nutrition during the stocker phase impacted many of the important compositional and palatability components of beef production in Texas. While feedlot feeding of high concentrate diets removes much of the variation induced by environment and nutrition during the stocker phase, nutrition and/or environmental stress in the post-weaning, pre-feedlot phase of beef production impacts beef yield and palatability. Steers that are subjected either to hotter climates (south Texas) or low planes of nutrition (defined as Low in this study) tended to grow slower during the stocker phase and they gained more rapidly during the feedlot phase to

compensate for losses in the stocker phase. While .4 inches of fat would be considered an industry desirable fat endpoint, feeding steers to this compositional endpoint may not have allowed for full compensation of environment and/or nutritional stress during the stocker production phase. It can be concluded that management systems in Texas impact the variability in composition and palatability of Texas beef.

This study was designed to understand how environment/nutrition during the stocker phase impacts Texas beef production. While the results are not as clear-cut as would be desirable, there is sufficient evidence that these varying management systems impact Texas beef composition and palatability. When chemical components that have been used to understand why meat varies in eating quality were evaluated, differences were not found in these components. As this study included only 92 steers that were produced during one year of production, an understanding of the physiological factors impacting Texas beef composition and palatability may have been diminished by the use of insufficient animal numbers. It is obvious that animal variation was high for all variables measured. Additional research is being conducted as a continuation of this study using steers of similar genetics and background that differ greatly in their ability to convert feed to live animal gain. The metabolic efficiency of these animals is being determined. We will be measuring the tenderness, palatability, composition and chemical tenderness factors to try and understand factors that impact variability in Texas beef.

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Introduction

Numerous studies have been done on the effect of pre-slaughter nutrition on growth, production efficiency, carcass characteristics, carcass quality, and meat palatability. Many of these studies have compared the effects of forage-based and grain-based feeding. Source of dietary energy, such as lower-energy forage diets as compared to higher-energy grain diets, has an effect on the quality of the meat. Early research suggested grain feeding produced more positive effects on meat quality and palatability than forage feeding; however, other results have been contradictory.

Forage feeding has been shown to increase meat toughness as measured by Warner-Bratzler shear force values in young steers and heifers (Bowling et al., 1977, Leander et al., 1978, Schroeder et al., 1980, Aberle et al., 1981, Davis et al., 1981, Dolezal et al., 1982, Hedrick et al., 1983, Berry et al., 1988, Bennett et al., 1995). However, when young steers and heifers were fed grain prior to slaughter, trained sensory panelists have shown that their meat was more tender (Schroeder et al., 1980, Aberle et al., 1981, Davis et al., 1981, Dolezal et al., 1982, Berry et al., 1988, Mitchell et al., 1991, Bennett et al., 1995). This has been the basic premise for feeding young cattle high concentrate diets prior to slaughter. This segment of the beef industry, commonly called the feedlot segment, accounts for the improvement in overall palatability of U.S. grain-fed beef.

There is a preconceived idea that cattle produced from Texas, the largest cattle-producing state in the United States, is tougher than beef produced from Northern states. There have been many hypotheses as to why differences may exist. Originally, the beef industry identified the high percentage of *Bos indicus* cattle as the causative factor. However, research has shown that beef tenderness is not affected in young steers and

heifers as long as no more than 50% *Bos indicus* breeding is incorporated into the final slaughter animal. *Bos indicus*-influence is important in Texas beef cattle meat production system as this influence provides disease resistance and improves the ability of animals to handle heat stress. Therefore, in our study we used half-blood *Bos indicus* steers so that our steers would be representative of beef from Texas.

The question still remains, why in studies like the National Beef Tenderness Survey (Morgan et al., 1989), does the meat from the Southern portion of the United States tend to be tougher than meat from the Northern regions? We have hypothesized that the diverse climate and nutritional grazing systems inherent in Texas beef production systems may play a role in effecting beef tenderness and palatability. It has been known for a long time that genetic regulation, environment and nutrition are interrelated. In order for an animal to be able to express their genetic potential, proper nutrition under non-stressful environmental conditions is needed. The beef industry has invested a large amount of dollars into development of genetic markers to assist them in identifying animals that have the genetic potential to express desirable carcass and meat palatability characteristics. However, the question that remains is how much of an animal's resultant carcass characteristics and meat palatability is genetically regulated and how much is environmentally and nutritionally influenced? While this study will not fully address this issue, it is the first step in understanding or providing evidence to answer this question.

Animal nutrition and environment also have been shown to influence carcass characteristics and meat palatability. Texas is highly diverse geographically. The panhandle, west Texas, east Texas, south Texas, central Texas, and the coastal areas of Texas vary greatly in the amount of rainfall, average temperature and variation in

temperature, humidity, and soil types. These climatic conditions result in varying types of native grass that are available for cattle grazing and they also influence the type and nutritional value of the forage available for beef cattle grazing. These climatic conditions and variation in soil types influence the quality or nutritional value of the forages that are produced. Yet, all of these areas are used as forage and land sources for beef production.

Diet has been shown to influence meat quality and palatability. A tremendous amount of research has been conducted to examine the influence of diet on beef cattle growth, production efficiency, carcass characteristics and meat palatability. However, understanding the combined effects of environment and nutrition on subsequent beef carcass characteristics and meat palatability has not been clearly examined. For example, why do we produce tender meat in our studies where we control the nutrition (good quality forage during forage feeding followed by high-energy diets during the feedlot phase of production or calf feeding for the finishing phase) and we have moderate environmental conditions at the McGregor Experiment Station in McGregor, TX. For example, we found that after 14 days of aging, the steaks from calf-fed F1 steers from the Bos indicus sire evaluation all had shear force values less than 10 lbs. And almost all of the steaks were below 8 lbs. of shear force. The average shear force value at 14 days of aging was 6.49 lbs. indicating that the meat from these animals was tender. Therefore, if F1 Bos indicus steers are managed properly, meat tenderness does not appear to be a major issue. However, not all steers for beef production are managed the same in Texas. How much of this unexplained variation in southern-produced beef is due to the environment and subsequent nutritional aspects that result from the diverse environmental and nutritional conditions in Texas and how much is due to genetics?

This question has not been addressed and if the Texas beef industry is going to utilize genetic markers to select beef animals that have the genetic potential to produce tender meat, we must begin to understand the nutritional, environmental and genetic interactions involved in producing beef with acceptable carcass characteristics and palatability in Texas.

Beef carcass characteristics and palatability are endpoints that determine beef's economic value; however, these attributes are determined from the biochemical and physiological components of the beef animal during growth. There are biochemical factors that have been attributed to or have been implicated as contributing to differences in meat tenderness. **It is important not only to measure how animal nutrition and environment impact carcass characteristics and palatability, but to also measure the biochemical factors that may be responsible for these differences.**

The biochemical factors that have been attributed to explain the variability in meat tenderness are the amount of marbling or intramuscular fat, degradation of the muscle structure postmortem by endogenous proteases, connective tissue components, and the contractile state of muscle. For example, Crouse et al. (1989) compared the inheritance of carcass characteristics and palatability of *Bos indicus* and *Bos taurus* cattle. Palatability and carcass characteristics were analyzed on 422 different *Bos indicus* and *Bos taurus* composites. The study suggested that tenderness variation was due to the fragmentation of the myofibrillar component and the connective tissue portion of the muscle. In another study, the mechanisms associated with variation in tenderness from Brahman and Hereford cattle (Wheeler et al., 1990) were evaluated using 10 purebred Hereford and 10 purebred Brahman steers. Cattle were slaughtered at a fat thickness

measurement of 1 cm, at which point the longissimus muscle was obtained from each animal. Differences in meat tenderness using the Warner-Bratzler shear force was determined with increased length of time of post-mortem aging. These differences were attributed to breed differences, and differences were explained by the amount of calcium-dependent protease inhibitor, now defined as calpastatin, present in the meat. They explain that the higher the amount of calpastatin in the muscle, the less breakdown of the muscle and connective tissue structure during post-mortem aging.

Another important factor affecting tenderness is connective tissue. The evidence supports that there is no significant difference from the amount of total collagen present intramuscularly; instead, the effect on tenderness is derived from the percent of soluble collagen. Hill (1966) established that the real effect of collagen on tenderness is in the amount of soluble collagen in meat. This collagen amount decreases as an animal increases in age. Hill (1966) stated that as animals increased in age, the strength or amount of crosslinking between intramuscular collagen also increased. Cross et al. (1973) found that differences in the amount of collagen in varying muscles from different anatomical locations influenced tenderness variation within a carcass. Total concentrations of a combination of elastin and collagen did not effect tenderness, instead the variance of tenderness was significantly related to percent soluble collagen.

The effects on collagen solubility by feeding a high grain ration prior to slaughter were demonstrated by Miller et al. (1983). Samples from steers chosen from varying age ranges and fed a high grain ration 185 days prior to slaughter, were analyzed for total amount and percent soluble collagen. Mature and youthful steers with varying maturity, but similar marbling scores and fat thickness levels, were used in the study. The amount

of total collagen was higher in more mature carcasses, but percent soluble collagen was not significantly different between the youthful and mature carcasses. These data indicated that rapid growth of muscle, regardless of age, allowed for animals to produce more soluble collagen. This is plausible due to the slow rate that collagen becomes cross-linked. Thus establishing that a high-energy diet prior to slaughter would have more effect on soluble collagen than the age of the animal.

The weakening of connective tissue during aging has been extensively evaluated in several studies. Stanton and Light (1987, 1988, 1990) studied the effects of aging on collagen in several studies. Overall, they found evidence of proteolytic degradation of collagen during aging. Nishimura et al. (1995, 1996, 1998) used scanning electron microscopy to study the changes in collagen during aging of beef. Structural changes were minimal during the first 10 days of aging, but were clearly distinguishable after d 14 of aging (Nishimura et al., 1995). The main factor for degradation of intramuscular connective tissue appears to be due to proteoglycans. Proteoglycans separate collagen fibers from endomysium and perimysium causing partial tenderization of meat (Nishimura et al., 1996). Nishimura et al. (1998) established that weakening of the mechanical strength of collagen, during aging, could be another reason for meat becoming more tender. This effect was not significant until around d 14 postmortem. Nishimura et al. (1999) suggested that intramuscular fattening of cattle contributed by decreasing collagen's mechanical strength. This is the result of fat deposition in the connective tissue matrix causing it to weaken and to produce a more tender product.

Therefore, it is important to not only measure carcass characteristics and meat palatability, but to simultaneously measure the underlying factors that contribute to

differences in these characteristics such as marbling, connective tissue, calpastatin as an indicator of muscle fiber degradation and sarcomere length as an estimate of the contractile state of the muscle.

Objective

The objective of this project is to examine the effect of three different environments and their native or rye pasture forage systems on carcass characteristics, carcass composition, and meat palatability. The different forage environments of Uvalde, Texas (south Texas), McGregor, Texas (central Texas) and Overton, Texas (east Texas) will be examined.

Materials and Methods

Project Protocol

Ninety two F2 Angus x Brahman steers were selected from the Agricultural Research Center, Texas Agriculture Experiment Station in McGregor, Texas, to evaluate carcass and tenderness traits. The 92 steers were randomly assigned to one of eight environment/nutritional treatments. Calves were weaned on October 27, 1999 and fed hay ad lib and up to 5 lbs per head per day of Acu-Ration prior to the initiation of the study on November 23, 1999.

The McGregor calf-fed group of steers (n=15) were fed a traditional high concentrate diet at the Agricultural Research Center, Texas Agriculture Experiment Station in McGregor, Texas immediately post-weaning and were defined as the **McGregor-Calf** treatment. A second group of steers (n=18) were fed hay ad lib and 5 lb per head per day of Acu-Ration at the Agricultural Research Center, Texas Agriculture Experiment Station in McGregor, Texas, until April 12, 2000 and then they were feedlot

fed at the Agricultural Research Center in McGregor, Texas. This group was defined as the **McGregor-Low** treatment. A third group of steers (n=10) were fed the same diet as the McGregor-Low steers until they were placed on native pasture beginning on December 10, 1999 and ending on April 25, 2000 at the Agricultural Research Center, Texas Agricultural Experiment Station in Uvalde, TX. This treatment was to induce a low rate of gain in a Southern Texas climate. These steers were then transported to the Texas Agriculture Experiment Station in McGregor, TX for feedlot feeding. This group was defined as the **Uvalde-Low** treatment. A fourth group of steers (n=16) were fed the same diet as the McGregor-Low steers until February 28, 2000 when a rye grass pasture was available at the Agricultural Research Center, Texas Agriculture Experiment Station in Uvalde, Texas. On February 28, 2000, these steers were placed on the rye grass pasture until April 21, 2000. This treatment was to induce a higher rate of gain during prefinishing and to simulate a higher rate of gain in a Southern Texas climate. After prefinishing these steers were feedlot fed. This group was defined as the **Uvalde-High** group. A fifth group of steers (n=8) were fed the same diet as the McGregor-Low steers until February 7, 2000 when these steers were placed on mature rye (*Secale cereale*) and TAM-90 (*Lolium multiflorum* L.) ryegrass pasture at the Agricultural Research Center, Texas Agriculture Experiment Station in Overton, Texas until May 22, 2000. This group of steers was fed on pastures with a high stocking rate to induce a lower rate of gain during prefinishing in an East Texas climate. During rye-grass feeding these steers were fed on a rotational grazing system. Rotational steers grazed on an 8-paddock system. All paddocks assigned to rotationally stocked treatments were grazed for two days with a 14 d rest period. This group was defined as the **Overton-Low, Rotational**

group. A sixth group of steers (n=7) were fed the same diet as the McGregor –Low steers until February 7, 2000 then steers were placed on mature rye (*Secale cereale*) and TAM-90 (*Lolium multiflorum* L.) ryegrass pasture at the Agricultural Research Center, Texas Agriculture Experiment Station in Overton, Texas until May 22, 2000. This group of steers was fed on pastures with a high stocking rate to induce a lower rate of gain during prefinishing in an East Texas climate. During rye-grass feeding these steers were fed on a continuous grazing system where steers constantly grazed a single pasture. This group was defined as the **Overton-Low, Continuous** group. A seventh group of steers (n=6) were fed on the same pastures as the Overton-Low, Rotational group, however, they were placed on pasture at a lower stocking rate to induce a higher rate of gain during prefinishing in an East Texas climate. This group of steers was defined as the **Overton-High, Rotational** group. An eighth group of steers (n=9) were fed on the same pastures as the Overton-Low, Continuous group, however, they were placed on pasture at a lower stocking rate to induce a higher rate of gain during prefinishing in an East Texas climate. This group of steers was defined as the **Overton-High, Continuous** group. All steers fed at the Agricultural Research Center at Overton remained on pastures until May 22, 2000 when all steers were transported to the Agricultural Research Center, Texas Agriculture Experiment Station in McGregor, Texas for feedlot feeding.

For feedlot feeding, all groups were fed a high concentrate feedlot diet at the Agricultural Research Center, Texas Agriculture Experiment Station in McGregor, Texas until reaching a visually assessed fat constant endpoint of 0.4 inches of external fat over the 12th rib within a pen treatment group.

Once reaching the fat constant endpoint, steers were transported and slaughtered at Sam Kane Beef Processors in Corpus Christi, TX. Carcasses received electrical stimulation with three bars, 27 seconds each. The first stimulation was 150 V at 1.9 amp. The second and third stimulation was delivered at 300 V and 3.0 amp. Carcasses were chilled for 36 hours at 1° C. Approximately 100 grams of *Longissimus lumborum* muscle was collected at 24 hours postmortem. The sample came from an area 15 cm anterior from the 12-13th rib interface and was used for calpastatin and sarcomere length evaluation. USDA quality and yield characteristics were obtained by trained personnel from Texas A&M University.

The carcasses were commercially fabricated and strip loins (IMPS 180A) were obtained from both sides of the carcass. The strip loins were vacuum-packaged and shipped to the Texas A&M University Rosenthal Meat Science and Technology Center in College Station, TX. Strip loins were fabricated into 6 sections, 8 cm thick. The sections were randomly assigned into aging periods of 1, 7, 14, 21, 28, or 35 days. From each section two-2.54 cm steaks were cut with the first being used for Warner-Bratzler shear force determination and the next adjacent steak used for trained meat descriptive attribute sensory evaluation. The steaks were stored at 1° C for their designated aging time (1, 7, 14, 21, 28, or 35 days). After appropriate aging, the steaks were frozen at -10° C until analysis.

The 9-10-11th rib section was removed from each carcass for determination of carcass separable and chemical composition.

Analytical Techniques

Warner-Bratzler Shear Force. After aging for 1, 7, 14, 21, 28, or 35 days and storage, steaks were broiled on a Farberware Open Hearth grill (model 450N, Kidde, Inc., Broncs, NY) according to AMSA (1995) to an overall internal temperature of 70° C. After reaching an internal temperature of 35° C, steaks were turned once during cooking. Internal temperature of the steaks were detected by copper constantan thermocouples connected to a strip chart recorder (model RD4031, Omega Engineering, Inc., Stamford, CT). Raw weight, cooked weight, temperature on/off, and cook time were recorded. Steaks were cooled to room temperature (25° C) for approximately four hours after cooking. Six-2.54 cm cores were removed using a machine corer from each steak at a predetermined location parallel to the longitudinal orientation of the muscle fibers. Cores were sheared using an Instron Universal Testing Machine (Model 4411, Instron Corp., Canton, MA) with a Warner-Bratzler shear attachment. Crosshead speed was 200 mm/min. Maximum force was recorded in kilograms as a mean of the six cores.

Sensory Evaluation. Steaks aged 1, 7, 14, 21, 28, and 35 days were broiled on a Farberware Open Hearth grill (model 450N, Kidde, Inc., Broncs, NY) according to AMSA (1995) to an overall internal temperature of 70° C, turning once after reaching 35° C. Internal temperature of the steaks were detected by copper constantan thermocouples connected to a strip chart recorder (model RD4031, Omega Engineering, Inc., Stamford, CT). Raw weight, cooked weight, temperature on/off, and cook time was recorded. Cooked steaks were cut into 1.27 cm x 1.27 cm x 2.54-cm cubes and presented to an eight-member trained sensory panel. Panelists were seated in individual booths with red filtered lights to mask color variation in samples (AMSA, 1995). Panelists received

distilled water and ricotta cheese for cleansing of their pallets. They received 16 samples per day in a randomized order using 3 digit identification codes.

Sarcomere Length. Sarcomere length of each animal was determined following the guidelines in Cross et al. (1980) using a Spectra-Physics model 155SL helium-neon laser (0.95 mW) (Spectra-Physics, Inc., Eugene, OR). Samples for sarcomere length determination were obtained approximately 24 hours postmortem from the longissimus muscle. Approximately 5 grams of cubed sample were placed in a vial with 15-20 ml of cold (4° C) homogenization solution. The homogenization solution consisted of 0.25-M sucrose, 0.002-M KCl, and 0.005-M iodoacetate. Final pH of the solution was 7.0. The sample and homogenate were homogenized at low speeds for 10-15 seconds or until fiber fragmentation was noted. A drop of homogenate was then placed on a glass microscope slide, covered with a coverslip, and the slide placed on the holding stage of the laser stand. Distance from the top of the slide to the baseboard of the laser stand was 100 mm. The slide was moved past the laser until a diffraction pattern was seen on the baseboard. The distance between the origin and the first order diffraction band was measured and recorded.

Calpastatin. Approximately 100 grams of longissimus muscle tissue was placed into 30 ml of chilled (5° C) extraction buffer. The extraction buffer consisted of 100 mM Tris, 5 mM EDTA, and 10 mM beta-mercaptoethanol. Samples were homogenized in a chilled Waring Blender (model 31BL92, Waring Products Division, New Hartford, CT) three times for 30 seconds each with a 30 second lag time between homogenizations (blender cups were not be allowed to warm). Samples were kept cool and centrifuged at 35,000xg for 60 minutes. Supernate was transferred equally into five 13 x 100

borosilicate tubes and placed into a 95° C water bath for 15 minutes. The tubes then were placed on ice to chill for approximately 15 minutes. The coagulated protein in each tube was scrambled with glass rods to separate pellet and supernate. The samples were transferred to centrifuge tubes and centrifuged as before for 30 minutes. The supernate was filtered through a glass wool plug into a sterile 50-ml conical tube. The volume of supernate was measured and recorded for calculation of calpastatin activity. Samples were assayed by adding the sample, elution buffer, purified calpain, and calcium to a tube. Heating, spinning, and then reading the sample on a spectrophotometer at 278 nanometers (Wheeler and Koohmaraie, 1991) followed.

Chemical Analyses. From the steak used for collagen analyses, 5 grams of powdered samples were used to determine chemical moisture and lipid percentages as described by AOAC (1995). Moisture was determined using the oven-dry method and lipid was determined using ether extraction procedures in a Soxhlet extraction apparatus. The soft tissue from the 9-10-11th rib dissection soft tissue was analyzed for chemical moisture, lipid and protein following AOAC (1995) procedures. Moisture will be determined using the oven-dry method and lipid was determined using ether extraction in a Soxhlet apparatus. Protein was determined using the Lecco protein extraction system.

Statistical Analysis

Data were analyzed by analysis of variance (ANOVA) using the general linear model (GLM) procedure from SAS (1991). The significant level was predetermined at $P < 0.05$. All data, except for the live animal growth data reported in Table 1 and carcass adjusted fat thickness reported in Table 2, were adjusted to a constant adjusted fat thickness by covariate analyses to remove the effect of varying fat thickness at the point

of slaughter. A main effect for slaughter day within treatment was included in the model to account for variation due to differences in slaughter days across treatments. For the carcass characteristics, 9-10-11th rib dissection and chemical data, and chemical measurements of tenderness the main effect of treatment (McGregor-Calf; McGregor-Low; Uvalde-Low; Uvalde-High; Overton-Low, Rotational; Overton-Low, Continuous; Overton-High, Rotational; Overton-High, Continuous) was included in the model. Least squares means were calculated and when a significant effects were identified in the Analysis of Variance table ($P < 0.05$), the least squares means were separated using the standard error pdiff function of SAS (1991). For the Warner-Bratzler shear force data, the effect of aging time and the interaction of aging time by treatment were included in the aforementioned model. Least squares means were generated and differences were determined as previously described. For the sensory evaluation data, the effect of panelist also was included in the model as a main effect to account of panelist effects.

Simple correlation coefficients were calculated to understand general relationships between live animal growth traits, chemical measurements of tenderness and Warner-Bratzler shear force determinations.

Results and Discussion

Environment/Nutritional Effects

Live Animal Production Characteristics. At the beginning of the trial, steers across treatment groups did not differ in beginning weight (Table 1). However, by the end of the stocker-feeding phase, steers fed to gain higher rates were heavier than steer fed in the same location, but on diets to induce a lower rate of gain. The average daily gains during

the stocker phase show that the location/environmental treatments induced differences in gains during the stocker phase as defined by the experimental design. Across locations, the steers fed the Uvalde-Low and the Overton-Low, Rotational treatments were lighter and had lower average daily gains than the steers fed on the McGregor-Low and Overton-Low, Continuous treatments. Within treatments designed to induced higher rates of gains, the Uvalde-High steers had lower rates of gain and were lighter in live weight after the stocker phase than the Overton-High, Continuous steers. Therefore, not only did the nutritional treatments during the stocker phase induced rate of gain differences as defined by the experimental protocol, but the environment or location affected rates of gains during the stocker phase.

During the feedlot phase, McGregor-Calf steers had the lowest rate of gain (Table 1). This would be expected as these steers were placed on a high concentrate diet immediately after weaning and their rate of gain in the feedlot would have been expectantly lower throughout the high concentrate-feeding period. Note that the length of time that these steers were fed a high concentrate diet was longest. The Overton-Low, Rotational; Overton-Low, Continuous; and Overton-High, Continuous steers had the highest rates of gain and were on feed a shorter number of days during the feedlot phase than the McGregor-Low steers. The steers from the Uvalde-Low; Uvalde-High, and Overton-High, Rotational were intermediate in feedlot average daily gain and the number of days on feed in the feedlot. Based on the average daily gain of the Uvalde-Low steers during the stocker phase (0.55 lbs/day), it would have been expected that these steers would have had higher rates of gain in the feedlot phase.

At the end of the feedlot phase, steers differed in live weight due to treatment. This is especially important as these steers were of similar biological-type and were slaughtered at a fat-constant endpoint. The McGregor-Calf steers were lightest in live weight and the Overton-Low, Rotational; Overton-High, Rotational; and Overton-High, Continuous steers were heaviest. The other treatments were intermediate in final live weight. Therefore, stocker treatments induced differences in live weight gain during the stocker phase that resulted in differences in feedlot average daily gain, length of time on feed during high concentrate feeding and subsequent final live weight at slaughter was affected. These results are not surprising as it has been well documented that growth rates post-weaning and prior to feedlot feeding affect feedlot average daily gains, length of time in the feedlot and final live weight. What is different about our study is that the rates of growth were induced not only by nutrition, but environment. The hotter climate of South Texas has been shown to effect rate of growth. In our study, the Uvalde cattle had lower average daily gains than the comparable treatments in Overton. Whether the difference in rates of gain were due to differences in nutrition or environment cannot be determined in this study (not the objective of the study), but the differences in steer growth was affected by the management systems in the two locations.

These treatments are representative of management systems used in Texas. It has been hypothesized that while differences in environment and nutrition in the stocker phase induces differences in growth, that these differences are reduced or eliminated during the feedlot phase of production. As beef producers are paid based on weight, these environmental/nutritional treatments may affect final value. While these treatments affected live animal production factors, understanding if these treatments affected carcass

characteristics is important in assessing if environment and nutrition impact final meat quality and carcass composition.

Carcass Characteristics. Stocker treatments affected carcass yield grade characteristics (Table 2), but had minimal effects on carcass quality grade characteristics (Table 3). While steers were targeted for slaughter at a constant fat endpoint, carcass fat endpoint was assessed based on visual evaluation of the pens during the feedlot phase. While not statistically significant ($p = 0.39$), the Uvalde-High and McGregor-Calf groups had less carcass adjusted fat thickness than the other treatments. As fat thickness differed slightly across treatments, the remainder of the data were statistically adjusted to a constant fat thickness to remove the effects of differences in carcass fat thickness on other attributes. The P-values for the effect of adjusted fat thickness is presented for attributes where it was included in the statistical analyses. This is to indicate where adjusted fat thickness may have influenced the attribute; however, by including fat thickness in the model the influence of fat thickness at slaughter has been removed from the least squares treatment values.

Treatments affected ribeye area, kidney, pelvic and heart fat percentage (KPH), and hot carcass weight, but final yield grade was not influenced by nutritional/environmental treatments. The carcasses from the Uvalde-Low steers had smaller ribeye area than carcasses from the Overton-Low, Continuous and the Overton-High, Continuous. The ribeye areas from the carcasses of the other treatments did not differ from the ribeye areas of the Uvalde-Low steers. However, differences in ribeye area of 1.2 inches between carcasses from the Uvalde-Low (11.46 inches²) and Overton-Low, Rotational (12.66 inches²), while not statistically different, this difference would be considered important

within the meat industry. This indicates that there was a high amount of variation (Root Mean Square Error = 1.413) in ribeye areas within treatments. This indicates that ribeye area, an indication of muscle growth and size, is influenced by nutrition/environment and that these differences are not removed during high concentrate feedlot feeding. Feeding cattle in milder environments that had high levels of grass during the spring of the year appeared to have assisted in maximizing ribeye area at slaughter after feedlot feeding.

Carcasses from the McGregor-Calf and Overton-Low, Rotational treatments had lower KPH than the carcasses from the McGregor-Low, Uvalde treatments, and Overton-High, Continuous treatments. The carcasses from the Uvalde-High steers had the highest KPH, but these carcasses did not differ in KPH from carcasses from the McGregor-Low, and Overton-High, Continuous carcasses. Carcasses from calf-fed steers have been shown to be lower in KPH when compared to steers fed on grass, then fed high concentrate diets and slaughtered as older yearlings. As steers from calf-fed treatments are almost always younger in age at the time of slaughter and fat is deposited sequentially with age, younger animals expectantly would have lower amount of KPH.

Least squares means for hot carcass weight varied from 667.7 lbs to 790.9 lbs. Considering that carcasses from these steers had a constant fat thickness and were derived from steers of similar biological type, it is obvious that treatment impacted hot carcass weight. The steers fed at McGregor and Uvalde had lighter hot carcass weights than steers fed at Overton, except that carcasses from the Overton-High, Rotational treatment did not differ in hot carcass weight from carcasses from the other treatments. It should be noted that carcass weights were highly variable within treatments (Root Mean Square Error = 67.90) indicating that fairly large differences in hot carcass weight were

needed between treatments for statistical differences. This implies that location or environment impacted hot carcass weight.

These environmental/nutritional management treatments, while impacting individual carcass yield grade components, did not affect final carcass yield grade. Carcasses ranged in mean yield grade from 2.82 to 3.24 as would be expected by the experimental design. As steers within a treatment pen were slaughtered at a visually assessed fat content and then the data were adjusted statistically to a constant fat content, it is not surprising that yield grades did not differ. Fat thickness is the yield grade component that has the greatest impact on calculating yield grade. As this component was held constant, differences among treatments in ribeye area, KPH and hot carcass weight were not sufficient to result in a statistically different yield grade across treatments. It should also be noted that rotating pastures during the stocker phase obviously affected live animal growth for the Overton-High steers. As rotational grazing requires movement from one paddock to another, the adaptation to new paddocks obviously impacted forage utilization of these steers and this effect in live animal growth impacted subsequent carcass yield grade characteristics. As Rotational versus Continuous grazing only impacted steers in Overton that were fed on a high stocking rate to induce a lower rate of gain, it can be hypothesized that when forage is limited (in this case by stocking rate and competition between animals for the forage), adaptation to new paddocks impacts growth and subsequent carcass yield grade components.

Skeletal maturity was the only quality grade factor affected by treatment (Table 3). The carcasses from the Overton-High, Continuous and the Overton-Low, Continuous steers had higher skeletal maturity ratings than the McGregor-Low and Uvalde-Low

treated carcasses. Within steers fed at Overton, the carcasses from steers fed on the Rotational treatments had lower skeletal maturity than the Overton-High, Continuous. However, differences in skeletal maturity due to treatment, while significant, were not large and all carcasses were within the A maturity classification. These differences in skeletal maturity would most likely not affect final USDA Quality Grade. While marbling score varied from Slight⁸¹ to Small⁷², almost one marbling score difference; significant differences were not reported ($p=0.37$). The high amount of variation within treatments most likely contributed to lack of significance. This experiment was originally designed as a two-year study. While the number of animals per treatment are sufficient to test our hypotheses, including a second set of animals managed and fed in a second year would help to determine if marbling and quality grade differences reported in Table 3 would be significant and repeatable.

While yield grade differed across treatments, quality grade did not differ. This implies that treatments affected growth and composition of steers with minimal effects on carcass quality. To understand the effect of treatment on carcass composition, the 9-10-11th rib was dissected and separable and chemical composition was determined (Table 4).

Rib Dissection. Rib weight was affected by treatment. Ribs from steer fed at Overton were heavier than ribs from steers fed from the Uvalde-Low treatment (Table 4). Ribs from the Uvalde-Low steers were the lightest ribs. Even though rib weight differed, separable fat and lean percentages in the rib did not differ across treatments. However, ribs from McGregor-Calf, and Overton-Low had lower percentages of bone than ribs from steers fed at Uvalde and the steers fed the Overton-High, Rotational treatment. As

some variation in separable lean was reported, muscle to bone ratio was calculated to determine if treatments influenced the amount of muscle in relationship to bone within carcasses from the eight treatments. Muscle to bone was lowest for the McGregor-Low, Uvalde, and Overton-High, Rotational steers and highest for the steers from the Overton-Low, Continuous. Chemical composition of the 9-10-11th rib sections was not affected by treatment (Table 5). These results indicate that treatments impacted growth of the three major carcass components of lean, fat and bone; however, bone growth and muscle to bone ratio were impacted as steers were fed to a fat constant endpoint. Steers from treatments that resulted in lighter final carcass weights, the calf-fed, McGregor-Low, Uvalde-fed and Overton-High, Rotational, in general, had lighter ribs and lower muscle to bone ratios indicating that growth of muscle and bone were effected by treatment. Steers that had higher rates of gain tended to have more muscling and higher muscle to bone ratios. As these steers were the same biological type and slaughter at the same fat thickness, differences in fatness would not be expected; however, the differences in muscle to bone ratio indicate that as bone and muscle are slower growing tissue, nutritional/environmental treatments affected their growth and feedlot feeding did not allow for full realignment of tissue deposition by the time these steers reached the .4 inch constant fat endpoint.

Warner-Bratzler Shear Force and Sensory Evaluation. Treatment did not affect Warner-Bratzler shear force; however, length of storage time, also referred to as meat aging, was influenced by Warner-Bratzler shear force (Table 6). Steaks from the McGregor-Calf fed steers were highest in Warner-Bratzler shear force values, but shear force values were above 9 lbs. for all treatments. The interaction between treatments and

storage day was not significant ($p=0.16$); however, the relationship is presented in Figure 1. This indicates that aging rates did not differ across the eight treatments, but that steaks from all treatments improved in tenderness with storage. Steaks were toughest at 1 and 7 days of storage and with subsequent storage past 7 days, Warner-Bratzler shear force values were lower or steaks were more tender. This aging response or the improvement in tenderness with storage was expected and has been well documented in the scientific literature.

Treatment influenced steak juiciness and cook loss percentage (Table 7). Steaks from McGregor-Calf steers were juicier than steaks from McGregor-Low and Overton-High steers. Steaks from the Uvalde-High treatment had the highest cooking losses and steaks from the Overton-High treatments had the lowest cooking losses. As cooking loss did not follow a pattern that related to differences in sensory attributes, cooking loss differences are not explainable. Length of storage did not affect sensory attributes and the interaction of treatment and storage day was not significant ($P>.05$) for sensory attributes.

The sensory panel rated each steak for specific positive and negative flavor attributes (Table 8). Cooked beefy/brothy, cooked beef fat, serum/bloody off-flavor, soured off-flavor, browned off-flavor and chemical off-flavor sensory flavor attributes were affected by treatment. Steaks from the McGregor-Calf, McGregor-Low and Uvalde-High had higher levels of cooked beefy/brothy than steaks from the Overton-Low, Continuous and the Overton-High, Rotational. Steaks from Uvalde-fed steers had slightly higher amounts of cooked beef fat than steaks from Overton-fed steers. While serum/bloody off-flavor was low across treatments, steaks from the Overton-High,

Continuous treatment had slightly higher serum/bloody off-flavors than the steaks from the Overton-High, Rotational treatment. Steaks from the Uvalde-Low and the Overton-High, Rotational steers had higher levels of sour off-flavor than steaks from McGregor-Calf and Overton-High Continuous steers. Browning flavors were highest in steaks from the McGregor-Low and Overton-High, Rotational steers. Whereas, steaks from Overton-High, Rotational had the highest levels of chemical off-flavor.

It was interesting that sensory flavor attributes were not affected by storage time or the treatment by storage time interaction. This indicates that the flavor of steaks did not change with storage and that during storage, treatments did not influence changes in steak flavor.

These results indicate that sensory attributes were influenced by environment and nutritional management of half-blood *Bos indicus*-influenced steers. While consistent trends of how one treatment differed from another treatment across the sensory attributes was not apparent, it is apparent that environment and nutrition impact the palatability or eating quality of beef.

Chemical Measurements of Tenderness. To understand how chemical or physical components within the muscle cell may impact the results of the Warner-Bratzler shear force and sensory data, chemical tenderness measurements are reported in Table 9. Differences in chemical measurements were not reported except that treatments influenced collagen amount. As all carcasses were electrically stimulated during the slaughter process, differences in sarcomere length were not expected. As cattle grew at different rates during the stocker and feedlot phase of production, differences in calpastatin and collagen solubility may have differed based on previous research. These

results indicate that by slaughtering cattle at a constant fat thickness, differences in these chemical tenderness measurements were negated. However, the McGregor-Calf steers had lower total amount of collagen than that the steers from the Uvalde-High, Overton-Low, Continuous and the Overton-High treatments. As the calf-fed steers were slaughtered first and at the youngest physiological age and collagen, while slow growing, does increase with age; therefore, these results would be expected. As the calf-fed steers had the highest shear force values, though not significant ($P=0.43$), total collagen amount most likely did not affect steak tenderness in this study. As all carcasses were A maturity, or they were young at slaughter, collagen amount would expectantly not affect meat tenderness. Steers from the McGregor treatments and the Uvalde-Low treatment had lower amounts of collagen than the Overton-Low and High, Continuous treatments. Chemical moisture and lipid percentages did not differ across treatments. As marbling scores were not affected by treatment, it is not surprising that chemical lipid and moisture were not affected by treatment. However, it was interesting that the Overton-High, Rotational steaks had almost 2% less chemical lipid than steaks from the Overton-Low, Continuous steers. The Overton-High, Rotational steers did not gain at the same rate during the feedlot phase and they had the lightest live weight when compared to steers from the other Overton treatments.

Simple correlation coefficients were calculated to examine the relationships between chemical components of tenderness and Warner-Bratzler shear force (Table 10). Lipid and shear force at 1 and 14 days were slightly related to each other; however, correlation coefficients were low and strong relationships were not found. Similar results were reported by Hager (2000). Hager (2000) examined the interrelationships between

Warner-Bratzler shear force and chemical measurements of tenderness in F1 British x *Bos indicus* steers from 15 different sires over a 5 year period. Low to not significant relationships also were reported. Additionally, simple correlation coefficients were calculated between shear force at the six days of aging and the live animal parameters of stocker and feedlot average daily gain and days on feed (Table 10). Only days on feed and shear force values at 28 days were significantly correlated. This indicates that steers with higher number of days on feed had lower shear force values after 28 days of aging. Simple correlation coefficients between chemical measures and live animal parameters are reported in Table 11. Lipid and marbling were highly related, as would be expected, and moisture and lipid were highly related. Other than these relationships, simple correlations were low and not significant between the other chemical attributes. As would be expected, average daily gain in the feedlot and days on feed were highly and negatively correlated.

Conclusions

Environment and nutritional treatments induced variation on half-blood *Bos indicus* steer live animal production characteristics that resulted in differences in live animal and carcass weights. The treatments resulted in carcasses that differed in yield grade and that had slight, but not significant, differences in marbling and quality grade. Steers from treatments that resulted in lighter final carcass weights, the calf-fed, McGregor-Low, Uvalde-fed and Overton-High, Rotational, in general, had lighter ribs and lower muscle to bone ratios indicating that growth of muscle and bone were effected by treatment. Steers that had higher rates of gain tended to have more muscling and higher muscle to

bone ratios. As these steers were the same biological type and slaughter at the same fat thickness, differences in fatness would not be expected; however, the differences in muscle to bone ratio indicate that as bone and muscle are slower growing tissue, nutritional/environmental treatments affected their growth and feedlot feeding did not allow for full realignment of tissue deposition by the time these steers reached the .4 inch constant fat endpoint.

Meat palatability was impacted by environment and nutrition treatments. Sensory attributes were influenced by environment and nutritional management of half-blood *Bos indicus*-influenced steers. While consistent trends of how one treatment differed from another treatment across sensory flavor attributes, it was apparent that environment and nutrition impacted the palatability or eating quality of beef. Steaks from the McGregor-Calf fed steers were highest in Warner-Bratzler shear force values, but shear force values were above 9 lbs. for all treatments. Increased aging or increased length of storage time impacted Warner-Bratzler shear force values. Steaks were toughest at 1 and 7 days of storage and with subsequent storage past 7 days, Warner-Bratzler shear force values were lower or steaks were more tender. It is apparent that to reduce variation in tenderness and to improve eating quality in beef from *Bos indicus*-influenced steers that are managed in environments representative to south, east and central Texas, aging the meat at least 14 days is paramount.

Chemical components of tenderness were measured and the total amount of collagen was affected by environment/nutritional treatments. The McGregor-Calf steers, that were slaughtered at a younger physiological age, had lower total amount of collagen than that the steers from the Uvalde-High, Overton-Low, Continuous and the Overton-

High treatments. Steers from the McGregor treatments and the Uvalde-Low treatment had lower amounts of collagen than the Overton-Low and High, Continuous treatments. As all carcasses were A maturity, or they were young at slaughter, collagen amount would expectantly not affect meat tenderness. The other chemical factors of sarcomere length, calpastatin activity, collagen solubility and chemical lipid and moisture were not affected by treatments.

This study showed that environment and nutrition during the stocker phase impacted many of the important compositional and palatability components of beef production in Texas. While feedlot feeding of high concentrate diets removes much of the variation induced by environment and nutrition during the stocker phase, nutrition and/or environmental stress in the post-weaning, pre-feedlot phase of beef production impacts beef yield and palatability. Steers that are subjected either to hotter climates (south Texas) or low planes of nutrition (defined as Low in this study) tended to grow slower during the stocker phase and they gain more rapidly during the feedlot phase to compensate for losses in the stocker phase. While .4 inches of fat would be considered an industry desirable fat endpoint, feeding steers to this compositional endpoint may not have allowed for full compensation of environment and/or nutritional stress during the stocker production phase. It can be concluded that management systems in Texas impact the variability in composition and palatability of Texas beef.

This study was designed to understand how environment/nutrition during the stocker phase impacts Texas beef production. While the results are not as clear-cut as would be desirable, there is sufficient evidence that these varying management systems impact Texas beef composition and palatability. When chemical components that have

been used to understand why meat varies in eating quality were evaluated, only differences in total collagen were found. As this study included only 92 steers that were produced during one year of production, an understanding of the physiological factors impacting Texas beef composition and palatability may have been diminished by the use of insufficient animal numbers. It is obvious that animal variation was high for all variables measured. Additional research is being conducted as a continuation of this study using steers of similar genetics and background that differ greatly in their ability to convert feed to live animal gain. The metabolic efficiency of these animals is being determined. We will be measuring the tenderness, palatability, composition and chemical tenderness factors to try and understand factors that impact variability in Texas beef.

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Table 1. Least squares means for average daily gain and live weight characteristics.

| Nutrition/ Environmental Treatment | Beginning Test Weight, lbs. | End Weight Stocker Phase, lbs | Average Daily Gain Stocker Phase, lbs/day | Average Daily Gain Feedlot Phase, lbs/day | Length of Time Fed A High Concentrate Diet | End Weight Feedlot Phase, lbs |
|--|--------------------------------------|--|---|---|--|--|
| | .93 ^a | .0001 | .0001 | .0001 | .0001 | .0001 |
| McGregor-Calf | 625.2 | -- | -- | 1.82 ^c | 225.0 ^e | 1055.7 ^c |
| McGregor-Low | 617.0 | 778.4 ^d | 1.37 ^d | 3.10 ^d | 139.5 ^d | 1203.2 ^{de} |
| Uvalde-Low | 619.2 | 708.5 ^c | 0.55 ^c | 3.83 ^{ef} | 128.0 ^{cd} | 1134.8 ^{cd} |
| Uvalde-High | 632.0 | 836.6 ^e | 1.50 ^d | 3.46 ^{de} | 114.8 ^c | 1197.5 ^{de} |
| Overton-Low, Rotational | 641.7 | 734.9 ^{cd} | 0.79 ^c | 4.60 ^g | 124.0 ^c | 1253.7 ^{ef} |
| Overton-Low, Continuous | 632.8 | 780.1 ^{de} | 1.44 ^d | 4.11 ^{fg} | 130.0 ^{cd} | 1245.7 ^{ef} |
| Overton-High, Rotational | 613.0 | 840.5 ^{ef} | 2.03 ^e | 3.41 ^{de} | 119.3 ^c | 1203.3 ^{de} |
| Overton-High, Continuous | 648.2 | 895.2 ^f | 2.28 ^e | 4.10 ^{fg} | 119.3 ^c | 1311.1 ^f |
| Root Mean Square Error ^b | 65.48 | 72.74 | .375 | .635 | 17.79 | 104.94 |

^aP-value from the Analysis of Variance table.^bFrom the Analysis of Variance table.^{cdefg}Least squares means within a column lacking a common superscript differ (P < .05)

Table 2. Least squares means for carcass yield grade traits.

| Effect | Adjusted Fat Thickness (inches) | Ribeye Area (inches ²) | Kidney, Pelvic, and Heart Fat (%) | Hot Carcass Weight (lbs) | Yield Grade |
|-------------------------------------|---------------------------------|------------------------------------|-----------------------------------|--------------------------|-------------|
| Kill (Treat) ^a | .39 | .97 | .0003 | .91 | .55 |
| Fat Thickness ^a | | .32 | .0001 | .0001 | .0001 |
| <u>Treatment</u> ^a | .39 | .03 | .0005 | .0017 | .37 |
| McGregor-Calf | .39 | 12.32 ^{cd} | 1.89 ^c | 683.1 ^c | 2.83 |
| McGregor-Low | .57 | 11.95 ^{cd} | 2.45 ^{de} | 691.6 ^c | 3.09 |
| Uvalde-Low | .51 | 11.46 ^c | 2.31 ^d | 667.7 ^c | 3.13 |
| Uvalde -High | .40 | 11.90 ^{cd} | 2.78 ^e | 709.9 ^{cd} | 3.24 |
| Overton-Low, Rotational | .52 | 12.66 ^{cde} | 1.93 ^c | 758.8 ^{de} | 3.02 |
| Overton-Low, Continuous | .54 | 13.60 ^{de} | 2.18 ^{cd} | 774.2 ^{de} | 2.82 |
| Overton-High, Rotational | .50 | 12.38 ^{cde} | 2.14 ^{cd} | 733.0 ^{cde} | 3.05 |
| Overton-High, Continuous | .54 | 13.65 ^e | 2.36 ^{de} | 790.9 ^e | 2.90 |
| Root Mean Square Error ^b | .200 | 1.413 | .380 | 67.897 | .389 |

^a P-value from analysis of variance tables.

^b From the Analysis of Variance table.

^{cde} Mean values within a column and followed by the same letter are not significantly different ($P > 0.05$).

Table 3. Least squares means for carcass quality grade traits.

| Effect | Marbling ^b | Lean Maturity ^c | Skeletal Maturity ^c | Overall Maturity ^c | Quality Grade ^d |
|-------------------------------------|-----------------------|----------------------------|--------------------------------|-------------------------------|----------------------------|
| Kill (Treat) ^a | .58 | .94 | .008 | .75 | .76 |
| Fat Thickness ^a | .0001 | .09 | .01 | .43 | .0001 |
| <u>Treatment^a</u> | .37 | .54 | .0001 | .38 | .47 |
| McGregor-Calf | 539 | 165 | 153 ^g | 159 | 392 |
| McGregor-Low | 572 | 162 | 143 ^f | 153 | 404 |
| Uvalde-Low | 481 | 155 | 138 ^f | 146 | 368 |
| Uvalde-High | 551 | 164 | 148 ^{fg} | 156 | 416 |
| Overton-Low, Rotational | 547 | 144 | 152 ^g | 148 | 415 |
| Overton-Low, Continuous | 523 | 147 | 156 ^{gh} | 152 | 398 |
| Overton-High, Rotational | 501 | 172 | 153 ^g | 162 | 380 |
| Overton-High, Continuous | 521 | 155 | 164 ^h | 160 | 400 |
| Root Mean Square Error ^e | 79.4 | 27.62 | 9.02 | 15.47 | 45.01 |

^a P-value from analysis of variance tables.

^b Marbling: 400=slight, 500=small.

^c Maturity: 100=A, 200=B.

^d Quality Grade: 200=Standard, 300=Select, 400=Choice.

^e From the Analysis of Variance table.

^{fg} Mean values within a column and followed by the same letter are not significantly different ($P > 0.05$).

Table 4. Least squares means for 9-10-11th rib separable dissection components.

| Nutrition/Environmental Treatment | n | Rib Weight, lbs | Separable Fat, % | Separable Lean, % | Separable Bone, % | Muscle to Bone Ratio |
|-------------------------------------|----|----------------------|------------------|-------------------|----------------------|----------------------|
| Kill (Treatment) ^a | | .05 | .29 | .11 | .90 | .24 |
| Fat Thickness ^a | | .0003 | .0001 | .07 | .0001 | .24 |
| <u>Treatment</u> ^a | | .0002 | .32 | .07 | .004 | .0001 |
| McGregor-Calf | 15 | 10.87 ^{de} | 32.86 | 49.00 | 17.03 ^a | 2.90 ^e |
| McGregor-Low | 18 | 10.44 ^{cd} | 31.02 | 50.00 | 19.02 ^{cde} | 2.65 ^{cde} |
| Uvalde-Low | 10 | 9.17 ^c | 29.83 | 49.68 | 20.31 ^e | 2.47 ^{cd} |
| Uvalde-High | 16 | 10.67 ^{cde} | 33.44 | 45.95 | 19.96 ^{de} | 2.33 ^c |
| Overton-Low, Rotational | | 12.45 ^{ef} | 33.32 | 49.64 | 17.67 ^{cd} | 2.81 ^{de} |
| Overton-Low, Continuous | | 13.01 ^f | 28.39 | 54.73 | 16.44 ^c | 3.39 ^f |
| Overton-High, Rotational | | 11.11 ^{def} | 27.66 | 50.69 | 21.68 ^e | 2.39 ^{cd} |
| Overton-High, Continuous | | 12.10 ^{ef} | 28.92 | 51.86 | 18.69 ^{cde} | 2.82 ^{de} |
| Root Mean Square Error ^b | | 1.492 | 5.153 | 3.968 | 2.381 | .328 |

^aP-value from the Analysis of Variance table.^bFrom the Analysis of Variance table.^{cdef}Least squares means within a column lacking a common superscript differ (P < .05).

Table 5. Least squares means for 9-10-11th rib chemical analyses.

| Nutrition/Environmental Treatment | Moisture, % | Lipid, % | Protein, % |
|-------------------------------------|-------------|----------|------------|
| Kill (Treatment) ^a | .55 | .80 | .34 |
| Fat thickness ^a | .60 | .17 | .11 |
| <u>Treatment</u> ^a | .56 | .90 | .62 |
| McGregor-Calf | 49.79 | 21.96 | 14.16 |
| McGregor-Low | 49.97 | 23.48 | 14.33 |
| Uvalde-Low | 49.40 | 24.27 | 14.82 |
| Uvalde-High | 48.54 | 24.23 | 12.30 |
| Overton-Low, Rotational | 50.66 | 22.22 | 13.18 |
| Overton-Low, Continuous | 54.96 | 21.20 | 14.50 |
| Overton-High, Rotational | 54.72 | 24.93 | 12.37 |
| Overton-High, Continuous | 49.44 | 22.93 | 13.56 |
| Root Mean Square Error ^b | 4.847 | 4.578 | 2.520 |

^aP-value from the Analysis of Variance table.^bFrom the Analysis of Variance table.

Table 6. Least squares means for Warner-Bratzler shear force values.

| Effect | Shear Force (lbs) |
|--------------------------------------|---------------------|
| Kill (Treat) ^a | .0001 |
| Fat Thickness ^a | .14 |
| <u>Treatment^a</u> | .43 |
| McGregor-Calf | 10.27 |
| McGregor-Low | 9.27 |
| Uvalde-Low | 9.81 |
| Uvalde-High | 9.25 |
| Overton-Low, Rotational | 9.52 |
| Overton-Low, Continuous | 9.99 |
| Overton-High, Rotational | 9.52 |
| Overton-High, Continuous | 9.63 |
| <u>Storage Day^a</u> | .0001 |
| 1 | 10.58 ^{de} |
| 7 | 10.85 ^e |
| 14 | 8.92 ^c |
| 21 | 9.85 ^d |
| 28 | 8.92 ^c |
| 35 | 8.80 ^c |
| Treatment x Storage Day ^a | .16 |
| Root Mean Square Error ^b | 2.626 |

^a P-value from analysis of variance tables.

^b From the Analysis of Variance table.

^{cde} Mean values within a column and followed by the same letter are not significantly different ($P > 0.05$).

Table 7. Least squares means for sensory attributes of myofibrillar tenderness, juiciness, connective tissue, overall tenderness, and overall flavor intensity and cook loss.

| Effect | Juiciness ^c | Muscle Fiber Tenderness ^c | Connective Tissue Amount ^c | Overall Tenderness ^c | Overall Flavor Intensity ^c | Cook Loss,% |
|--------------------------------------|------------------------|--------------------------------------|---------------------------------------|---------------------------------|---------------------------------------|---------------------|
| Kill (Treat) a | .0001 | .0001 | .0003 | .0001 | .45 | .0001 |
| Fat Thickness ^a | .73 | .54 | .58 | .57 | .16 | .77 |
| <u>Treatment^a</u> | .0001 | .14 | .10 | .11 | .17 | .0001 |
| McGregor-Calf | 5.4 ^{fg} | 6.1 | 6.8 | 6.2 | 5.0 | 11.61 ^c |
| McGregor-Low | 4.7 ^d | 5.8 | 6.5 | 5.8 | 5.1 | 14.19 ^g |
| Uvalde-Low | 5.3 ^{fg} | 6.3 | 6.9 | 6.3 | 5.3 | 11.82 ^{ef} |
| Uvalde-High | 4.5 ^g | 6.6 | 7.2 | 6.6 | 5.2 | 16.83 ^h |
| Overton-Low, Rotational | 5.2 ^{efg} | 6.2 | 6.7 | 6.2 | 5.1 | 11.30 ^{de} |
| Overton-Low, Continuous | 5.0 ^{def} | 5.9 | 6.7 | 5.9 | 5.1 | 13.52 ^{fg} |
| Overton-High, Rotational | 4.9 ^d | 6.4 | 7.0 | 6.4 | 5.3 | 10.50 ^{de} |
| Overton-High, Continuous | 5.0 ^{de} | 6.0 | 6.6 | 6.0 | 5.1 | 9.48 ^d |
| <u>Storage Day^a</u> | .89 | .87 | .33 | .86 | .10 | .80 |
| 1 | 5.1 | 6.1 | 6.2 | 6.2 | 5.2 | 13.23 |
| 7 | 5.2 | 6.2 | 6.2 | 6.2 | 5.4 | 12.15 |
| 14 | 5.1 | 6.2 | 6.2 | 6.2 | 5.0 | 11.92 |
| 21 | 5.1 | 6.0 | 6.0 | 6.0 | 5.0 | 12.19 |
| 28 | 5.1 | 6.2 | 6.2 | 6.2 | 5.0 | 12.03 |
| 35 | 5.0 | 6.3 | 6.3 | 6.3 | 5.2 | 12.92 |
| Treatment x Storage Day ^a | .89 | .99 | .96 | .99 | .43 | 1.00 |
| Root Mean Square Error ^b | .83 | 1.21 | 1.80 | 1.20 | .65 | 4.394 |

^a P-value from analysis of variance tables.

^b From the Analysis of Variance table.

^c Sample evaluated on an 8-point scale for myofibrillar tenderness (8=extremely tender, 1=extremely tough), juiciness (8=extremely juicy, 1=extremely tough), connective tissue amount (8=none, 1=abundant), overall tenderness (8=extremely tender, 1=extremely tough), and overall flavor intensity (8=extremely intense, 1=extremely bland).

^{defgh} Means within a column and followed by the same letter are not significantly different (P > 0.05).

Table 8. Least squares means for cooked beefy/brothy flavor, cooked beef fat flavor, bitter off-flavor, metallic off-flavor, serum/bloody off-flavor, sour off-flavor, browned off-flavor, and chemical off-flavor sensory flavor attributes.

| Effect | Cooked Beefy/Brothy ^c | Cooked Beef Fat ^c | Bitter Off-flavor ^c | Metallic Off-flavor ^c | Serum/Bloody Off-flavor ^c | Sour Off-flavor ^c | Browned Off-flavor ^c | Chemical Off-flavor ^c |
|--------------------------------------|----------------------------------|------------------------------|--------------------------------|----------------------------------|--------------------------------------|------------------------------|---------------------------------|----------------------------------|
| Kill (Treat) ^a | .01 | .08 | .89 | .68 | .49 | .002 | .74 | .003 |
| Fat Thickness ^a | .07 | .17 | .99 | .19 | .96 | .44 | .85 | .91 |
| <u>Treatment^a</u> | .05 | .003 | .49 | .85 | .03 | .0007 | .05 | .001 |
| McGregor-Calf | 4.2 ^f | 1.4 ^{ef} | 0.5 | 1.7 | 1.1 ^{ef} | 0.9 ^d | 0.4 ^{ef} | 0.0 ^d |
| McGregor-Low | 4.1 ^f | 1.2 ^{de} | 0.5 | 1.8 | 0.8 ^{de} | 1.1 ^{de} | 0.5 ^f | 0.2 ^{de} |
| Uvalde-Low | 4.1 ^{ef} | 1.6 ^f | 0.5 | 1.7 | 1.1 ^{ef} | 1.5 ^e | 0.1 ^d | 0.3 ^{de} |
| Uvalde-High | 4.2 ^f | 1.3 ^{def} | 0.8 | 1.7 | 1.0 ^{def} | 1.3 ^{de} | 0.3 ^{def} | 0.3 ^{de} |
| Overton-Low, Rotational | 4.0 ^{def} | 1.2 ^{de} | 0.6 | 1.6 | 1.1 ^{ef} | 1.5 ^e | 0.3 ^{def} | 0.5 ^{ef} |
| Overton-Low, Continuous | 3.7 ^{de} | 1.1 ^d | 0.6 | 1.6 | 0.9 ^{def} | 1.2 ^{de} | 0.1 ^{de} | 0.4 ^e |
| Overton-High, Rotational | 3.7 ^d | 1.2 ^{de} | 0.7 | 1.8 | 0.6 ^d | 1.6 ^e | 0.5 ^{ef} | 0.8 ^f |
| Overton-High, Continuous | 4.0 ^{def} | 1.3 ^{de} | 0.4 | 1.7 | 1.2 ^f | 0.9 ^d | 0.3 ^{def} | 0.3 ^{de} |
| <u>Storage Day^a</u> | .42 | .0003 | .91 | .14 | .36 | .84 | .78 | .54 |
| 1 | 4.1 | 1.4 ^{ef} | 0.6 | 1.8 | 0.8 | 1.3 | 0.2 | 0.3 |
| 7 | 1.6 | 1.6 ^f | 0.6 | 1.6 | 1.1 | 1.3 | 0.3 | 0.4 |
| 14 | 1.2 | 1.2 ^{de} | 0.5 | 1.8 | 1.0 | 1.3 | 0.4 | 0.4 |
| 21 | 1.1 | 1.1 ^d | 0.5 | 1.5 | 0.8 | 1.2 | 0.2 | 0.6 |
| 28 | 1.0 | 1.0 ^d | 0.6 | 1.6 | 0.9 | 1.2 | 0.4 | 0.3 |
| 35 | 1.4 | 1.4 ^{ef} | 0.5 | 1.7 | 1.1 | 1.1 | 0.3 | 0.2 |
| 1 | | | | | | | | |
| Treatment x Storage Day ^a | .84 | .53 | .77 | .87 | .66 | .86 | .81 | .36 |
| Root Mean Square Error ^b | .84 | .60 | .72 | .65 | .82 | .99 | .75 | .88 |

^a P-value from analysis of variance tables.^b From the Analysis of Variance table.^c Sample evaluated on an 8-point scale for flavor intensity (8=extremely intense, 1=extremely bland).^{defg} Mean values within a column and followed by the same letter are not significantly different (P > 0.05).

Table 9. Least squares means for chemical tenderness measures.

| Nutrition/Environmental Treatment | Sarcomere length, μm | Calpastatin, activity | Total Collagen, mg/g | Collagen Solubility, % | Moisture, % | Lipid, % |
|-------------------------------------|---------------------------------|-----------------------|----------------------|------------------------|-------------|----------|
| Kill (Treatment0 ^a | .35 | .62 | .03 | .31 | .41 | .40 |
| Fat Thickness ^a | .63 | .98 | .10 | .06 | .04 | .003 |
| <u>Treatment</u> | .36 | .41 | .003 | .30 | .96 | .36 |
| McGregor-Calf | 1.63 | 2.54 | 2.31 ^c | 5.02 | 70.31 | 3.98 |
| McGregor-Low | 1.57 | 3.47 | 2.78 ^{cd} | 4.23 | 70.87 | 3.81 |
| Uvalde-Low | 1.61 | 4.09 | 2.66 ^{cd} | 6.55 | 71.12 | 3.96 |
| Uvalde-High | 1.66 | 3.63 | 3.63 ^{de} | 4.60 | 70.58 | 3.97 |
| Overton-Low, Rotational | 1.60 | 2.90 | 3.26 ^{cde} | 2.94 | 70.43 | 3.17 |
| Overton-Low, Continuous | 1.51 | 2.26 | 4.17 ^{ce} | 3.81 | 69.71 | 4.74 |
| Overton-High, Rotational | 1.67 | 1.71 | 3.84 ^{de} | 5.92 | 70.88 | 2.83 |
| Overton-High, Continuous | 1.63 | 2.10 | 4.14 ^e | 3.31 | 70.01 | 3.56 |
| Root Mean Square Error ^b | .11 | 2.139 | 1.056 | 2.581 | 2.538 | 1.340 |

^aP-value from the Analysis of Variance table.

^bFrom the Analysis of Variance table.

Table 10. Simple correlation coefficients between Warner-Bratzler shear force and marbling score, chemical measurements of tenderness, and live animal average daily gains.

| Warner-Bratzler shear force by storage day | Marbling | Sarcomere length, μm | Calpastatin activity, activity/gm | Collagen | | Moisture, % | Lipid, % | Stocker average daily gain, lbs / day | Feedlot average daily gain, lbs / day | Days on feed |
|--|----------|------------------------------------|---|----------|---------------|------------------|-------------------|--|--|-------------------|
| | | | | Amount | Solubility, % | | | | | |
| Shear force at 1 day | -.20 | -.18 | -.11 | .01 | .00 | .19 | -.20 | .09 | -.14 | .18 |
| Shear force at 7 days | -.14 | -.24 ^a | -.07 | -.03 | .05 | .07 | -.07 | -.11 | .11 | -.01 |
| Shear force at 14 days | -.10 | -.17 | -.10 | -.09 | -.09 | .23 ^a | -.21 ^a | -.02 | -.02 | .00 |
| Shear force at 21 days | .02 | -.12 | -.01 | .03 | .22 | .08 | -.04 | .14 | -.03 | .01 |
| Shear force at 28 days | -.10 | -.12 | .04 | .05 | .19 | .06 | -.06 | .05 | .09 | -.30 ^a |
| Shear force at 35 days | -.10 | -.20 | -.16 | .04 | -.00 | -.01 | -.15 | -.04 | .22 ^a | -.18 |

^a Significantly different from 0.00 at $P < .05$.

Table 11. Simple correlation coefficients between marbling score, chemical measurements of tenderness, and live animal average daily gains.

| Trait | Marbling | Sarcomere length, μm | Calpastatin activity, activity/gm | Collagen Amount | Collagen Solubility, % | Moisture, % | Lipid, % | Stocker average daily gain, lbs / day | Feedlot average daily gain, lbs / day |
|----------------------------|-------------------|---------------------------------|-----------------------------------|-------------------|------------------------|-------------------|----------|---------------------------------------|---------------------------------------|
| Sarcomere length | .04 | -- | | | | | | | |
| Calpastatin activity | .13 | -.01 | -- | | | | | | |
| Total collagen, mg/g | -.15 | .01 | -.02 | -- | | | | | |
| Collagen solubility | .10 | -.07 | .02 | -.05 | -- | | | | |
| Moisture, % | -.29 ^a | -.13 | -.04 | .01 | .00 | -- | | | |
| Lipid, % | .43 ^a | .11 | .11 | .14 | -.03 | -.65 ^a | -- | | |
| Stocker average daily gain | .14 | .08 | -.14 | .27 ^a | .07 | -.12 | -.01 | -- | |
| Feedlot average daily gain | .13 | -.15 | -.04 | .22 ^a | .04 | -.08 | .06 | -.00 | -- |
| Days on Feed | -.06 | .15 | -.10 | -.28 ^a | -.11 | -.00 | .05 | -.15 | -.77 ^a |

^a Significantly different from 0.00 at $P < .05$.

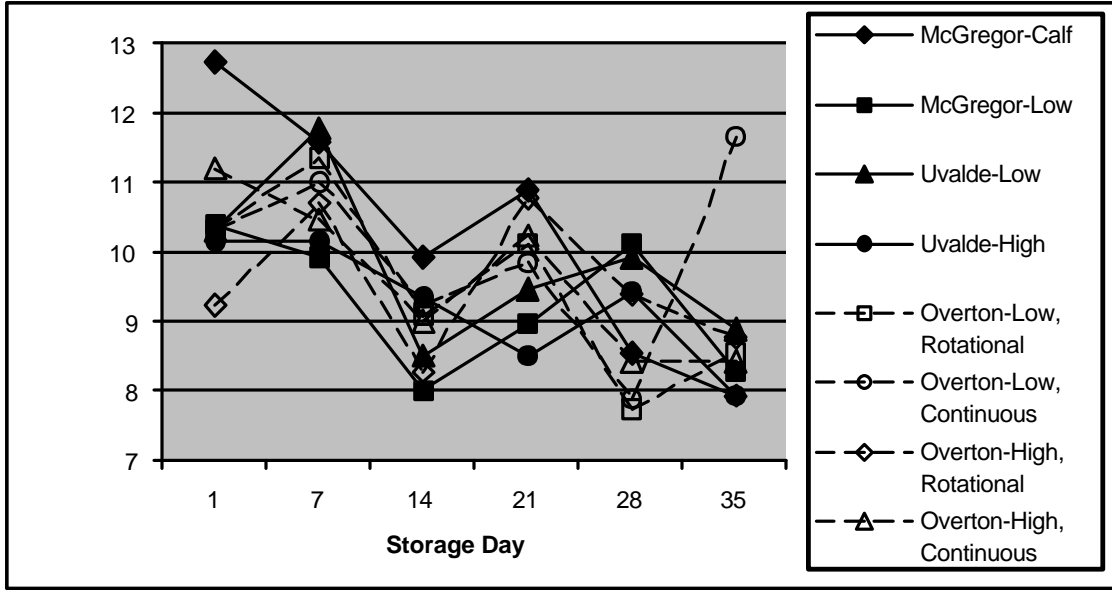


Figure 1. Least squares means for storage day by treatment interaction of Warner-Bratzler shear force (P = 0.16).