THE ROLE OF COAT TYPE ON THERMOREGULATION IN BRANGUS HEIFERS AND THE RELATIONSHIP BETWEEN MEAT QUALITY CHARACTERISTICS AND TENDERNESS OF STEAKS FROM BRANGUS STEERS

By

HEATHER M. HAMBLEN

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To my great-grandpa Albert E. Wilson
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By
Heather M. Hamblen

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Chair: Raluca Mateescu
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The goal of the heat tolerance study is to develop genomic tools to be used in selection programs to improve heat tolerance. Hair type influences thermoregulation in cattle, with variation suggesting selection for a coat advantageous for improved thermotolerance is possible. Coat characteristics and body temperatures at 5-min intervals over a 5-day period were recorded on two-year old Brangus heifers (n=725). A repeated measures mixed model was used to investigate the effect of coat score on body temperature (P < .0001). Heifers with smooth coats maintained lower body temperatures than wooly. A genome wide association study (GWAS) was conducted on coat score, resulting in 141 SNP’s associated at P < 0.001, 21 SNP’s at P < 0.00001, and identification of regions harboring potential candidate genes.

The objective of the tenderness study was to investigate the relationship between USDA quality grade and tenderness, assessed by slice shear force (SSF). Brangus steers (n = 1043) were harvested with approximately 1.27 cm fat over the ribeye and carcass characteristics were evaluated. A steak from the longissimus dorsi muscle was collected from each carcass, aged for 14 d, and used for slice shear force testing. Data
were analyzed with a general linear model with cooking loss, ranch, and feedlot as fixed effects. The quality grades ranged from high standard to average prime and the average SSF was 26.09 ± 8.76 kg. Quality grade had a significant effect on SSF (P = 0.0078). However, there was a high level of variation within quality grades.
CHAPTER 1
BACKGROUND

Cattle producers in tropical and subtropical climates face the challenge of raising animals in environments that often cause heat stress. Heat stress causes significant economic losses to these producers, and losses are only expected to rise with the rapidly increasing population and rise in global temperatures. Heat stress impacts animals negatively and also hinders production. Animals suffering from heat stress reduce feed intake, show a decreased growth rate, decreased reproductive success, and increased mortality (St-Pierre et al., 2003).

Heat stress occurs when the amount of heat produced by an animal is greater than the amount of heat lost to the environment. Producers have been selectively breeding animals for increased production traits for decades, and consequently have also been selecting for greater heat production. This occurs because favorable traits for production often also increases metabolic rate. The focus on production traits has also disregarded selection for adaptability traits such as the ability to regulate heat exchange. An animal’s ability to regulate heat exchange has a major impact on its heat tolerance. In response to extreme heat conditions animals go through two stages of coping (Hahn, 1999). The first stage is to increase heat lost to the environment, through sweating and panting. Ideally an animal would always be able to bring its body temperature back to its thermal neutral zone during this stage, as stage two is when production losses occur. In stage two, the animals will reduce their metabolic rate by reducing feed intake and activity levels.

Multiple factors affect an animal's ability to regulate body temperature through increasing heat loss; one of the major factors is hair coat. Coat color influences the
amount of heat absorbed by the animal’s body from the sun, with black coats absorbing more radiation (Collier and Gebremedhin, 2015). Additionally, coat type (hair length and density) is one of the most important factors influencing the dispersion of heat from the body to the environment (Collier and Gebremedhin, 2015). Longer, thicker hair traps more sweat next to the skin, not allowing it to evaporate efficiently, restricting the primary mechanism cattle use to increase heat loss at high environmental temperatures. The correlation between hair coat score and body temperature in cattle suggests that coat type affects thermoregulatory abilities (Turner and Schleger, 1960), meaning that if producers selected for coat type they may be able to increase the heat tolerance of their animals.

Producers can use crossbreeding as a mating strategy in their herds to allow them to take advantage of the benefits of each breed. Many producers in tropical and subtropical areas cross Bos indicus breeds, such as Brahman, with Bos taurus breeds, like Angus. The adaptability traits of Brahman cattle such as heat tolerance, parasite resistance, and the ability to thrive off low quality forages contribute positively to crossbred herds (Hansen, 2004). B. indicus cattle, such as the Brahman breed, lose heat more efficiently than B. taurus breeds, allowing them to regulate body temperature more effectively (Turner, 1980). However, the B. indicus breed brings less desirable production traits such as slower growth rates and lower quality carcasses, as a result of lower marbling scores, are tougher, and often do not qualify for branded beef programs. In crossbred herds, the B. taurus contributes higher carcass quality and faster growth rates.
Brangus is a breed composed of 3/8 Brahman and 5/8 Angus and is growing in popularity in the Southern U.S. as it was designed to combine the adaptability traits of the Brahman with the positive carcass and growth traits of the Angus. However, even with this mating combination, there are still improvements to be made related to heat tolerance and meat quality.

Beef quality, or the predicted eating satisfaction, determines the price consumers are willing to pay for a product and the price producers receive for a carcass. Currently in the United States, beef carcasses are classified according to quality grades specified by the USDA. Quality grades are determined based on the amount of intramuscular fat (marbling) within the ribeye, between the 12th and 13th rib, and the maturity of the carcass. Producers are paid a premium for high quality and receive discounts for low quality carcasses. The purpose of the quality grading system is to identify carcasses that will bring superior eating satisfaction to the consumer. However, the beef quality grading system does not always accurately predict tenderness or consumer acceptability. According to Campion et al. (1975), marbling accounts for no more than 10% of the variation in sensory traits of beef rib steaks and is a relatively weak predictor of overall consumer acceptability, with an adjusted $R^2$ value of 0.053 according to Platter et al. (2003). Tenderness is the most important quality attribute and inadequate tenderness is a major cause of dissatisfaction in consumers (Morgan et al., 1991). This presents a challenge for the beef industry as tenderness is difficult and expensive to predict due to a large number of factors that influence the ultimate tenderness of a cut of meat, including animal management strategies, rate of post mortem proteolysis, connective tissue, maturity of the animal, breed type, and genetics.
Cattle Production in Tropical Environments

Animal products are an important part of a balanced diet, providing 17% of calorie and 33% of protein consumption for people around the world (Rosegrant et al., 2009). Not only does the livestock industry provide the world with highly nutritious products, but it also employs 1.1 billion people around the world (FAO et al., 2007). This emphasizes that any major concern within the livestock industry should be addressed promptly, as it affects many people. One challenge currently facing the livestock industry is heat stress. It is estimated that the U.S. livestock industry alone loses between 1.69 and 2.36 billion dollars per year due to heat stress (St-Pierre et al., 2003). Furthermore, much of the world’s meat and animal products are produced in tropical and subtropical environments, where the impacts of heat stress on animals are exacerbated. This is an issue that hits home as 40% of the U.S. beef cattle are being raised in environments where they are often exposed to hot and humid conditions ideal for heat stress and 50% of cow/calf producers are located in these areas (FAO, 2010). It is likely that losses due to heat stress will only increase, as animal production continues to increase, especially in these environments. The human population is expected to increase to 9.7 billion people by 2050, up from 7.3 billion in 2015 (UN, 2015). Much of the population growth will be in developing countries, many of which are located in hot and humid environments. In addition to the increase in population, the standard of living is also on the rise in developing countries. An increase in standard of living typically is reflected in an increase in per capita consumption of meat. Animal production must increase significantly, especially in developing countries, to
meet this growing demand. However, the heat stress problems facing these areas may become even worse as global climate change is expected to impact environmental conditions (IPCC, 2007; Bernabucci et al., 2010). Progress needs to be made towards breeding animals that are better adapted for hot environments in order to insure the growing demand will be met.

**Heat Stress**

Heat stress is the sum of environmental conditions that act on the animal to reduce its ability to regulate body temperature. Producers have been selectively breeding animals for increased production traits for decades; consequently, they have also been selecting for greater heat production. This occurs because favorable traits for production often also increase metabolic rate. One example is the growth rate in beef cattle.

Heat stress has many negative impacts on animals, which in turn hinders production and causes economic losses. For producers, some of the most concerning impacts of heat stress on animals are reduced feed intake, decreased growth rates, decreased reproductive success, and increased mortality (St-Pierre et al., 2003). These traits that are being impacted by heat stress are the most important ones for producers, as they affect profits. Animals experiencing heat stress commonly reduce their feed intake, and have decreased growth rates and efficiency of feed conversion (Hahn, 1985). The reduction of feed intake is an effort taken by the animal to decrease the amount of heat produced within the body, in order to keep its body temperature low despite hot conditions. This decrease in feed intake leads to reduced growth rates. Producers are paid for their cattle according to how much they weigh, therefore lower growth rates return lower profits, as producers must either sell animals at a lower weight
or maintain them for a longer period. Dry matter intake, feed efficiency, and growth rates of beef cattle have been reported to decrease at temperatures as low as 27°C if the relative humidity is above 80% and 30°C if it is below 80% (Hahn, 1999). Heat stress not only impacts feed intake and growth rates but also digestion and the environment of the rumen. The pH in the rumen declines, possibly leading to rumen acidosis (Collier and Gebremedhin, 2015), which can cause symptoms such as diarrhea, lethargy, and increased heart and respiratory rate. This change in the pH is mostly due to decreased feed intake, leading to less rumination, therefore less saliva production (Bernabucci et al., 2010). The saliva is a buffering agent that keeps the pH of the rumen high. Additionally, electrolyte concentrations are reduced in ruminal fluid in heat stressed cattle (Sunil Kumar et al., 2011). The alterations in the digestive system lead to the decrease in feed conversion efficiency observed in cattle experiencing heat stress, which increases costs.

Heat stress also affects reproductive performance in cattle. Reduced libido and fertility have been reported in cattle experiencing heat stress, all of which impact reproductive success (Sunil Kumar et al., 2011). Decreased expression of estrus, altered hormone secretion, as well as lowered oocyte growth and quality in heifers and cows are at least partially to blame for the decreased fertility seen in animals exposed to hot conditions (Bernabucci et al., 2010). Expression of estrus is the first major step towards an animal successfully conceiving. Ovulation occurs during estrus, therefore if estrus expression does not occur, conception also does not. Producers can try to combat the issue of decreased conception rates by altering the breeding season to a cooler season, when the negative impact of heat stress is at a minimum. However,
some producers are in regions where cattle are exposed to heat stress conditions almost all year. Additionally, heat stress also affects fetal growth. Fetal growth is reduced if the dam experiences heat stress in late gestation (Sunil Kumar et al., 2011). This issue could lead to calves being born small and frail. Moreover, heat stress may also influence bull fertility. A study conducted using Holstein bulls found that sperm concentration decreases during the summer months (Mathevon et al., 1998). Heat stress has a negative impact on most processes that influence reproductive success from the expression of estrus in females and low sperm concentration in males to fetal development.

Hot environments can also cause health issues in animals, as heat stress has been linked to decreased functioning of the immune system (Sunil Kumar et al., 2011). This finding indicates that cattle suffering heat stress may also be more susceptible to pathogens. The hottest months bring a higher risk of mortality for livestock (Vitali et al., 2009). This could be due to the weakened immune system and the risk of heat stroke. When the body temperature reaches about 3-6°C above normal body temperature, many animals will die (Silanikove, 2000).

As discussed, heat stress causes many issues in beef cattle from decreased growth, decreased reproductive success, and a compromised immune system. These consequences negatively affect both the animal and the producer. Losses to producers incurred by heat stress are high, with an estimated $369 million dollar annual loss for the U.S. beef industry (St-Pierre et al., 2003). Since this problem is so important to the cattle industry, it is imperative to understand the causes of heat stress in cattle and how the problem may be alleviated.
Heat Exchange

Heat is absorbed and lost through heat exchange, which is grouped into two categories: sensible and latent. Sensible heat exchange includes conduction, convection, and radiation. All of these rely on a temperature gradient, or difference between the temperature of the animal and the temperature of the environment.

Conduction is the heat transfer through direct contact with another surface. For cattle, this exchange occurs between the animal’s hooves and the ground or the body and the ground when laying down. If the ground is cooler than the animal, heat is lost and transferred to the ground and vice versa. However, since the surface area of the cow that is in contact with the ground is relatively small, this type of heat exchange does not account for much of the overall heat exchanged. Heat loss by convection occurs when cool air meets the animals warm body, the air is warmed and rises, leaving the animal cooler. The impact of convection depends on the outside temperature. If the outside temperature is higher than the animal’s temperature, the animal will absorb heat instead of eliminating it. Panting is a form of convective heat exchange. Radiant heat exchange involves the absorption or reflection of infrared waves from the sun. Latent heat exchange is the type we will focus on, as it is the only mechanism available when the environmental temperature is high. The two major forms of latent heat exchange are sweating and panting.

Animals have a thermoneutral zone, which is the body temperature range at which an animal does not have to change metabolic processes in order to maintain a normal body temperature, regardless of environmental temperature. Animals attempt to maintain a body temperature within the thermoneutral zone, by regulating heat exchange and production.
In response to extreme heat conditions cattle will go through two stages of coping (Hahn, 1999). The first stage is to increase heat loss. Animals increase heat loss through sweating and panting. Sweating is the primary method cattle use to dissipate heat, with panting being used as a last resort (Collier and Gebremedhin, 2015). Sweat carries heat from the core to the outside of the body. When the sweat is evaporated off the body, it takes heat with it, leaving the animal cooler. As the relative humidity increases, sweating rate becomes less efficient because there is moisture in the air, not allowing evaporation to occur as rapidly. Additionally, increased blood flow to the skin is positively correlated to the sweating rate (Blazquez et al., 1994). By increasing blood flow to the skin, the animal increases the transport of heat from the core of the body to the skin via blood, then allowing it to be excreted in the form of sweat. If sweating alone does not sufficiently cool the animal, panting will occur. As the animal exhales, heat is taken with the air leaving the core of the body cooler. Ideally, animals would remain in their thermal neutral range through using these mechanisms alone, because the second stage is when production losses occur. In the second stage, animals decrease heat production, which occurs if the animal cannot achieve heat balance in the first stage. The animal will reduce its metabolic rate by reducing feed intake and activity in an attempt to decrease the amount of heat its body is producing.

Multiple factors affect an animal’s ability to regulate body temperature through increasing heat loss.

**Hair Coat and Thermoregulation**

The hair coat of an animal is an important factor influencing the ability of cattle to maintain a normal body temperature under extreme environmental conditions. Coat color influences the amount of radiant heat absorbed by the animal, from the sun. Black
coats absorb more solar radiation than lighter coat colors (Collier and Gebremedhin, 2015), due to dark hair possessing a lower reflective ability (da Silva et al., 2003). This causes an increase in the temperature of the skin. One study found that the surface temperature of the skin in Holstein cows increases by 4.8°C for black coat and only 0.7°C for white coat, when exposed to direct sunlight (Collier and Gebremedhin, 2015).

In addition to influencing the skin temperature, hair color also influences rectal temperature, which can be used as an indicator of heat stress. Rectal temperatures of Holstein cows exposed to direct sunlight increased at a rate of 0.7°C/h for black cows and 0.3°C/h for white cows (Hillman et al., 2001). Cattle with black coats spent 89% of their time in the shade, while cattle with white coats spent 55% of their time in the shade (Gebremedhin et al., 2011). Shade reduces the amount of radiation reaching the animals skin from the sun, therefore reducing the amount of heat gained from the environment. The fact that animals with black coats spend more time in the shade than those with white coats suggests that black cattle are more vulnerable to heat stress and must find ways to reduce their heat absorption, in order to regulate body temperature.

Coat type, which is determined by hair length and density, also affects an animal’s ability to regulate body temperature. Hair coat type is one of the most significant factors influencing heat dispersion from the body to the environment (Collier and Gebremedhin, 2015). Hair insulates the body by trapping air and sweat next to the skin, making sensible heat exchange less efficient. A study conducted in Holstein cattle found that evaporative heat loss from sweating was greater in slick haired animals when compared to those with longer, thicker hair (Dikmen et al., 2008). Longer, thicker hair traps more sweat next to the skin, not allowing it to evaporate efficiently. This restricts
the primary mechanism cattle use to increase heat loss. Another study using Holstein cattle further emphasized the importance of the hair type and quantified the effect of hair coat on sweating rate. Sweating rate was measured on shaved areas and unshaved areas on the same animals. There was a significant difference in sweating rate between the shaved and unshaved regions, with the sweating rate of the shaved regions being significantly higher (Dikmen et al., 2008). When sweating rate was measured on shaved regions, the differences in sweating rates between individual animals were eliminated, indicating that hair impedes sweating rate and emphasizes that it is the major determinate for sweating rate in cattle.

Furthermore, hair coat type is correlated with body temperatures in cattle, which suggests that coat type impacts thermoregulatory abilities in cattle (Turner and Schleger, 1960). The thermoregulatory benefits of short and thin hair provides for cattle can be carried over to profits for producers, as there is a correlation between coat score and growth rate as well (Turner and Schleger, 1960). For this reason, producers should place emphasis on coat score when selecting cattle, especially in areas where heat stress has a major impact. Coat score is highly heritable with a heritability estimate of 0.63 (Turner and Schleger, 1960), meaning that producers could make improvements in their herds by selecting for coat score. Additionally, a gene known as the SLICK gene has been identified to influence hair coat type (Dikmen et al., 2014). This suggests that genetic selection programs could utilize genetic testing to select for coat type in cattle.

Not only is hair coat color and type important in determining thermoregulatory abilities in cattle but hair shedding is as well.
The time at which animals shed their winter coats has been known to impact weaning weights. Calves born from dams that shed their winter coats by June 1st were 11.1 kg heavier at weaning (Gray et al., 2011). Hair coat characteristics have a significant effect on an animal’s ability to regulate its body temperature and is of great interest to producers looking to raise more heat tolerant animals.

*Bos indicus Influence and Thermotolerance*

Heat stress is a growing concern for producers; however it is not a new concern. Producers in tropical areas commonly introduce *B. indicus* cattle into their herds, to cope with heat stress. The most common *B. indicus* breed used in the U.S. is the Brahman. Brahman cattle are known to be well adapted to the hot and humid environments found in tropical and subtropical areas. They bring heat tolerance, parasite resistance, and adaptability to cow herds and are considered heat tolerant because their productivity is not greatly depressed in hot environments (Finch, 1986). Brahman cattle lose heat more efficiently through evaporative cooling than *B. taurus* breeds, allowing them to regulate their body temperature more effectively (Turner, 1980). The sweating rate of *B. indicus* cattle increases exponentially with rises in body temperature, which contrasts *B. taurus* breeds in which the sweating rate tends to plateau after the initial increase (Finch, 1986). Additionally, Brahman cattle thrive on the low quality forage grown in most of the Southeastern United States because of lower feed intake and maintenance requirements (Turner, 1980). This is important because higher quality forages are difficult and expensive to grow in these regions. Furthermore, Brahman cattle are resistant to many of the parasites that thrive in tropical and subtropical conditions (Turner and Short, 1972). These attributes all contribute to the Brahman breed having a positive impact on the adaptability of tropical cattle herds.
However, with all those desirable adaptability traits, Brahman cattle also have less desirable production traits. A few of the very same traits that allow Brahman cattle to be better adapted to the heat hinder production. Brahman cattle have lower maintenance metabolic rates, feed intake, and growth rates than B. taurus cattle in the absence of heat stress (Frisch and Vercoe, 1977). The low metabolic rate causes the animals to produce less heat, allowing them to be more heat tolerant, but it also decreases growth rates. Additionally, Brahman cattle tend to have lower carcass quality attributes, with lower tenderness and quality grades, which will be discussed in the next section. Producers commonly cross Brahmans with B. taurus breeds, such as Angus, in an attempt to increase meat quality while maintaining the desirable adaptability traits of the Brahman. An example of this is the Brangus breed that is growing in popularity in the Southern U.S. Brangus is a breed made up of 3/8 Brahman and 5/8 Angus. However, this has not solved all of the heat stress and meat quality problems.

**Beef Quality**

Beef quality, or the predicted eating satisfaction, determines the price consumers are willing to pay for a product and the price producers receive for a carcass. Currently in the United States, beef carcasses are classified according to quality grades specified by the USDA. The original standards were adopted in 1926 and have been amended 12 times, but the same major elements have been retained since the beginning. The quality grading system is voluntary, with each processing facility determining if they want to participate. Prior to 2006, every carcass was graded by a trained USDA grader. Camera assisted grading has since been approved, meaning that a USDA grader does not have to be present in order for carcasses to be graded. Quality grades are determined based on the amount of intramuscular fat (marbling) within the ribeye,
between the 12th and 13th rib, and the maturity of the carcass. Marbling is the amount of fat within the muscle. The amount of marbling in the ribeye is scored using categories (Practically Devoid, Traces, Slight, Small, Modest, Moderate, Slightly Abundant, Moderately Abundant, and Abundant) and also given a score from 0 to 100 within the category, with a Practically Devoid0 having the least amount of marbling and an Abundant100 having the greatest amount. Maturity is determined by lean color and ossification in the vertebral column. More mature carcasses tend to have a darker lean color. Additionally, older animals will have a greater amount of ossification in the vertebrae. Ossification occurs when the cartilage turns to bone, which happens as an animal ages. Carcass maturity is classified as A, B, C, D, or E based on a combination of lean color and ossification, with an A being the youngest and an E being the most mature. The maturity level determines the quality grades a carcass qualifies for. The USDA quality grades available for youthful carcasses (A or B maturity) are Prime, Choice, Select, and Standard, based on the amount of marbling in the ribeye. The animals in these categories are all assumed to be less than 42 months of age. Commercial, Utility, Cutter, and Canner are the quality grades that carcasses classified as hardbone, or old (C, D, and E maturity) are eligible for. Many processing facilities do not grade carcasses that are classified as C or greater maturity, but classify them as No Roll. No Roll includes all hardbone carcasses, dark cutters, B maturity with slight marbling, blood splash, and carcasses with other defects.

Each carcass is assigned a quality grade based on a combination of the amount of marbling in the ribeye and the maturity, as shown in Table 2-1. The quality grades
given to carcasses determine the payout, as producers are paid a premium for high quality carcasses and discounts for low quality.

Table 2-1. Maturity classification and marbling scores corresponding to each quality grade

<table>
<thead>
<tr>
<th>USDA quality grade</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prime ‡</td>
<td>Abundant⁰⁰</td>
<td>Abundant⁰⁰</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prime †</td>
<td>Moderately Abundant⁰⁰</td>
<td>Moderately Abundant⁰⁰</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prime ‡</td>
<td>Slightly Abundant⁰⁰</td>
<td>Slightly Abundant⁰⁰</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Choice ‡</td>
<td>Moderate⁰⁰</td>
<td>Moderate⁰⁰</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Choice †</td>
<td>Modest⁰⁰</td>
<td>Modest⁰⁰</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Choice ‡</td>
<td>Small⁰⁰</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select ‡</td>
<td>Slight⁰⁰</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select †</td>
<td>Slight⁰⁰</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard ‡</td>
<td>Traces⁰⁰</td>
<td>Traces⁰⁰</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard †</td>
<td>Partially Devoid⁰⁰</td>
<td>Partially Devoid⁰⁰</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial ‡</td>
<td>Moderate⁰⁰</td>
<td>Slightly Abundant⁰⁰</td>
<td>Abundant⁰⁰</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial †</td>
<td>Modest⁰⁰</td>
<td>Moderate⁰⁰</td>
<td>Slightly Abundant⁰⁰</td>
<td>Abundant⁰⁰</td>
<td></td>
</tr>
<tr>
<td>Commercial ‡</td>
<td>Small⁰⁰</td>
<td>Modest⁰⁰</td>
<td>Moderate⁰⁰</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utility ‡</td>
<td>Slight⁰⁰</td>
<td>Small⁰⁰</td>
<td>Modest⁰⁰</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utility †</td>
<td>Traces⁰⁰</td>
<td>Slight⁰⁰</td>
<td>Small⁰⁰</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utility ‡</td>
<td>Partially Devoid⁰⁰</td>
<td>Traces⁰⁰</td>
<td>Slight⁰⁰</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The purpose of the quality grading system is to identify carcasses that will bring superior eating satisfaction to the consumer. The traits being used to determine quality grade are used to predict this. A higher degree of marbling tends to lead to more tender meat (Aberle et al., 2001) as well as protecting the other qualities such as juiciness from improper cooking methods, and positively influencing flavor. Maturity is measured in order to decrease the likelihood of a consumer being dissatisfied with the tenderness of a product. Mature carcasses tend to have tougher meat.

The quality traits that primarily determine overall consumer liking of beef are flavor, tenderness, and juiciness (Hunt et al., 2014); of these, tenderness is the most important (Huffman et al., 1996; Miller et al., 2001). A steak with a higher degree of marbling tends to be more tender, juicy, have a more intense flavor and a higher likelihood of delivering a positive eating experience (Emerson et al., 2013). Overall consumer acceptance increased about 10% for each full marbling score in a study conducted by Platter et al. (2003).

**Tenderness**

The beef quality grading system does not always accurately predict tenderness or consumer acceptability. It has been reported that marbling accounts for no more than 10% of the variation in sensory traits of beef rib steaks (Campion et al., 1975) and has been found to have a relatively weak prediction of overall consumer acceptability, with an adjusted $R^2$ value of 0.053 (Platter et al., 2003). Inadequate tenderness is the biggest cause dissatisfaction with beef products (Morgan et al., 1991), presenting a challenge for the beef industry. Consumers are willing to pay a higher price if a beef cut is guaranteed to be tender (Miller et al., 2001). In fact, when it comes to a purchasing decision tenderness is ranked higher than price by consumers (Reicks et al., 2011).
Shackelford et al. (2001) showed that 50% of consumers were willing to pay $1.10 per kilogram premium for beef that was guaranteed tender. Tenderness is of great interest to producers since consumers place high importance on it and are even willing to pay a premium. Therefore, if tenderness of a carcass is known, producers could receive premiums for producing tender beef, instead of the quality premiums being placed solely on quality grades. However, tenderness is influenced by many different factors, making it difficult to control and predict. A few of the factors influencing beef tenderness are management and handling techniques, post mortem proteolysis, connective tissue, maturity, breed type, and genetics (Aberle et al., 2001). The decline of pH post mortem and the ultimate pH of beef influences the rate of post mortem proteolysis and the ultimate tenderness (Watanabe et al., 1996). Management practices and techniques used on the carcass post mortem, such as electrical stimulation and aging, can also influence overall tenderness of the final product.

**Post-mortem Proteolysis**

Proteolysis, or the breakdown of proteins, begins post mortem and is a major contributor to the overall tenderness of beef. Meat becomes tougher following slaughter because the sarcomeres, which are the contractile units of muscle, shorten and actomyosin cross-bridges form during rigor development (Koohmaraie et al., 1996), making the muscle more dense. After this initial toughening phase, proteolysis begins. During proteolysis, enzymes degrade myofibrillar proteins. The common practice of aging beef takes advantage of proteolysis to improve the tenderness. The extent of proteolysis of key target proteins within muscle fibers is the main determinant of the ultimate tenderness of beef (Taylor et al., 1995; Koohmaraie and Geesink, 2006).
The calpain system is widely recognized to play a major role in post mortem tenderization. Calpains are calcium activated proteases, or enzymes, that degrade key myofibrillar proteins (Huffman et al., 1996). Calpastatin also plays an important role in beef tenderness as an inhibitor of calpain. There is a positive relationship between calpastatin content and meat toughness (Johnson et al., 1990; Wheeler et al., 1990; Shackelford et al., 1991). In fact, 40% of the variation in the tenderness of aged beef can be accounted for by differences in calpastatin activity 24 hours post mortem (Shackelford et al., 1994).

**Connective Tissue**

The type, abundance, and state of crosslinking of connective tissue has an influence on tenderness. A major determinant of the impact connective tissue has on tenderness is the maturity of the animal. Connective tissue is made up primarily of collagen with crosslinks holding the collagen molecules together. The collagen in young cattle hydrolyzes to form gelatin during cooking, minimizing its negative impact on tenderness (Tatum, 2001a). This occurs because the crosslinks between collagen is heat labile. In contrast, as animals age, crosslinks become more stable and heat resistant, which has a negative impact on tenderness (Tatum et al., 1982).

Nevertheless, the results from the 2005 National Beef Quality Audit showed that only 3% of fed steers and heifers were classified as B maturity or older (Garcia et al., 2008). Therefore, to improve tenderness our focus should be elsewhere.

**Meat quality Traits: *Bos taurus* vs. *Bos. indicus***

Meat quality traits such as tenderness and marbling vary significantly between *B. taurus* and *B. indicus* breeds. On average, Brahman (*B. indicus*) cattle have less desirable carcass and meat palatability traits than meat from *B. taurus* breeds (Johnson
et al., 1990; Shackelford et al., 1991; Pringle et al., 1997; Wheeler et al., 2010). Steaks from Brahman steers are less tender and tenderness is more variable than those from Angus steers based on both objective tenderness measurement by Warner-Bratzler shear force and consumer sensory panels (Bidner et al., 2002; Elzo et al., 2012a). Brahman cattle are often used in crossbred herds; therefore, it is important to investigate the influence of Brahman genetics on tenderness in crossbred animals. High percentage Brahman animals have meat with lower tenderness (Peacock et al., 1982; Crouse et al., 1989). However, tenderness fluctuates as the percentage of Brahman decreases. Johnson et al. (1990) found that steaks from Angus-Brahman crossbred steers with a 25% or lower percentage Brahman breeding were more tender than steaks from steers with 50% or higher Brahman percentage. There appears to be a more tender to less tender continuum when moving from Angus to Brahman breeding (Elzo et al., 2012a). Elzo et al. (2012) found that limited negative impacts on meat quality occurred in crossbred animals with percentage Brahman up to 50% while maximizing meat yield due to heterosis. Thus, animals with Brahman genetics can produce an acceptably tender product, but producing animals with lower percentages of Brahman breeding may be the key. Johnson et al. (1990) found that proteolysis on steaks from Brahman-Angus crossbred cattle with 50% or 75% Brahman composition occurred at a slower rate than steaks from Angus or 25% Brahman cattle. Furthermore, O’Conner et al. (1997) identified that beef from 3/8 Brahman cattle was relatively tender if it was aged for 21 days, which is longer than the industry standard of 14 days. Lower tenderness and slower rate of post mortem aging in B. indicus breeds is caused in part by higher calpastatin activity in the muscle (O’Connor et al., 1997; Pringle et al., 1997).
This increases the inhibition of calpain proteinases, therefore negatively impacting the post mortem tenderization process (Koohmaraie, 1992). Additionally, calpastatin activity has been found to increase as the percentage of Brahman breeding increases (Pringle et al., 1997; Wright et al., 2018)

**Genetic Influences on Tenderness**

Genetics also play an important role in the ultimate tenderness of beef, as suggested by the tenderness differences between *B. taurus* and *B. indicus* influenced cattle. Tenderness and calpastatin activity are moderately to highly heritable within breeds (Shackelford et al., 1994; Wulf et al., 1996). This suggests that selection for and prediction of ultimate tenderness may be possible. Once identified, genetic markers could be used to determine an animal’s genetic capability of producing acceptably tender meat.

Single nucleotide polymorphisms (SNPs) are used as markers for commercial genetic tests and can be used in genetic selection programs. A SNP is a change of a single base pair in the DNA. This change, if in an encoding region, can change the amino acid composition of the protein. Genetic markers have been identified within *CAPN1* and *CAST*, the genes that encode for µ-calpain and calpastatin, respectively (Casas et al., 2006). Multiple SNPs causing amino acid substitutions have been identified in *CAPN1*, and these SNPs are associated with tenderness (Page et al., 2002). Polymorphisms that are associated with tenderness have also been found in the *CAST* gene. However, these genetic markers should be identified within the breed they will be used in order to achieve the highest accuracy (Kachman). Furthermore, the accuracy of markers found in *B. taurus* breeds to predict traits in *B. indicus* breeds is very low. The reason for low accuracy is that the genetic relatedness is not close,
therefore the linkage disequilibrium between breeds may be completely different. For example, a SNP found in Angus may not be polymorphic in a Brahman population. This means that all animals have the same nucleotide base at that locus. Another challenge is that breeds like Brangus are derived from *B. taurus* and *B. indicus* genetics, meaning research needs to be done within the breed to identify genetic markers specifically associated with the trait in that breed, in order for prediction to be maximally accurate.

**Prediction of Tenderness**

Improving tenderness is an important issue facing the beef cattle industry. Consumers are willing to pay more for beef that is guaranteed to be tender. However, with so many factors influencing the ultimate tenderness outcome, predicting tenderness, in a cost effective, manner proves to be a challenge. Currently, shear force testing is the only reliable method to determine beef tenderness (Koohmaraie and Geesink, 2006). With this method, some product must be sacrificed for the testing and it must be done after the carcass has already started to be fabricated. Additionally, it would be too costly to implement at an estimated $4.35 per carcass to automatically classify carcasses using shear force (Wheeler et al., 1999). A possible future prediction method is genetic testing. As more markers in different breeds are identified to predict an animal's genetic potential for producing acceptably tender meat, the accuracy of prediction will increase. Commercial genetic tests could be used to predict ultimate tenderness of beef products, provided environmental conditions are specified and uniform. This could lead to a greater profit for producers whose animals qualify for a branded beef program or a specific marketing claim.
Branded Beef Programs and Marketing Claims

Branded beef programs and marketing claims can add value to a carcass. *B. indicus* influenced cattle are at a disadvantage when it comes to qualifying for high dollar branded beef programs and marketing claims. Most branded beef programs require a choice or higher quality grade as well as have restrictions on hump height, leaving *B. indicus* cattle at a disadvantage (USDA Certified Beef Programs). However, *B. indicus* influenced cattle can produce tender meat that is acceptable to the consumer. An AMS approved marketing claim that is currently on the market is Certified Tender beef. In order for a carcass to qualify for the Certified Tender claim, the tenderness of the longissimus dorsi muscle must be directly measured using Warner Bratzler Shear Force (WBSF) or Slice Shear Force (SSF). The minimum tenderness value for this claim is 4.4 kg for WBSF and 20 kg for SSF. If the WBSF measurement is 0.5 kg less or 4.6 kg less for SSF the product can be labeled Very Tender.

Conclusion

Heat stress causes economic losses for producers, as it causes decreased growth rates, decreased reproductive success, and increased mortality in cattle. Producers in tropical and subtropical environments where animals are exposed to hot conditions for much of the year are hit hardest by losses occurring from heat stress. Heat stress in cattle will continue to be a challenge as global climate change is expected to cause increases in temperature. The demand for beef is also expected to increase, causing production levels to increase, especially in tropical areas. Research has shown that certain animals regulate body temperature more effectively and are more resistant to heat stress. Hair coat plays an important role in temperature
regulation, as it influences the amount of radiant heat absorbed from the sun and sweating rate, the primary heat loss mechanism for cattle. Hair coat type is under genetic control, therefore producers can improve the heat tolerance in their herd by selecting for lighter colored, shorter, smoother hair coats. The introduction of Brahman cattle to herds and the use of breeds such as Brangus, have increased the adaptability of cattle in harsh environments. However, the *B. indicus* influence also tends to bring poorer meat quality traits. The beef quality traits most important to consumers are tenderness, juiciness and flavor. In the United States carcasses can be given a USDA quality grade to predict the eating satisfaction of each particular carcass, which determines the price the consumer pays and the price paid to the producer. This system does not, however, always accurately predict tenderness, which is the most important attribute to consumers (Tatum, 2001b). Prediction of tenderness is challenging because it is influenced by many different factors including management and handling techniques, post mortem proteolysis, connective tissue, maturity, breed type, and genetics. Although *B. indicus* influenced animals tend to produce less tender meat, some individuals produce tender meat that is acceptable to consumers. Genetics impact tenderness, making it possible for producers to select animals that will produce more tender meat. Furthermore, producers raising *B. indicus* influenced cattle could capitalize on their tender carcasses by qualifying and using the guaranteed tender claim on their products.
CHAPTER 3
THERMOREGULATORY RESPONSE OF BRANGUS HEIFERS TO NATURALLY OCCURRING HEAT EXPOSURE ON PASTURE

Introduction

In 2003, it was estimated that the U.S. livestock industry suffers an annual economic loss of 1.69 to 2.36 billion dollars due to heat stress (St-Pierre et al., 2003). These losses expected to increase upon the realization of predicted climate change (IPCC, 2007), with average temperatures in the United States projected to increase 2° to 6°C, by 2100 (USGCRP, 2009). Approximately 50% of the total world meat and 60% of milk originates from tropical and subtropical environments, where climate change is expected to impact the most (FAO, 2010). B. indicus genetics are commonly introduced into beef cattle herds in these areas, as they are better adapted to hot and humid conditions (Hansen, 2004). This practice has improved the heat adaptability in the crossbred herds (Hammond et al., 1998; Olson et al., 2003); however, it also introduced other challenges primarily related to meat quality and reproduction (Freetly and Cundiff, 1997; Elzo et al., 2012b; Elzo et al., 2014). Identification of animals with the ability to regulate body temperature in hot and humid environments, while still maintaining high performance for important production traits will hold the key to future success for cattle production in harsh environments. Hair type, sweating rate and temperament are among the factors affecting the ability of animals to maintain their body temperature within normal physiological limits in a heat stress situation. However, the magnitude of the impact these factors have on body core temperature of animals maintained on pastures has not been previously investigated. The first objective of this study was to assess the phenotypic variability of sweating rate and vaginal temperature of Brangus heifers, grazing pasture in South Florida. The second objective was to evaluate the
effect of coat type, temperament behavior as described by chute and exit scores, and

weight on sweating rate and vaginal temperature.

Materials and Methods

Animals and Sample Collection

The University of Florida Institutional Animal Care and Use Committee approved
the research protocol used in this study (number 201503578).

A total of 725 two-year old Brangus heifers from the Seminole Tribe of Florida, Inc. were evaluated under hot and humid conditions during August and September 2016 at the Seminole Ranch, west of Lake Okeechobee (Brighton Reservation, FL, 27-04’46” N; 081-04’11” W). The heifers were randomly assigned to one of four groups and were maintained on pasture for the duration of the study. The first group (n = 200) was monitored from August 15 to August 19, the second group (n = 189) from August 22 to August 26, the third group (n = 197) from August 29 to September 2, and the fourth group (n = 139) from September 9 to September 12, 2016.

Environmental Measurements

Dry bulb temperature (Tdb) and relative humidity (RH) were measured every 15 min during the entire time of data collection from August 15 to September 12, 2016 using HOBO U12 data loggers (Onset Company, Bourne, MA, USA).

The temperature-humidity index (THI) was used to quantify heat stress, as it is a better indicator of heat stress conditions than temperature alone. It was calculated as follows (NRC, 1971):

\[
THI = (1.8 \times Tdb + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times Tdb - 26)]
\] (3-1)
Physiological Measurements

All heifers within a group were gathered early in the morning and were individually restrained in a squeeze-chute for insertion of temperature-recording devices and measurement of sweating rate, coat color, coat score, chute score and exit score. Additionally, live weight was recorded as they passed over the scale, immediately before entering the chute. A blood sample was also collected at this point in time, by tail vein.

Vaginal temperature, a direct measurement of an animal’s ability to prevent hyperthermia during heat stress, was recorded for five consecutive days using iButton data loggers, type DS1922L, temperature range -40°C to 85°C, accuracy +/- 0.5°C, 11-bit for 0.0625°C resolution (Maxim Integrated, San Jose, CA). The iButtons were attached to a blank controlled internal drug-releasing device (CIDR) and were inserted into the vagina. Each iButton was calibrated before the start of the study and pre-programmed to record body temperature at 5 min intervals on a 24-h cycle. At the end of the 5-day trial, the data was downloaded and iButtons and CIDRs were sanitized for the next group.

Sweating rate was measured on the rump, 4 inches from spine and halfway along horizontal axis with a calibrated, digital moisture sensor (Vapometer; Delphin Tech. Ltd., Kuopio, Finland) that determines trans-epidermal water loss. The Vapometer uses a closed system approach, free of ambient airflow, to measure ambient relative humidity and temperature. The evaporation rate is displayed in g/(m²·h) with an accuracy of ±10%. The sweating rate was measured for all heifers in groups 2, 3 and 4.

Coat color and coat score were recorded for each heifer while in the chute. A picture of the coat was taken and was used for final confirmation of the coat score. The
coat (COAT) was scored as 1 = very smooth, 2 = smooth, 3 = long, and 4 = woolly (Marufu et al., 2011), as in Figure 3-1. Coat color was excluded from analysis, due to a low number of animals showing a non-black coat. Coat scores 2, 3, and 4 were combined for analysis, due to a low number of animals falling into the 3 and 4 categories.

![Figure 3-1. Coat Score examples, descriptions, and the number of heifers](image)

The chute behavior (CHUTE) was scored as 1 = calm, no movement; 2 = slightly restless; 3 = squirming, occasionally shaking the squeeze chute; 4 = continuous, very vigorous movement and shaking of the squeeze chute; or 5 = rearing, twisting of the body and struggling violently (Grandin, 1993).

Exit behavior (EXIT) was scored as 1 = slow exit, calm or 2 = jump, trot or run.

A blood sample was collected by tail vein. The blood samples were stored on ice until getting back to the lab, where they were stored at -20 C.
Statistical Analysis

For each animal, the average vaginal temperature for each 15-minute window of environmental data was calculated and matched with the measurements of environmental Tdb and THI recorded at the same time. Hourly averages were calculated for environmental measurements and vaginal temperature. Only data recorded during three 24-hour periods starting at 2400 h the day of iButton insertion was used in subsequent analyses to reflect vaginal temperature of cows maintained on pastures without any human interaction. Repeatability of vaginal temperature was calculated:

\[
\text{Repeatability} = \frac{\sigma^2_u}{\sigma^2_u + \sigma^2_e} \tag{3-2}
\]

Data were analyzed with the MIXED procedure in SAS 9.4 (SAS Inst. Inc., Cary, NC) and Restricted Maximum Likelihood (REML) estimation. The linear mixed model (LMM) was:

\[
Y = X\beta + Zu + e \tag{3-3}
\]

where the design matrices X and Z relate phenotypic observations in the vector Y to fixed (β) and random (u) effects, respectively. The vector e contains random residual effects specific to each animal. The vectors u and e were assumed to be normally distributed with 0 means and variances \(\sigma^2_u\) and \(\sigma^2_e\), respectively.

The sweating rate was measured when heifers were in the chute and a time variable was created to represent the hour when a heifer was measured relative to the starting time of the protocol (\(\text{HOUR} = 1, 2, 3 \text{ or } 4\)). The model included group and hour nested within group as random effects. The fixed effects included in LMM were coat score (\(\text{COAT} = 1 \text{ or } 2\)), chute score (\(\text{CHUTE} = 1, \geq 2\)) and exit score (\(\text{EXIT} = 1 \text{ or } 2\)).
Weight of the heifer was included in the model as a covariate. The sweating rate was also adjusted for linear and quadratic effect of time within each HOUR.

The hourly vaginal temperatures were analyzed using repeated measures in a linear mixed model with a first-order autoregressive error structure. Each group of heifers was exposed to different environmental conditions during the three days of data recording used in the analysis. The model included group, day and heifer nested within group and day as random effects. The RANDOM statement was used to model the crossover part of the data and REPEATED statement with a first order autoregressive model AR (1) was used to model the covariance structure of repeated measures on the same heifer during a day. The fixed effects included in LMM were coat score (COAT = 1 or 2), chute score (CHUTE = 1, ≥2) and exit score (EXIT = 1 or 2). Weight of the heifer was included in the model as a covariate.

To quantify the thermal challenge the animals were exposed to during the recording period, a heatstress load (HSL) was calculated for each experimental day. Based on the livestock weather hazard guide (LWSI; LCI, 1970), the following thresholds were used to define the thermal environment: minimal heat stress when THI ≤ 77, moderate heat stress for THI between 77 and 80, major heat stress for THI between 80 and 85, and critical heat stress THI ≥ 85. For group 2 and 3, two extreme days relative to the heat stress conditions (low and high) were identified and subsequently used to assess the thermal response of the same heifers to different HSL. Group 1 and 4 were excluded from this analysis because the difference in HSL was not sufficient to categorize days as low and high heat-stress load. The random variable included in LMM was day within group and first order autoregressive model AR (1) was
used to model the covariance structure of repeated measures on the same heifer during within each day.

**DNA Extraction and Genotyping**

DNA was extracted from the blood sample collected, using the Qiagen DNeasy Blood & Tissue Kit. Each DNA sample was genotyped with the 250K functional SNP chip. Quality control filters were used for minor allele frequency (5%) and call rate for sample and SNP (95%).

**Genome-Wide Association Study**

A GWAS was performed on the phenotype coat score using the single-locus mixed linear model procedure implemented in Golden Helix SVS v8.4.4 software. The efficient mixed model association (EMMAX) approach in combination with a genomic relationship matrix was used to directly estimate the genetic and residual variance components and the proportion of variance explained by the effects of significant SNPs. Significance levels for SNP’s were set at P < 0.001 and P < 0.00001.

**Results and Discussion**

**Sweating Rate**

Summary statistics for sweating rate by group and hour are presented in Table 3-1. Heifer weight and the linear and quadratic effect of time on sweating rate for animals within each hour within a group were significant and kept in the model. A similar time effect was observed in recorded rectal temperature of beef cattle, which was dependent on the order animals were processed through the chute (Hammond and Olson, 1994; Magona et al., 2009; McManus et al., 2009). The estimated variance (σ²u) of groups and hours within group sets was 338.94 ± 155.58 and the estimated residual variance (σ²e) between heifers was 385.89 ± 26.07. The intra-class correlation, calculated as
\( \frac{\sigma^2_u}{\sigma^2_u + \sigma^2_e} \), was 0.47. The intra-class correlation in this dataset represent the repeatability of the trait, or the proportion of variance that is due to permanent environmental and genetic differences among individuals and indicates that one measurement of sweating rate would be sufficient to adequately describe the sweating capacity of an individual.

Table 3-1. Number of animals, average, and standard error for sweating rate of animals in 3 different groups measured within the first, second, third, or fourth hour of the protocol.

<table>
<thead>
<tr>
<th>Group/day</th>
<th>Hour</th>
<th>N</th>
<th>Mean</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 2</td>
<td>1</td>
<td>45</td>
<td>53.86</td>
<td>2.53</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>57</td>
<td>63.63</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>48</td>
<td>83.41</td>
<td>4.03</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>23</td>
<td>80.42</td>
<td>4.82</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>33</td>
<td>69.49</td>
<td>3.25</td>
</tr>
<tr>
<td>Group 3</td>
<td>2</td>
<td>56</td>
<td>68.25</td>
<td>2.42</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>43</td>
<td>82.52</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>44</td>
<td>118.55</td>
<td>3.94</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>36</td>
<td>76.63</td>
<td>3.45</td>
</tr>
<tr>
<td>Group 4</td>
<td>2</td>
<td>39</td>
<td>91.48</td>
<td>3.16</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>51</td>
<td>104.76</td>
<td>2.3</td>
</tr>
</tbody>
</table>

**Vaginal Temperature**

The between heifer’s variance was 0.049 and the within heifer’s variance of hourly vaginal temperature was 0.06, showing that there is variation both between and within heifers (Table 3-2.). The correlation between adjacent hourly measures of vaginal temperature on the same heifer was 0.79. The correlation between any two observations on the same heifer in different days, or the repeatability of vaginal temperature was 0.44. This estimated repeatability is a good indicator that one
measurement of vaginal temperature under heat stress would be sufficient to adequately describe the thermoregulatory capacity of an individual.

Table 3-2. Covariance parameters describing the variability of hourly vaginal temperatures.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>Z value</th>
<th>Pr Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma^2_u$</td>
<td>0.049</td>
<td>0.003</td>
<td>16.18</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>$P$</td>
<td>0.791</td>
<td>0.003</td>
<td>275.63</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>$\sigma^2_e$</td>
<td>0.062</td>
<td>0.001</td>
<td>73.44</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Estimate, standard errors, and statistical significance for between heifer variance ($\sigma^2_u$), correlation between two adjacent vaginal temperature measures ($P$), and within heifer variance ($\sigma^2_e$).

The THI ranged from a minimum of 73 to a maximum of 89. Days within all heat stress load categories (minimal < 77, moderate 77-80, major 81-85, and critical heat stress >85) were encountered in the present study. There was also a high level of variation in the vaginal temperature, which ranged overall from 36.6°C to 42.3°C. Most importantly, there was a high level of variation in the maximum vaginal temperature for the individual animals ranging between 38.8°C and 42.3°C, allowing for investigation of factors responsible for this variation. Table 3-3 shows the mean vaginal temperatures, environmental temperature and THI for each day and each group of cattle. The intensity and duration of a thermal challenge determines an animal’s response to the environmental conditions. Heat stress load for each day was determined using the THI. Figure 3-2 show the THI over 3 days for all four groups.
Table 3-3. Vaginal temperature and environmental conditions during the study

<table>
<thead>
<tr>
<th>Group</th>
<th>Day</th>
<th>Vaginal Temperature</th>
<th>Dry bulb temperature</th>
<th>Relative humidity</th>
<th>THI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>38.88 (0.45)</td>
<td>28.68 (0.37)</td>
<td>81.35 (1.62)</td>
<td>80.53 (0.35)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>39.01 (0.41)</td>
<td>28.28 (0.33)</td>
<td>82.01 (1.58)</td>
<td>80.05 (0.30)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>39.04 (0.41)</td>
<td>28.24 (0.31)</td>
<td>82.02 (1.39)</td>
<td>80.08 (0.31)</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>39.01 (0.53)</td>
<td>28.71 (0.4)</td>
<td>79.47 (1.79)</td>
<td>80.21 (0.37)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>38.90 (0.37)</td>
<td>26.92 (0.23)</td>
<td>90.55 (0.96)</td>
<td>79.13 (0.25)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>38.98 (0.43)</td>
<td>26.53 (0.16)</td>
<td>92.66 (0.55)</td>
<td>78.83 (0.22)</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>38.73 (0.39)</td>
<td>25.94 (0.23)</td>
<td>94.80 (0.97)</td>
<td>78.00 (0.33)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>38.81 (0.35)</td>
<td>26.10 (0.30)</td>
<td>94.84 (0.97)</td>
<td>78.14 (0.39)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>38.96 (3.95)</td>
<td>27.93 (0.41)</td>
<td>87.14 (1.42)</td>
<td>80.12 (0.51)</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>38.95 (0.49)</td>
<td>28.37 (0.49)</td>
<td>81.70 (1.81)</td>
<td>79.79 (0.54)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>39.03 (0.47)</td>
<td>29.04 (0.46)</td>
<td>80.41 (1.96)</td>
<td>80.68 (0.46)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>39.01 (0.44)</td>
<td>28.98 (0.46)</td>
<td>80.33 (1.90)</td>
<td>80.61 (0.45)</td>
</tr>
</tbody>
</table>

Means (standard deviations) for three 24 hour periods, over all four groups of animals for vaginal temperature (°C), dry bulb temperature (°C), relative humidity (%), and temperature-humidity index.
Two extreme days in their heat-stress load were identified for Groups 2 and 3 (Figure 3-3), each having one day with a high heat stress load and one with a low heat stress load. The THI during the high heat-stress load day was greater than 80 (major heat stress) for 11 hours for group 2 and greater than 85 (critical heat stress) for 6 hours for group 3. Both groups had a low heat-stress load day with only 7 hours of THI greater than 80 and no THI over 85. Because the same heifers within groups 2 and 3 were exposed to days with different heat stress loads, the estimation of the response in vaginal temperature for an increase in THI could be calculated.
For group 2, the high heat stress day was day 1 and the low heat stress day was day 3. For group 3, the high heat stress day was day 3 and the low heat stress day was day 1. Day 1 is represented by the orange line and day 2 by the blue line.

The least squares means of THI for low and high heat stress days is shown in Figure 3-4 and the least squares means for vaginal temperature of the same groups of heifers over the same days are shown in Figure 3-5. As expected; vaginal temperatures were higher when animals were exposed to high heat stress versus low heat stress. The maximum difference (5.99) in THI between these 2 days was recorded at hour 0017, while the maximum difference in vaginal temperature (0.68°C) between these two days (difference calculated within each cow) was recorded at hour 0018 indicating that there is an approximately one hour lag in the animal’s response to the increase in THI. This is in agreement with previous reports that changes in body temperature follow changes in the environmental temperature with some delay (Hahn, 1999; Brown-Brandl et al., 2005).
Figure 3-4. Least squares means for temperature-humidity index during the two extreme days in group 2 and 3

The open circles represent the low heat stress days and the closed circles represent the high heat stress days.

Figure 3-5. Least squares means for vaginal temperature of group 2 and 3 heifers during low heat stress days (open circles) and high heat stress days (closed circles).
Coat Score

Coat score had a significant effect on vaginal temperature ($P < 0.0001$), where cows with a very smooth coat had significantly lower vaginal temperatures throughout the 3 days of continuous measurements relative to heifers with a less smooth coat type (Table 3-4). These findings are consistent with results from previous studies, which observed a correlation between hair coat characteristics and body temperature. Turner and Schleger (1960) found that hair coat score significantly impacted body temperature of cattle, with animals possessing shorter hair coats maintaining a lower body temperature, indicating that coat type plays an important role in the regulation of core body temperature.

Table 3-4. Effect of coat, chute, and exit score on vaginal temperature (C) and sweating rate (g/[m²×h]).

| Trait / Effect | Estimate | SE  | t-value | Pr > |t| |
|---------------|----------|-----|---------|------|---|
| Vaginal Temperature | | | | | |
| Coat 1 vs 2  | -0.097   | 0.021 | -4.64   | <.0001 |
| Chute 1 vs 2 | -0.047   | 0.019 | -2.42   | 0.015 |
| Exit 1 vs 2  | 0.011    | 0.02  | 0.57    | 0.567 |
| Sweating Rate | | | | | |
| Coat 1 vs 2  | 0.32     | 2.12  | 0.15    | 0.879 |
| Chute 1 vs 2 | -5.49    | 2.12  | -2.59   | 0.009 |
| Exit 1 vs 2  | -4.13    | 2.15  | -1.92   | 0.055 |

Data represents differences of Least Square Means and their standard errors.

Similarly, the more extreme slick-hair phenotype observed in dairy cattle (Olson et al., 2003; Dikmen et al., 2008) was shown to confer superior thermoregulation. Riley
et al. (2012) found a low positive genetic correlation between rectal temperature and coat score in Brahman cattle. A smooth coat can minimize heat gained from the sun by providing greater resistance to heat transfer to the skin (Finch, 1986). Additionally, a long, wooly coat traps sweat interfering with an efficient evaporation process. Because sweat is the most important cooling mechanism that carries heat out of the body, trapping the sweat next to the skin will also trap the heat (Berman, 2004). Although it is clear that coat score impacts an animal’s ability to regulate vaginal temperature, there is still a good amount of variation within coat scores, suggesting that hair coat is not the only factor influencing thermoregulatory ability (Figure 3-6). Data shows that coat score has an effect on vaginal temperature under both high and low heat stress conditions; however its effect is much great when animals are exposed to high heat stress conditions (Figure 3-7)

![Graph showing the effect of coat score on vaginal temperature.](image)

**Figure 3-6.** Effect of coat score on vaginal temperature of all heifers, in all four groups

Blue represents coat score 1 and red represents coat score 2, with the lines representing the average, and the dots each individual animal.
Figure 3-7. Effect of coat score on vaginal temperature within heat stress class, for groups 2 and 3.

The graph focuses on the four hours where the maximum difference in THI was detected between the high heat stress and low heat stress days. The red lines represent the high heat stress days and the blue lines represent the low heat stress days, with the lighter colored lines representing animals with a coat score 1 (excessively smooth coat) and the darker lines representing animals with a coat score 2 (fairly smooth coat).

**Temperament**

Chute behavior is an indicator of temperament for cattle (Grignard et al., 2001; Turner et al., 2011). Heifers with a calm temperament (CHUTE = 1) were able to maintain a significantly lower (P = 0.015) vaginal temperature during the entire duration of the experiment (Table 3-4). These results suggest that the temperament observed while heifers are handled is a good indicator of their temperament in the field and a restless animal would tend to have a higher internal body temperature.
Weight

Heifer weights ranged from 229 kg to 528 kg. The estimate of the regression coefficient for weight (-0.0011 ± 0.0003) was significantly different from zero (P < .0001), which indicates that heavier heifers are able to maintain a lower vaginal temperature relative to lighter weight heifers. The small regression coefficient is somewhat misleading, as weight has a meaningful impact on the vaginal temperature. For example, based on the estimated regression coefficient, a difference of 50 kg in live weight has a similar effect on vaginal temperature as one class difference in the chute score, and 100 kg difference in live body weight has a similar effect as one class difference in the coat score. Numerous studies have found that cattle under heat stress decrease their dry matter intake and have a reduction in average daily gain (Hahn, 1999; Brown-Brandl et al., 2006). Heifers that are better adapted to hot and humid environments tend to have higher average daily gain, and will be heavier than other cattle of similar age which are not adapted to these hot conditions. This could also explain the results observe in this study where heavier heifers were the ones with a lower core body temperature during the study.

Genome-Wide Association Study

The Genome-Wide Association Study (GWAS) conducted on the trait coat score resulted in 141 SNPs associated at P < 0.001 and 21 SNP at P < 0.00001. The most significant regions for coat score were identified, in order of significance, on chromosomes BTA20, 25, 23, 19, and 6 (Figure 3-8). Most of these chromosomal regions harbor potential candidate genes for coat score or thermotolerance. Among these, BAG2, FAM83B, and ASL were identified as potential genes of importance. BAG2 is a gene known to interact with heat shock proteins in the cellular response to
heat stress in mammals. *FAM83B* functions in epithelial cell proliferation and hair follicle development. Additionally, mutations in the *ASL* gene have been shown to cause abnormal hair shaft growth in people, leaving hair thin and brittle.

![Manhattan plot for coat score genome-wide association study](image)

**Figure 3-8.** Manhattan plot for coat score genome-wide association study

Each dot is an individual SNP (Single Nucleotide Polymorphism) plotted with its effect on the trait coat score
CHAPTER 4
RELATIONSHIP OF SLICE SHEAR FORCE AND QUALITY GRADE OF STRIP LOIN
STEAKS FROM BRANGUS STEERS

Introduction

Currently in the United States, beef carcasses are classified according to quality grades specified by the USDA. Quality grades are determined based on the amount of intramuscular fat (marbling) within the ribeye, between the 12th and 13th rib, and the maturity of the carcass. Producers are paid a premium for high quality carcasses and discounts for low quality. The purpose of the quality grading system is to identify animals that will bring superior eating satisfaction to the consumer. The quality traits that primarily determine overall consumer liking of beef are flavor, tenderness, and juiciness (Hunt et al., 2014); of these, tenderness is the most important (Huffman et al., 1996; Miller et al., 2001). A steak with a higher degree of marbling tends to be more tender, juicy, have a more intense flavor and a higher likelihood of delivering a positive eating experience (Emerson et al., 2013). With an increase in each quality grade, overall consumer acceptance increased about 10% in a study conducted by Platter et. al. (2003).

However, the beef quality grading system does not always accurately predict tenderness or consumer acceptability. It has been reported that marbling accounts for no more than 10% of the variation in sensory traits of beef rib steaks (Campion et al., 1975). Inadequate tenderness is the biggest cause of dissatisfaction with beef products (Morgan et al., 1991), presenting a challenge for the beef industry. Consumers are willing to pay a higher price if a beef cut is guaranteed to be tender (Miller et al., 2001). In fact, when it comes to a purchasing decision, tenderness is ranked higher than price by consumers (Reicks et al., 2011). Therefore, if tenderness of a carcass is known,
producers could receive premiums for producing tender beef, instead of the quality
premiums being placed solely on quality grades. However, tenderness is influenced by
many different factors, making it difficult to control and predict. The objective of the
tenderness study was to investigate the relationship between USDA quality grade and
tenderness, assessed by slice shear force (SSF).

**Materials and Methods**

**Animals**

The University of Florida Institutional Animal Care and Use Committee approved
the research protocol used in this study (number 201003744.). The population for this
study consisted of 1043 steers from multiple ranches in the state of Florida, finished at a
commercial feedlot (Quincey Cattle Company, Chiefland, Florida). Cattle were
implanted with Revalor XS (Merck & Co., Inc., Kenilworth, NJ) and fed a standard
commercial corn-based diet until they reach a common physiological endpoint, with the
goal of 1.27 cm of subcutaneous fat over the back. Final live weight (Wt, kg.), lot at
feedlot (LOT; n= 16), and ranch of origin (Ranch; n= 17) were recorded for each animal.
Cattle were transported to a commercial processing facility (FPL Food LLC., Augusta,
Georgia) one day prior to harvest.

**Harvest and Sample Collection**

Cattle were harvested under USDA-FSIS inspection. Hot carcass weight was
recorded immediately following harvest. Carcasses were ribbed between the 12th and
13th rib at 48 hours post mortem and carcass traits were recorded. Marbling score
(MAB; 100 to 199 = practically devoid (PD), 200 to 299 = traces (TR), 300 to 399=slight
(SL), 400 to 499=small (SM), 500 to 599=modest (MT), 600 to 699=moderate (MD), 700
to 799=slightly abundant (SLAB), 800 to 899=moderately abundant (MAB), and 900 to
999=abundant (AB)), fat over the ribeye (FOE; cm), ribeye area (REA; cm²), subjective lean color score (Color; 1=light cherry red, 2=cherry red, 3=slightly dark cherry red, 4=moderately dark cherry red, 5=dark red, 6=very dark red, 6=very dark red, 7=black), lean texture score (Text; 1=very fine, 2=fine, 3=moderately fine, 4=slightly coarse, 5=coarse, 6=very coarse, 7=extremely coarse), and lean firmness score (Firm; 1=very firm, 2=firm, 3=moderately firm, 4=slightly soft, 5=soft, 6=very soft, 7=extremely soft) were evaluated at the 12th rib. Lean maturity and skeletal maturity were recorded. Kidney, pelvic, and heart fat (KPH) was evaluated as a percentage of HCW. Adjusted back fat (AdjBF) was determined by adjusting the FOE depending on the fat cover over the entire carcass. Yield grade was calculated using the industry standard formula (Troxel and Gadberry, 2007):

\[
YG = 2.5 + (2.5 \times \text{AdjBF}) + (0.2 \times \text{KPH}) + (0.0038 \times \text{HCW}) - (0.32 \times \text{REA})
\]

(4-1)

Overall carcass maturity was calculated by averaging the bone maturity and lean maturity, using an industry standard method (Hale et al., 2006). If the bone maturity and lean maturity were within 40 units of each other, just a simple average was used. If more than 40 units separated the two, an average was taken and adjusted 10 percent towards the bone. USDA quality grade was calculated using marbling score and maturity. Quality grade codes (QGcode) were then assigned to each carcass, based on the quality grade (3= Standard, 4= Standard+, 5= Select, 6= Select+, 7= Choice, 8= Choiceo, 9= Choice+, 10= Prime, 11= Primeo, 12= Prime+). Dressing percentage (DP) was calculated as a percentage of hot carcass weight over live weight.

One 2.54 cm thick steak from the *longissimus lumborum*, posterior to the 12th rib was obtained from each carcass and kept on ice until returning to the University of
Florida meat laboratory. The L*, a*, and b* objective color measurements were taken using a calibrated Minolta Chroma Meter CR 310. Steaks were placed in individual bags, along with a tag indicating their ID, then placed in heat shrink vacuum pack bags (B2570; Cryovac, Duncan, SC) vacuum sealed with a Multivac C500 (Multivac Inc., Kansas City, MO), and quickly dipped in boiling water to shrink packaging. Steaks were aged for 14 days at approximately 2°C then placed in a freezer at approximately -12°C for storage.

**Slice Shear Force**

Steaks were prepared according to the American Meat Science Association Guidelines (Belk et al., 2015). Steaks were allowed to thaw for approximately 24 hours prior to cooking at approximately 2°C. Steaks were cooked on open hearth grills (Hamilton Beach Brand, Washington, NC) to an internal temperature of 71°C. The steaks were flipped once when the internal temperature reached 35°C. Internal temperature was monitored by placing a copper-constantan thermocouple thermometer (Omega Engineering Inc., Stanford, CT) in the geometric center of the steak.

Final cooked weight was recorded in grams and cooking loss (CookLoss) was calculated as the percentage of the raw steak weight over the cooked steak weight, representing the amount of water lost through cooking. A cut was made on the lateral end of the muscle, approximately 1-2 cm from the end, across the width, to square off the end of the muscle. A second cut is made across the width, using a sample size box. This cut was parallel and 5 cm from the first cut. The 5 cm long section was placed in the slice box with the angle of the two 45 degree slots lined with the muscle fiber angle and aligned so the slice will be cut from the center of the section. The lid of the box was closed and a double-bladed knife was inserted. The knife had two parallel blades that
are spaced 1 cm apart. After the cut was made, one 1 cm thick, 5 cm long slice parallel to the muscle fibers remains (Figure 4-1).

Figure 4-1. Method of cutting steak to prepare sample for Slice Shear Force test.

The degree of doneness (DoD) was recorded for each steak, to ensure uniform doneness among steaks (1=very well done, 2= well done, 3=medium, 4=medium rare, 5=rare, 6=very rare).

The force required to shear through the slice was measured using an Intron Universal Testing Machine (Instron Corporation, Canton, MA) with a 1.17 mm thick slice shear head and a crosshead speed of 500 mm/min. This slice was placed in the
machine so the blade shears perpendicular to the muscle fibers, down the center of the 5cm of the slice. This test was completed within 2 minutes of the steak being taken off the grill, while it was still hot.

**Statistical Analysis**

For the statistical analysis, QGcode 4 and 5, and 10 and 11 were combined due to low numbers. Slice Shear Force values (SSF) were analyzed using the general linear model (GLM) procedure in SAS 9.4. The following model was used:

\[ Y_{ijkl} = \text{CookLoss}_i + \text{QGcode}_j + \text{Lot(Ranch)}_k + e_{ijkl} \]  

(4-2)

Where Y represents SSF, CookLoss is the percent loss during cooking, QGcode is the code corresponding with the quality grade, Lot(Ranch) is the nested effect of lot at feedlot within the ranch of origin, and e is the residual variation. Differences in SSF by QG were identified using the least squares means (LSMEANS) function in SAS 9.4.

**Results and Discussion**

Means and standard deviations for carcass and quality traits are shown in Table 4-1. Based on previous reports, carcass traits observed in this study are comparable, with hot carcass weight and ribeye area slightly larger and all other traits similar to previously reported Brangus and Angus x Brahman steer carcass characteristics (Lonergan et al., 2001; Phelps et al., 2017; Wright et al., 2018). Cooking loss was slightly larger than reported by Phelps et al. (2017).

The average Yield Grade was 3.15, with the majority falling between 2.00 and 3.99 (Table 4-2), similar to the Yield Grades found by Phelps et. Al. (2017) in Brangus steers.
Table 4-1. Carcass and quality traits

<table>
<thead>
<tr>
<th>Trait</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carcass Traits</td>
<td></td>
</tr>
<tr>
<td>HCW, kg</td>
<td>372.85 ± 36.29</td>
</tr>
<tr>
<td>DP, %</td>
<td>60.84 ± 3.00</td>
</tr>
<tr>
<td>FOE, cm</td>
<td>1.57 ± 0.61</td>
</tr>
<tr>
<td>REA, cm²</td>
<td>83.28 ± 9.49</td>
</tr>
<tr>
<td>KPH, %</td>
<td>2.47 ± 0.39</td>
</tr>
<tr>
<td>Quality Traits</td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>1.89 ± 0.85</td>
</tr>
<tr>
<td>Texture</td>
<td>2.53 ± 1.23</td>
</tr>
<tr>
<td>Firmness</td>
<td>2.03 ± 0.62</td>
</tr>
<tr>
<td>L*</td>
<td>36.85 ± 2.59</td>
</tr>
<tr>
<td>a*</td>
<td>22.02 ± 1.94</td>
</tr>
<tr>
<td>b*</td>
<td>7.63 ± 5.11</td>
</tr>
<tr>
<td>Cookloss, %</td>
<td>17.27 ± 3.89</td>
</tr>
</tbody>
</table>

Table 4-2. Yield Grade categories

<table>
<thead>
<tr>
<th>Yield Grade</th>
<th>Number of animals</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00-1.99</td>
<td>88</td>
<td>9.1</td>
</tr>
<tr>
<td>2.00-2.99</td>
<td>342</td>
<td>35.5</td>
</tr>
<tr>
<td>3.00-3.99</td>
<td>373</td>
<td>38.7</td>
</tr>
<tr>
<td>4.00-4.99</td>
<td>144</td>
<td>15.0</td>
</tr>
<tr>
<td>5.00-5.99</td>
<td>16</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Most of the carcasses in this study were classified as A and B maturity, with 87.3% classified as A, 12.5% B, and only 0.1% classified as C. Marbling scores ranged from 210 to 850, with an average of 436, which is consistent with Brangus and Angus/Brahman crossbred steers in previous studies (Lonergan et al., 2001; Phelps et al., 2017; Wright et al., 2018). The USDA quality grades ranged from high Standard to average Prime; high Standard was combined with low Select and average Prime with
low Prime for analysis. Twenty percent of the samples graded average Choice or better, which is important to note because typically a premium is paid for carcasses grading average Choice or higher (Table 4-3).

Table 4-3. Summary data for USDA quality grade and tenderness categories.

<table>
<thead>
<tr>
<th>Quality Grade</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select^-</td>
<td>92</td>
<td>8.82</td>
</tr>
<tr>
<td>Select^+</td>
<td>261</td>
<td>25.02</td>
</tr>
<tr>
<td>Choice^-</td>
<td>482</td>
<td>46.21</td>
</tr>
<tr>
<td>Choice^o</td>
<td>148</td>
<td>14.19</td>
</tr>
<tr>
<td>Choice^+</td>
<td>39</td>
<td>3.74</td>
</tr>
<tr>
<td>Prime^-</td>
<td>21</td>
<td>2.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tenderness</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Tender</td>
<td>97</td>
<td>9.30</td>
</tr>
<tr>
<td>Tender</td>
<td>223</td>
<td>21.38</td>
</tr>
<tr>
<td>Tough</td>
<td>723</td>
<td>69.32</td>
</tr>
</tbody>
</table>

N represents the number of animals falling in each category and % represents the percentage of animals falling in each category.

Each sample was categorized as tough, tender, or very tender based on Slice Shear Force values, with a value at or below 15.4 considered very tender, above 15.4 but at or below 20.0 considered tender, and any values above 20.0 considered tough (ASTM International., 2013). Slice Shear Force values ranged from 7.13 to 70.7 kg/g of force, with an average of 26.09. This average is lower than the average shear force value found by Phelps et. al. (2017) for Brangus steers, but higher than that found by
Lonergan et al. (2001). The tenderness classifications are as follows: 9.30% classified as very tender, 21.38% as tender, and 69.32% as tough (Table 4-3).

Cooking loss (P<0.0001), lot within ranch (P<0.0001), and USDA quality grade (P=0.0485) significantly influenced Slice Shear Force values (Table 4-4). Lot within ranch was expected to be significant, as tenderness is moderately to highly heritable within breeds (Shackelford et al., 1994; Wulf et al., 1996).

Table 4-4. Traits significantly (P<.05) influencing Slice Shear force values.

<table>
<thead>
<tr>
<th>Trait</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cookloss</td>
<td>15.76</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Quality Grade</td>
<td>2.24</td>
<td>0.0485</td>
</tr>
<tr>
<td>Lot(Ranch)</td>
<td>2.09</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Least Squares Means for Slice Shear Force by USDA quality grade are shown in Table 4-5. A significant difference in Slice Shear Force between each USDA quality grade was observed, as well as a slight trend from less tender to more tender when moving from Select to Prime. This is consistent with previous studies which found that a higher degree of marbling tends to lead to more tender meat (Aberle et al., 2001).

Although a trend in Slice Shear Force values is observed, individual Slice Shear Force values vary considerably even within USDA quality grade. Table 4-6 shows the range of Slice Shear Force values within each USDA quality grade. The range of Slice Shear Force values is large, especially in the lower quality grade categories.
Table 4-5. Least squares means, standard errors, and P-values for Slice Shear Force, by USDA quality grade.

<table>
<thead>
<tr>
<th>Quality Grade</th>
<th>LS Mean SSF</th>
<th>SE</th>
<th>PR &gt;IIt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select</td>
<td>28.72&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.18</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Select</td>
<td>27.91&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.78</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Choice&lt;sup&gt;-&lt;/sup&gt;</td>
<td>26.34&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.65</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Choice&lt;sup&gt;0&lt;/sup&gt;</td>
<td>25.29&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.90</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Choice&lt;sup&gt;+&lt;/sup&gt;</td>
<td>26.12&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>1.59</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Prime</td>
<td>26.67&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>2.05</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table 4-6. Means, standard deviations, and range of Slice Shear Force values, for each USDA quality grade

<table>
<thead>
<tr>
<th>Quality Grade</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select</td>
<td>7.93</td>
<td>66.09</td>
<td>27.43</td>
<td>9.96</td>
</tr>
<tr>
<td>Choice&lt;sup&gt;-&lt;/sup&gt;</td>
<td>7.40</td>
<td>59.07</td>
<td>25.83</td>
<td>8.63</td>
</tr>
<tr>
<td>Choice&lt;sup&gt;0&lt;/sup&gt;</td>
<td>7.13</td>
<td>53.95</td>
<td>24.60</td>
<td>7.87</td>
</tr>
<tr>
<td>Choice&lt;sup&gt;+&lt;/sup&gt;</td>
<td>7.85</td>
<td>41.44</td>
<td>25.92</td>
<td>7.85</td>
</tr>
<tr>
<td>Prime</td>
<td>17.83</td>
<td>47.21</td>
<td>24.34</td>
<td>7.29</td>
</tr>
</tbody>
</table>

These large ranges indicate that there is a lot of variation in tenderness, even within quality grade. The percentage of very tender, tender, and tough steaks in each quality grade are presented in Table 4-7. There are a noteworthy number of steaks classified with a low quality grade that still fall under the tender and even very tender category. Additionally, there are a considerable number of steaks that are classified in high quality grade categories that produced tough beef.

Slice Shear Force values by quality grade are shown in Figure 4-2. The high level of variation in tenderness within quality grade proves to be a problem because USDA Quality grades are how we predict consumer satisfaction of the product. For many of these steaks, the consumer satisfaction is inaccurately estimated due to the tenderness variation, with tenderness being the most important attribute to consumers.

A good portion of the carcasses that were discounted for low quality grade actually may
have a higher consumer satisfaction than some of the carcasses being awarded premiums, due to the differences in tenderness. This is a problem that is important for the industry to tackle, as dissatisfied consumers can lead to non-repeat consumers. Accurately predicting tenderness could lead to some producers receiving premiums, even if they typically produce animals with lower quality grade carcasses.

Table 4-7. Percentage of each USDA quality grade falling into each class of tenderness

<table>
<thead>
<tr>
<th>Quality Grade</th>
<th>Tender Class</th>
<th>Very Tender</th>
<th>Tender</th>
<th>Tough</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select⁺</td>
<td></td>
<td>30.43 (n=28)</td>
<td>10.87 (n=10)</td>
<td>58.7 (n=54)</td>
</tr>
<tr>
<td>Select⁺</td>
<td></td>
<td>14.94 (n=39)</td>
<td>12.64 (n=33)</td>
<td>72.41 (n=189)</td>
</tr>
<tr>
<td>Choice⁻</td>
<td></td>
<td>12.66 (n=61)</td>
<td>16.8 (n=81)</td>
<td>70.54 (n=340)</td>
</tr>
<tr>
<td>Choice⁰</td>
<td></td>
<td>10.14 (n=15)</td>
<td>23.65 (n=35)</td>
<td>66.22 (n=98)</td>
</tr>
<tr>
<td>Choice⁺</td>
<td></td>
<td>17.95 (n=7)</td>
<td>12.82 (n=5)</td>
<td>69.23 (n=27)</td>
</tr>
<tr>
<td>Prime</td>
<td></td>
<td>0 (n=0)</td>
<td>28.57 (n=6)</td>
<td>71.43 (n=15)</td>
</tr>
</tbody>
</table>
Figure 4-2. Slice Shear Force values by USDA quality grade

The blue points represent the Slice Shear Force value for each individual sample. The orange points represented the least squares means slice shear force values for each quality grade. The red dashed line represents the threshold for USDA certified tender beef and the green dashed line represents the threshold for USDA certified very tender beef.
CHAPTER 5
CONCLUSION

Vaginal temperature of Brangus heifers was higher when exposed to high heat stress when compared to low heat stress, with an approximately one hour lag in response to an increase in THI. Heifers with a smooth hair coat maintained a lower vaginal temperature than those with longer, thicker hair coats, especially when animals are exposed to high heat stress conditions, showing that hair coat is one of the factors influencing thermoregulatory ability. This suggests that if producers select for a smooth hair coat, they could increase the thermoregulatory ability of their herds. Multiple regions in the bovine genome were identified to harbor possible candidate genes for hair coat score, meaning genetic markers may be developed in the future to genetically select for a smoother hair coat and therefore a greater thermoregulatory ability. In addition to hair coat, temperament also influenced vaginal temperature, with heifers having a calmer temperament while being handled in the chute maintaining lower body temperatures than those that were more restless, indicating selecting for temperament while being handled could also influence thermoregulatory abilities of a herd. Furthermore, heavier heifers were able to maintain a lower vaginal temperature than the lighter heifers, which could be because heifers who are better able to adapt to heat stress conditions tend to have higher average daily gain.

A trend in tenderness from less tender to more tender, measured by Slice Shear Force, was observed as USDA quality grade increased. However, tenderness varied considerably even within quality grade, especially in the lower quality grade categories. Consequently, a fairly high percentage of steaks with a low quality grade are considered tender or very tender, as well as steaks classified as a high quality
grade that are considered tough. USDA quality grades are intended to predict consumer satisfaction and palatability, however, inaccurate estimation of tenderness can lead to dissatisfied consumers, which could lead to non-repeat customers, negatively impacting the industry. Additionally, more accurately identifying carcasses that are tender could lead producers who typically produce animals with carcasses of lower quality grades to receive premiums still if their meat is tender.
LIST OF REFERENCES


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Kachman, S. D. Where We Go From Here : Robustness of SNP effects across breeds.


Tatum, J. D. 2001b. Animal age, physiological maturity, and associated effects on beef tenderness.


USDA Certified Beef Programs.


BIOGRAPHICAL SKETCH

Heather Hamblen grew up in Ocklawaha, FL with parents Michael and Rachel Hamblen and younger sister Alicia. As a young child, she got involved in 4-H and FFA, which introduced her to many aspects of agriculture. The beef cattle industry really sparked her interest and eventually turned into a passion. Her senior year of high school, she decided to one day become an agriculture teacher FFA advisor, where she could share her passion for agriculture and youth, while making a positive impact on the lives of students. While studying as an undergrad, she served as a member of the Meat Judging Team, allowing an interest in the meat industry to be sparked. Heather graduated from the University of Florida in 2016 with a Bachelor of Science in Agriculture Education and Communication. She started a master’s program under Dr. Raluca Mateescu thereafter. During her time as a graduate student, she completed an industry internship and participated in many beef and meat industry activities as well as youth development activities. After graduation, she will take a job as a high school agriculture teacher and FFA advisor, where she will share her love and knowledge of agriculture with youth.