UTILIZATION OF HEAT ABATEMENT STRATEGIES ON MAINTAINING THERMOREGULATION IN A SOUTHEASTERN FEEDLOT SYSTEM

by

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(Under the Direction of Alex Stelzleni)

ABSTRACT

Two studies were conducted to evaluate the performance of feedlot steers finished under heat mitigation strategies in Southeastern US. The first study examined: cover with fan (CWF), cover with no fan (CNF), and outside drylot with no shade or fan (OUT). Cover successfully reduced solar load and morning and afternoon panting. Although CNF and CWF had similar performance traits, fans improved overall rate of gain. Carcass, sensory, and shelf life values were similar among treatments, while hot carcass weights (HCW) were heavier for CWF. The second study evaluated similar treatments to experiment 1 with optional shading (SHADE) added. Cover showed similar improvements to experiment 1, while SHADE and OUT were similar.. Covered steers exhibited improvements to carcass marbling and HCW; however, values were similar when steers were taken to a similar weight. Cover and fans enhanced performance allowing steers to achieve target weight and carcass characteristics in a shorter period.

INDEX WORDS: Heat mitigation, performance, carcass characteristics

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DEDICATION

The dedication of this work is to my mother, Terri Sims, and my father, Walter Sims Jr. With everything I strive to do, I do so with the support and love of the best parents a man could ask for. The hard work that both of you have put into your careers has, with out a doubt, been the driving force in all that I have achieved and will achieve in the future. I simply cannot thank you enough for the opportunities that you have provided me.

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CHAPTER 1

INTRODUCTION

Southeastern cow/calf operations in the United States are able to flourish due to the extensive marketing infrastructure, year-round subtropical environment, and abundant forages (Adkins et al., 2012). However, the hot subtropical climate, especially during the summer months, creates an environment of discomfort for the animals due to elevated temperatures and relative humidity, leading to a reduction in animal performance (Brown-Brandl et al., 2005). Furthermore, high-concentrate diets can further catalyze stress by contributing to elevated metabolic heat loads (Mader et al., 2002). In a survey performed by Onozaka et al. (2010) consumers found locally grown products to be superior in freshness (70%), supporting the local economy (65%), and improved eating quality (62%). However, the incentive for producers to produce locally grown cattle in the Southeast has been historically muted due to adverse environmental climates. Management strategies for heat mitigation including complete cover, shade, and/or fans could be utilized to improve animal performance and benefit Southeastern-finishing operations during the summer months.

The importance of integrating heat mitigation strategies is highlighted by 2 cases from the late 1990's where severe heat episodes occurred in the Northern Plains and Cornbelt, which cost the industry $20 million per episode (Mader et al., 2002). Furthermore, heat waves during the years 2006 and 2011 killed over 30,000 dairy cows and 4,000 beef cows in California and Iowa, respectively (Rhoads et al., 2013). As climate change proceeds, environmental stress factors including ambient temperature, solar radiation, and relative humidity will increase and heat episodes will continue to occur at a greater frequency (Rhoads et al., 2013). As climates become harsher, expression of physiological defense mechanisms including insensible/latent (evaporative) and sensible heat mitigation (convective, conductive, and radiation) will become more difficult (Collier and Gebremedhin, 2015). As a result, performance losses from reduced feed intake, body weight gain, reproduction rates along with increased incidences of morbidity and mortality will ensue (Mader et al., 2002). Heat abatement techniques such as shade or fans can be implemented in order to improve heat transfer into the environment through reductions in solar radiation, internal temperatures, and improvements to overall convective cooling strategies (Blaine and Nsahlai, 2010).

In addition to animal performance, adverse seasonal conditions are shown to influence muscle quality (Kadim et al., 2004). A 20-fold risk of dark cutting beef (DCB) was found to occur in cattle that were exposed to extreme environmental stress conditions 2-3 days prior to slaughter (Scanga et al., 1998). Miller (2007) concluded that cattle exposed to temperature above 35°C over a period of 24-48 hours can increase stress and incidences of DCB. In the 1995 National Beef Quality Audit (NBQA), DCB carcasses resulted in a loss of $6.08/CWT per animal harvested expressing DCB, which resulted in studying methods to reduce environmental heat load in order to maintain quality (Grandin 1992; Cundiff et al., 1994). Technological advances have allowed the industry to quantify environmental stress factors and improve heat mitigation response.

Environmental variables including temperature-humidity index (THI), heat load index (HLI), and accumulated heat load units (AHLU) have been used and modified over years to properly assess the heat load exposure of cattle (Gaughan et al., 2008). Although THI has been widely integrated in current research, it fails to account for microclimatic variables including solar radiation and wind speed (Dahl et al., 2020). Heat stress occurs when the animal's ability to disperse heat is compromised by ambient temperatures exceeding the thermoneutral zone. The inability to properly disperse heat will lead to an accumulation of excessive heat loads that may need additional management practices in order to disperse (Dahl et al., 2020). The HLI is a multifactorial linear regression model that quantifies heat load through black globe temperature (BG), wind speed (WS), and relative humidity (RH; Gaughan et al., 2008). In addition to measurements of environmental heat stress, HLI incorporates phenotypic, genotypic, and management variables allowing for a more accurate assessment of heat load for different types of cattle and management practices. Although heat abatement strategies reduce heat load, the harsh subtropical weather conditions may still prevent heat dissipation and induce accumulation of heat that can take multiple days to dissipate. Therefore, it is important to implement strategies during, or even before, extreme weather conditions in order to reduce the time at which the animal needs to dissipate heat.

The objectives of this study were to quantify environmental stress factors and evaluate the difference in performance, quality, and yield of crossbred Angus steers fed in a Southeastern feedlot operation during the summer months. In addition to evaluating heat stress, integration of heat abatement strategies including shade and/or fans were assessed as potential cooling strategies.

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CHAPTER 2

THE REVIEW OF THE LITERATURE

2.1 Stress

Stress is a very broad term that has no clear definition, etiology, or prognosis (Moberg, 2000). Moberg (2000) defines stress as, "the biological response elicited when an individual perceives a threat to its homeostasis", and, in order to mitigate ambiguity, will be the interpretation used for the purposes of this review. Furthermore, the term distress creates a dichotomy between good stress, and stress that may have deleterious effects on the individual's welfare (Moberg, 2000). Selye (1979), on the other hand, defined good stress as 'eustress', while also utilizing distress as its counterpart. Once a stressor is introduced to the animal, the response will first begin in the central nervous system, to which it will develop a physiological defense using one, or a combination of the following four mechanisms: the behavioral response, the autonomic nervous system response, the neuroendocrine response, or the immune response (Moberg, 2000). In most cases, a behavioral response will be the first sign of stress. Behavior is determined by many interactive factors including cognitive processes, which refers to the ability to form action to outcome cognitions (Ursin, 1988); the external stimuli, which there are intrinsic tendencies based on the stimulus, and transition-biasing processes that give animals a bias for certain sequences of functionally related behaviors (Toates, 2000). Following behavioral changes, the animal will try and remove itself from the threat.

In the case of heat stress, removal from the environment may be difficult in current feedlot systems. Simroth et al. (2017) found that only 17% of feedlots in the High Plains region of the United States (Texas, Oklahoma, Colorado, New Mexico, Kansas, and Nebraska) had available shade in feeding pens. The lack of shading in these states can be attributed to their cooler climate, however, shade has been shown to reduce bulling behavior and improve both average daily gain (ADG) and dry matter intake (DMI; Grandin, 2016). During severe or prolonged states of stress, animals can enter what is known as a prepathological state that is soon followed by the pathological state (Moberg, 2000). The prepathological state is the state in which the animal is at risk of developing pathologies, while the pathological state is when they succumb to the disease (Moberg, 2000). By definition, pathology is defined as "structural and functional deviations from the normal…" (Merriam-Webster, 2020). Therefore, the pathological stage of stress can be associated with animals that experience a deviation from normal production due to stressful conditions and coping mechanisms will ensue.

Overtime, animals will begin to exhibit signs of prepathological stress through increased/decreased tidal volumes and increased evaporative and non-evaporative cooling methods (Gaughan et al., 1999). Physiological changes that result from a pathological state may include vasodilation, reduced metabolic rate, and altered water metabolism (Farooq et al., 2010). Three types of intensity (sensitization, desensitization, or no alterations) can further influence stress rates (Ladewig, 2000). Sensitization is the increased intensity of a stressor, while desensitization and no alteration refers to a decrease or consistent exposure to stress, respectively (Ladewig, 2000). Stressors that are more intense cause frequent behavioral responses, while animals that are exposed to desensitization will gradually respond less intensely (Ladewig, 2000). Desensitization can be achieved by repeated exposure to the stimulus at full intensity, known as the flooding approach, or by repeated exposure to the stimulus with gradually increasing the intensity (Hart and Hart, 1985). Therefore, the stress of an animal can change based on length of exposure and may further affect the threshold to which a pathological state may occur. As a result, quantification of heat stress through temperature humidity index (THI) and heat load index (HLI) methods will become more apparent in the industry.

2.2 Temperature Humidity Index and Heat Load Index

Environment is defined as an external factor that can either have a positive or negative impact on growth, lactation, or reproduction, while “animal environment” consists of all the components that create the environment (Farooq et al., 2010). Homeotherms, such as cattle, have the ability to maintain body temperature, but can be affected by these environmental conditions by limiting the loss of metabolic heat and contributing to an increase in accumulated heat load (Dikmen and Hansen, 2009). Environmental conditions that impact an animal’s heat load accumulation include ambient temperature, black globe temperature (BG), relative humidity (RH), and wind speed (Mader and Davis, 2004). Over the past four decades the temperature-humidity index (THI) has played an important role as an indicator of thermal stress (Gaughan et al., 2008) and is the basis of the Livestock Weather Safety Index (Livestock conservation incorporated, 1970). The THI uses ambient temperature (°C) and relative humidity (%) in order to quantify the environmental stress that the animal is feeling (Gaughan et al., 2008).

$$\text{THI} = (0.8 \times \text{ambient temperature}) + \{[(\text{relative humidity}/100) \times (\text{ambient temperature} - 14.4)] + 46.4\}$$ (Thom, 1959)

Although THI has been utilized by producers and researchers for many years, it may not be an accurate representation of heat load exposure to cattle.

Ambient temperature, black globe temperature, relative humidity, and wind speed all contribute to heat stress, however, THI only accounts for two of the four listed. Other genotypic and phenotypic factors are also not assessed in the THI model and therefore all animals are essentially treated the same (Gaughan et al., 2008). This is because the THI model was originally used for humans under conditions with no exposure to wind or sunlight. The model fails to measure accumulation of high heat load over time and/or possible times for cooling (Gaughan et al., 2002). As a result a new model known as the heat load index model (HLI) was developed specifically for beef cattle, which incorporates the environmental factors of black globe temperature, relative humidity, and wind speed (Gaughan et al., 2008). Furthermore, the HLI has additional corrections for genotypic, phenotypic, and management differences amongst cattle. Below are the formulas that are used in order to measure HLI based on BG being above or below 25°C.

$$\text{HLI}_{BG>25} = 8.62 + (0.38 \times \text{RH}) + (1.55 \times \text{BG}) - (0.5 \times \text{WS}) + e^{(2.4-\text{WS})},$$

$$\text{HLI}_{BG<25} = 10.66 + (0.28 \times \text{RH}) + (1.3 \times \text{BG}) - \text{WS}$$ (Gaughan et al., 2008)

It is important to know the threshold at which cattle will be at risk of excessive heat load (EHL) exposure. The threshold is the point at which anything above the given THI would put the cattle at risk of accumulating heat (Gaughan et al., 2002). The HLI threshold was originally set to 79 (Gaughan et al., 2002), but later revised with phenotypic and genotypic factors to a threshold of 86 for unshaded, black hided, *Bos taurus* cattle (Gaughan et al., 2008). The HLI threshold must be adjusted based on environmental, phenotypic, and genotypic differences listed in Table 2 of Gaughan's *A New Heat Load Index* (2008). The HLI is further broken out into thermal neutral condition (TNC) HLI<70, Warm HLI 70.1 – 77.0, Hot 77.1 – 86.0, Very hot HLI 86.1 – 96, or Extreme >96 conditions (Gaughan et al., 2008). When cattle exceed their specified threshold, a dimension of time can be added to HLI as accumulated heat load units (AHLU) and below the threshold cattle are able to properly dissipate heat. Once AHLU reaches 0 the animal is in thermal balance and values cannot go lower. As for THI, animals that exceed their threshold are assessed by a 1-dimensional approach at one point in time known as THI-hours. The THI-hour measurement does not account for duration of exposure and over- or underestimates EHL events (Gaughan et al., 2008).

It has been observed that environmental stressors may not show immediate affects on production but instead may occur days after exposing cattle to excessive heat loads. Curtis et al. (2017) concluded a five day lag period when assessing the effect of BG and maximum THI as a predictor of feed intake. Adding a dimension of time allows producers to accurately evaluate the thermal status of their cattle and properly prepare for incidences of excessive heat. Heat load index has a greater correlation to tympanic temperature (r^2=0.67) when compared to the THI (r^2=0.26). Furthermore, the relationship of the HLI and AHLU to panting score was greater (r^2=0.93 and 0.92, respectively) compared to the THI and THI-hours (r^2=0.61 and 0.37, respectively; Gaughan et al., 2008). As a result, heat load index is an accurate assessment of heat load and heat accumulation in beef cattle.

2.3 Incorporation of Shade

Cattle respond to heat stress through increased secretion of glucocorticoids and catecholamine hormones, elevated respiratory rate, greater body temperatures, and displays of agonistic behavior (Foust and Headlee, 2017). Chronic exposure to stress can accumulate and force the animal into a prepathological state, and possibly cause pathological conditions (Moberg, 2000). There are three primary management strategies for attenuating thermal stress: 1) physical modification of the environment, such as reduction of solar radiation by shade, 2) genetic development of lower maintenance breeds that are not as sensitive to heat stress, or 3) improved nutritional management (Beede and Collier, 1986). The following section will focus on the mitigation of solar load through implementation of shade.

The primary purpose of shade is to protect the animal from intense, direct solar radiation and diffused and reflected radiation (Mader et al., 1999). However, Mader et al. (1999) stated that shade only changes the radiation balance of the animal and has no affect on air temperature or humidity. Thermal loads will lessen the appetite of the animal causing reduced average daily feed intake by 0.22 to 0.28 kg/d, and average daily gains by 0.06 to 0.10 kg/d (Mitlöhner et al., 2002; Mader et al., 1999; Blain and Nsahlai, 2010), especially when temperatures exceed 25°C (Beede and Collier, 1986; Mitlöhner et al., 2002; Curtis et al., 2017). Protection from solar radiation can reduce the radiant heat load on an animal by 30% (Mader et al., 1999) and prevent annual losses in weight gain (Mitlöhner et al., 2002; Blain and Nsahlai, 2010). Mitlöhner et al. (2002), and Blain and Nsahlai (2010) reported that shade improved dry matter intake (DMI) by 1.74% and 2.9%, hot carcass weight by 8.33 and 7.3 kg, and average daily gain by 0.15 and 0.10 kg/day, respectively. It was also reported that shaded cattle had a 10.8% reduction in DCB and a 19.6% increase in carcasses grading USDA Choice or better (Mitlöhner et al., 2002). This differed from Clarke and Kelly (1996) who found that shade (10 m^2/animal) had no improvements on animal performance or change in meat yield and quality. However, it was found that shade structures were instrumental in reducing rectal temperature by 2.5°C, and respiration rate by 40 breathes per minute (Clarke and Kelly, 1996; Mitlöhner et al., 2002). Respiration rate and body temperature are frequently used as indicators of thermal stress (Gaughan and Mader, 2013). The observed physiological changes were attributed to the reduction of heat load and as a result, the improvement of the thermal status of steers with provided shade. Most physiological factors are difficult to properly assess and record in real-time, therefore, other methods are required to measure real-time stress.

Panting scores have been shown to a good indicator of thermal load (Mader et al. 2006) because panting is a function of respiration rate and body temperature (Gaughan et al., 2010). Gaughan et al. (2010) concluded that mean panting scores were 0.5 greater for Angus cattle when HLI was above 96 than cattle exposed to HLI between 86 and 96.

Sweating is the primary evaporative cooling mechanism, which is followed by panting (Gaughan and Mader, 2014). As cattle begin to experience a heat load they will begin to release heat in the form of sweat in order to maintain homeothermy, but cattle are not efficient sweaters, so an increase in respiration rate quickly follows, leading to an increase in tidal volume causing open mouth panting (Gaughan and Mader, 2014). Energy expenditure increases as respiratory rate increases, as well as, energy that was originally used for growth will be redirected into thermoregulation to maintain body temperature (Blain and Nsahlai, 2010). Gaughan et al. (2010) reported that the mean body temperatures of shaded cattle were 0.73°C less than unshaded cattle resulting in shaded cattle being able maintain homeothermy thereby reducing total energy expenditure to maintain thermoregulation.

2.4 Incorporation of Fans

Though shades are a popular option for heat load mitigation, fans are also a strategy to physically modify the environment of cattle. Global warming has been characterized to cause adverse heat waves that can affect cattle production, especially in temperate regions of the United States (Beede and Collier, 1986; Magrin et al., 2016; Blaine and Nsahlai, 2010). Heat that is produced internally through metabolic processes can be exchanged into the environment through radiation, conduction, convection, and evaporative cooling methods (Garner et al., 1989). *Bos taurus* cattle have thick dense hair that reduces heat flow via convection and conduction (Hansen, 2004), as well as, darker hides that increase heat absorbance via radiation (Hutchison and Brown, 1969). Under warm environmental conditions, cattle are unable to displace a sufficient amount of heat from their skin, which can negatively affect welfare, productivity, and survival (Magrin et al., 2016). Fans can be utilized to provide forced ventilation, resulting in evaporative heat loss improvements (Garner et al., 1989). Bond et al. (1957) reported that a fan cooling system, over a two-year study, improved average daily gain of beef cattle by 0.47 and 0.24 kg, respectively. Urdaz et al. (2006) observed that the addition of cooling fans and shade in a dairy production increased 60-day postpartum milk yield and resulted in an annual increase of $2,131/cow. Magrin et al. (2016) studied the impact of ceiling fans had on the health, feeding, social behavior, and growth of young Charolais bulls. Bulls under fans were shown to have a 21.7% reduction in abnormal breathing, 30 breathes/minute, and a 35% reduction in panting scores above 2 (Margin et al., 2016). Furthermore, Margin et al. (2016) stated that bulls not under fans spent 6 minutes/hour ruminating, which was 4 minutes less than bulls exposed to fans, in order to reduce metabolic heat. Bulls that were provided with fans had improved cleanliness and overall integument conditions due to drier litter resulting from air movement leading to a 3.7% reduction of detected lameness (Magrin et al., 2016). This overall improvement to welfare may reduce the need for litter renewal and enhance cattle cleanliness, while also potentially repaying the investment of installing and running the fans.

2.5 Incorporation of a Sprinkler System

The application of water alleviates heat stress by transferring heat through evaporation and is normally the only strategy of heat dissipation during extreme environmental conditions (Davis et al., 2003). Furthermore, as water evaporates from the surface of the skin the ambient temperature surrounding the animal will also decrease.

The reduction in ambient temperature will result in an increased heat gradient allowing for greater heat flow away from the animal (Davis et al., 2003). When environmental and radiant temperatures are equal to or greater than the skin's, thermal comfort can only be achieved if heat is dissipated via evaporation (Arkin et al., 1991).

Arkin et al. (1991) found that as the coat of Holstein cattle became wet, there was a linear increase in the amount of heat dissipated. Furthermore, the provision of sprinklers for 1 minute every 30 minutes to shaded cattle during the summer in California resulted in greater feed consumption and rate of gain compared to cattle under shades and not sprinkled (Morrison et al., 1983). However, Morrison et al. (1973) did not see a difference in feed efficiency. Contrarily, sprinklers may negatively affect stress if the elevation in relative humidity restricts evaporative cooling by the animal (Sweeten, 1982; Mader et al., 2007). Sweeten (1982) suggested that application of water in humid climates should be applied during the early evening hours to prevent an increase in relative humidity when ambient temperature was increasing. Periodic wetting of cattle (5-10 minutes on and 15-20 minutes off) with large droplets (≥150 microns) that can penetrate through the hide to the skin's surface and will increase evaporative cooling (Meat and Livestock Australia, 2006). Alternatively, using misting or fogging may increase humidity, while also trapping surface heat in a layer close to the skin surface, preventing evaporative cooling (Meat and Livestock Australia, 2006). Cattle exposed to sprinklers with a THI above 68 vs. no sprinklers had a cooler microclimate (3.21°C to 7.19°C), an average THI that was 0.5 units lower (80.2 vs. 79.7), and reduced panting scores (Mader et al., 2007). However, Mader et al. (2007) also reported that the relative humidity increased by 3.5% when a wetting system was used. In addition to reducing heat stress, application of water has been the most effective method for controlling dust, which can also impair cattle feedlot performance (Sweeten, 1982).

Dry pulverized manure can create problems with dust and odor, therefore, a manure moisture of 25% to 30% is recommended and can be achieved through the use of sprinklers. In fact, Sweeten (1982) found that dust levels rose more than 850% when sprinklers were not used for 7 days. It was recommended that the initial application rate of sprinklers should be 4.53 L/m^2/d until a moisture level of 25% to 35% was achieved (Sweeten, 1982). Sweeten (1982) also suggested that once moisture levels are achieved, water should be applied at 2.26 to 3.40 L/m^2/d during dry weather. Sprinkler systems are a viable method for mitigating heat load and dust control but can also prevent convective cooling mechanisms in locations with greater humidity.

2.6 Nutritional Management

Nutritional plane and ration constituents can impact metabolic heat production during fermentation and digestion. Therefore, facilities and management do not necessarily need to eliminate environmental stress, but rather try and minimize the severity and aid in the animal's adaption (Mader et al., 2002). As stated, heat stress can negatively impact feed intake and overall production. West et al. (2003) observed a decrease of 0.51 kg DMI for every unit increase of THI from 72 to 84 per day. Due to the acute onset related to heat stress it is important that producers are aware of predictors of thermal strain in order to implement mitigation strategies as early as possible (Curtis et al., 2017). A report by Curtis et al. (2017) found that black globe temperature in combination with THI ($BGTHI_{sun}$) is the best predictor of feed intake in beef cattle when animals were exposed to 50% shade coverage. Curtis et al. (2017) further stated that producers could use rectal temperatures as a predictor of reduced feed intake in cattle (R=0.83), as well as being a predictor of rumen temperature. However, rumen temperature was not shown to be a superior method of predicting feed intake, and $BGTHI_{sun}$ was not a good predictor of rumen temperature (Curtis et al., 2017). Interestingly, Curtis et al. (2017) suggested that cutaneous heating and correlating receptors might cause animals to think they are hotter than they actually are, due to their exposure of solar radiation. Without exposure to solar radiation, rumen temperatures may become an accurate predictor along with rectal temperatures.

Mader et al. (2002) restricted *Bos taurus* steers to 25% of their ad libitum intake for 21 (RES21) and 42 (RES42) days and reported a reduction in DMI during and subsequent to restriction. Overall, DMI for RES21 and RES42 had an average decrease of 1.1 and 2.0 kg during each period when compared to cattle remaining on an *ad libitum* ration during a 63 d feeding period, respectively. Therefore, limiting DMI, following and/or prior to high environmental temperatures, may be used as a method to reduce body temperature by reducing metabolic heat production and a concurrent reduction in metabolic rate (Mader et al., 2002). Once the incidence of high environmental stress has passed, it is advised that cattle are placed back on an *ad libitum* intake (Mader et al., 2002). Mader and Davis (2004) observed cattle having a 7% compensatory increase in DMI following a 23-day period of providing feed at 85% of predicted *ad libitum* intake. As a result, cattle that were limit fed were compensating for the loss in weight gain over the 23-day period. Not only did limit fed cattle compensate for their loss of gain, but improved gain:feed were observed for cattle limit fed from days 24 to 82 of the feeding period (Mader and Davis, 2004). Periods of restriction followed by *ad libitum* can also lead to feed engorgement that may increase the risk of acidosis or bloat, leading to a subsequent elevation in body temperature, endotoxic shock, and/or liver abscesses (Meat and Livestock Australia, 2006).

Mader and Davis (2004) also looked at the affects thermoneutral (Mean THI<70), mild heat stress (Mean THI between 70 & 74), heat stress (Mean THI between 74.1 & 77), and severe heat stress (Mean THI >77) had on bunk scores for cattle fed limited (85% predicted *ad libitum* intake) and *ad libitum* intake over a 23-day period. Cattle fed *ad libitum* had the lowest bunk scores at 0900 during mild heat stress but had the highest bunk scores at 1700 and 2100 during severe heat stress. During periods of high heat stress, *ad libitum* fed cattle had greater bunk scores (~1.2) during the second period of high heat stress (d 21 and 22) compared to the bunk scores (~0.4) during the first period (d 11 and 12) at 1700. During the same period, cattle that were limit fed exhibited a 50% reduction in bunk scores during the second severe heat wave (Mader and Davis 2004). It is speculated that cattle that were limit fed were reducing their metabolic heat load, while simultaneously allowing for nighttime cooling to further cope with excessive heat. These coping mechanisms allow cattle to expend excess heat load accumulated during the day and prepare for any future environmental stresses.

In addition to limiting feed intake, Delehant and Hoffman (1997) examined the interaction of frequency of feeding and restriction of feed. They found that feeding steers daily in the morning improved average daily gains by 0.15 kg and decreased feed:gain by 0.42, while also producing 0.29% greater dressing percentages, greater ribeye areas, and less back fat compared to cattle fed once in the afternoon hours (Delehant and Hoffman, 1997). However, Davis et al. (2003) found that cattle fed an *ad libitum* diet at 0800, compared to an *ad libitum* diet at 1400, had 1°C greater tympanic temperatures during 1600 h – 1900 h of the day. As a result, Davis et al. (2003) suggested that a feeding regimen that starts at 1600 would be superior for mitigating heat stress but may become difficult to manage over time. In addition to frequency and time of feeding, Delehant and Hoffman (1997) concluded that restricting feed by 10%, and 5% of *ad libitum* intake improved overall feed efficiencies and quality grades. Limiting feed intake not only reduced accumulation of heat in cattle, but also improved overall carcass quality from Select (*ad libitum*) to Low Choice (10% and 5% limit fed; Delehant and Hoffman, 1997).

Through feeding studies, researchers concluded that a decrease in DMI begins at 25°C (Beede and Collier, 1986; Mitlöhner et al., 2002; Curtis et al., 2017), however, this is also influenced by diet composition (Beede and Collier, 1986). Cattle who are intensively managed will suffer less deleterious affects of rising temperatures than grazing animals, mainly caused by maintaining the heat balance, and intake through minimizing grazing activity (Beede and Collier, 1986). Peripheral vasodilatation and increased blood flow are physiological adaptations that promote cooling by evaporative and convective heat loss (Beede and Collier, 1986). Consequently, the increase in peripheral blood flow decreases blood flow to other major organ systems such as the reproductive tract (Oakes et al., 1976) and ruminant forestomachs (Engelhardt and Hales, 1977). Engelhardt and Hales (1977) were able to quantify the distribution of capillary blood flow to the muscular and mucosal layers of the rumen, reticulum, and omasum in sheep. As a result, they found that blood flow to the mucosal and muscle layers of the ruminant forestomachs decreased by 17 and 56%, respectively. As a result, thermal stress caused an increase in peripheral blood flow that reduced the amount of blood supplied to the mucosa to aid in nutrient absorption and the muscle layers to promote gut motility (Beede and Collier, 1986).

Different feed ingredients can also produce different amounts of metabolic heat and are measured using heat increment units (HI) that is associated with the digestion and assimilation of food (West, 1999). The order of greatest to least heat increment is as follows: protein, insoluble carbohydrates, soluble carbohydrates, and fats (Meat and Livestock Australia, 2006). Overall, as the diet becomes less digestible there will be a linear decrease in DMI as ambient temperatures increases (Beede and Collier, 1986).

2.7 Genotypic Factors

High output breeds of cattle serve as the bulk of the world's production and tend to be thermally intolerant (Gaughan et al., 2010). As the world's population grows, demand for increased livestock production will inevitably follow. Therefore, it is imperative to identify multiple management practices, not only physiological, but also genotypic, in order to take advantage of the adaptive aspects of different breeds. Since the 1970s the United States beef cattle inventory has decreased annually, while beef has increased, indicating that cattle size has increased over the years (Luna-Nevarez et al., 2010). Problematically, as Busby and Loy (1997) reported, animals that become heavier are also more susceptible to heat stress. The increase in animal size, combined with increasing global temperatures, has lasting impacts on the beef industry. Crossbreeding through diverse breeding techniques becomes a necessity in order to express heterosis while matching genetic potential with the market requirements, feed source, and climatic changes (Cundiff et al., 1994). Crossbreeding *Bos taurus* × *Bos indicus* is a common method of reducing heat stress and has been researched extensively (Hammond et al., 1996; Hammond et al., 1998; Gaughan et al., 1999; Chase et al., 2004; Gaughan et al., 2009). The United States primarily utilizes Zebu breeds (*Bos indicus*), specifically the American Brahman, in order to combat environments that are prone to high heat loads (Hammond et al., 1998).

According to Finch (1985), Brahman cattle have less tissue resistance to heat that flows from their body's core to the skin's surface, also known as tissue conductance, when compared to Shorthorn (*Bos taurus*) cattle. Finch (1985) speculates that this may be due to an increase density of the arteriovenous anastomoses (AVAs) in *Bos indicus* breeds, which allows for an increase blood flow to the skin's surface and the gut in order to maintain thermoregulatory processes and gut motility. Furthermore, Finch (1985) observed that before there was any inward flow of heat to the skin from the environment, *Bos taurus* cattle had a greater amount of moisture accumulation than is required to dissipate metabolic heat load. This reaction suggests a reduction in evaporative cooling due to the trapping of the humidified air. At ambient temperatures of 25°C, *Bos indicus* and *Bos taurus* non-evaporative heat loss comprised 55-65% of heat loss from the skin, while the remaining heat was lost through evaporative mechanisms (Finch, 1985). As ambient temperatures began to approach skin temperatures, Finch (1985) found that Brahman and Brahman crossbred cattle use of non-evaporative heat loss strategies decreased to 25%, while Shorthorn cattle sustained little non-evaporative heat loss. Finch (1985) found that the decrease in non-evaporative cooling methods was due to a 50% increase in sweating rates. Furthermore, the woolly coats of *Bos taurus* cattle trapped moisture caused by the high amounts of absolute humidity and resulted in a decrease in cutaneous and non-evaporative heat evaporation. Under the same conditions, *Bos indicus* cattle showed a slower decrease in non-evaporative cooling, most likely due to their sleek shorthaired coats.

The ability to properly dissipate heat from the skin's surface to the environment is known as external conductance (Finch, 1985). Finch (1985) claimed humidity played a much more significant role in *Bos taurus* cattle accumulating heat than *Bos indicus.* The reduction in non-evaporative cooling causes cattle that are less adapted to thermal stress to find alternative methods of cooling in order to maintain homeothermy. External conductance and tissue conductance are both factors that contribute to thermal conductance and influence the ability of cattle to acclimate to harsh climates. Given that panting scores can be used as an indicator of thermal load (Mader, 2006), Gaughan et al. (2009) evaluated panting scores in varying genotypes and reported greater mean panting scores for Angus cattle while Brahman and Brahman-cross steers exhibited the lowest mean panting scores when HLI was above 95 (1.30, 0.32, and 0.35, respectively).

A caveat to including breeds with known heat tolerance is that they often have reduced rates of growth and reproductive efficiency (Hammond et al., 1995; Gaughan et al., 2009) when compared with non-tolerant breeds (Gaughan et al., 2009). Brahman in particular express negative effects such as delayed age of puberty (Cartwright, 1980), lower vigor of newborn calves (Reynolds et al., 1980), less intramuscular fat (Gregory, 2010; Huffman et al., 1990), less tender beef (Crouse et al., 1989), and reduced meat juiciness (Gregory, 2010). Furthermore, a reduction in carcass quality, temperament, neonate survivability, production under ideal climates, nutrition, and overall cattle buyer discounts are attributed to phenotypic and genotypic influences of *Bos indicus* breeding (Hammond et al., 1995; Hammond et al., 1998; Gaughan et al., 1999). Crouse et al. (1989) stated that marbling decreased as the percentage of *Bos indicus* influence on Angus × Hereford cattle increased from 0% (431 = low Choice), 25% (393 = Select) , 50% (351 = Select), and 75% (306 = Select). In addition to less intramuscular fat, Crouse et al. (1989) also reported a similar trend for tenderness 0% (4.40 kg of force), 25% (5.17 kg of force), 50% (5.81 kg of force), and 75% (6.67 kg of force).

The negative effects associated with increased *Bos indicus* breeding can be reduced by limiting the proportion of *Bos indicus* in the terminal generation composites, increasing post-mortem aging period, or using heat adapted *Bos taurus* breeds (Gregory, 2010). Many researchers have published work with heat tolerant *Bos taurus* breeds including Senepol, Romo Sinuano (Clarke et al., 1993; Hammond et al., 1995; Hammond et al., 1998; Chase et al., 2004), Boran, and Tuli (Hammond et al., 1995; Gaughan et al., 1999; Chase et al., 2004) in order to improve productivity, maintain carcass quality, and mitigate heat sensitivity. Hammond et al. (1995) found that Senepol and Romo Sinuano cattle had core body temperatures of 39°C, while exposed to the hot and humid environment of Florida, which was equal to that of *Bos indicus* and greater than *Bos taurus.* Although the aforementioned heat tolerant breeds had greater core body temperatures, Hammond et al. (1996) found faster respirations rates in Angus, compared to Brahman, Romo Sinuano, and Senepol heifers, which can be attributed to greater heat tolerance. Gaughan et al. (1999) found similar results for Boran and Tuli breeds, which are tropically adapted *Bos indicus* and *Bos taurus* breeds, respectively. Both of these breeds have not only shown improved heat tolerance, but also improved reproductive efficiency and carcass quality compared to Brahman cattle (Oliver, 1983; Cundiff et al., 1994; Herring et al., 1996). Oliver (1983) reported that Angus sired progeny had similar marbling, tenderness, and flavor when compared to Tuli cattle, while Boran and Brahman cattle were lower for all traits. As a result, Tuli breeds produced crossbred progeny that were similar to *Bos taurus* breeds (Oliver 1983). Additionally, marbling, tenderness, ribeye area, and overall acceptability were similar in Angus x Romo Sinuano and purebred Angus cattle (Clarke et al., 1993). As a result, thermo-tolerant *Bos taurus* breeds were able to maintain meat quality, while also maintaining homeothermy.

2.8 Meat Quality and Consumer Acceptability

2.8a Dark, Firm, and Dry

Studies have suggested that ultimate pH and meat color are the most important indices of meat quality (Węglarz, 2010). Adverse seasonal changes can affect meat quality characteristics (Kadim et al., 2004; Węglarz, 2010) through certain physiological changes. It has been found that exposure to temperatures > 35°C and < 0°C for 24 to 48 hours can lead to Dark Firm and Dry (DFD) carcasses (Miller, 2007). Furthermore, Grandin (1992) reported that the occurrence of DFD is most prominent during weather that is very cold with high precipitation, which can cause shivering through increased body-heat loss. The dark red state of DFD meat in a retail display case has shown to be one of the leading causes of consumer rejection of dark cutting beef (Miller, 2007). The main endocrine response during times of stress may release hormones that suppress energy storage while promoting utilization, mainly in the form of mobilized glucose. Exposure to high temperatures leads to adrenergic stress responses that stimulate peripheral vasodilation and muscle glycogenolysis (Gregory, 2010). The increase in glucose mobilization will ultimately lower the amount of stored glucose (glycogen), which will lead to a greater ultimate meat pH (Bray et al., 1989; Muchenje et al., 2009; Gregory, 2010; Węglarz, 2010). Muscles that have a normal pH of 5.5, show positive qualities such as light color, structure, tenderness, and taste, while meat with a pH of 6.0 will start to show negative dark characteristics that are known to lower quality (Gardner et al., 2001; Węglarz, 2010). Depleted glycogen stores lead to decreased lactate and hydrogen production during rigor mortis, resulting in a greater ultimate pH (Gardner et al., 2001). Greater ultimate pH leads to increased occurrences of DCB (Kadim et al., 2004; Muchenje et al., 2009) characterized by increased water-holding capacity, sticky texture, and dark color (Kreikemeier & Unruh, 1993; Egbert & Cornforth, 1986). High ultimate pH, normally above 6.0, will also promote the growth of microorganisms, which leads to off-odors, and the formation of slime (Gardner et al., 2001). Contrarily, meat that maintains a pH of 5.8 or less will slow microbial growth and impair mitochondrial oxygen consumption (Kreikemeier et al., 1993). The lower ultimate pH allows the meat to properly bloom by shifting more oxygen to the myoglobin, increasing the proportion of pigment in the oxymyoglobin state (AMSA, 2012).

Kadim et al. (2004) found that the pH of meat ranged from 5.45 – 5.64 during cool seasons, while warm seasons ranged from 5.74 – 6.93. Additionally, increased time at plant prior to slaughter, increased lot size, and lighter weights are all factors that further exacerbated DCB (Kreikemeier & Unruh, 1993). An increased incidence of DFD was also reported for the months of July and August (0.9% and 1.4%, respectively), with October showing similar results to August and eventually a decline to 1.13% in September (Kreikemeier & Unruh, 1993). This increase in DFD during the months of August, September, and October may be due to the stress of transitioning seasons. These results are supported by Miller (2007), who stated that the transition period between the months of October and September left little to no time for cattle to acclimate to the environment. Ladewig (2000) stated that the time between stress exposures was a critical factor when considering the damaging effects of stress. During the transition period, cholesterol stores build up in the adrenals, enzymes and receptors are synthesized, and systems are replenished for the next event (Ladewig, 2000). It was stated earlier that Foust and Headlee (2017) found greater levels of catecholamine hormones during moments of stress and specifically in this case, heat stress. Muchenje (2009) and Moberg (2000) further explained that catecholamine hormones play a role in depletion of muscle-stored glycogen, which resulted in high pH and darker meat. The DCB condition and subsequent loss in quality has been estimated to cost the US beef industry between $6.08 (1998) to $5.43 (2007) for across all animals harvested in the United States because it is more dry, more prone to spoilage, and has limited durability (Warriss, 1990; Scanga et al., 1998; Miller, 2007; Węglarz, 2010). Moberg (2000) stated that glycogen stores are quickly replenished following stress. However, McVeigh and Tarrant (1983) found that the repletion of glycogen into the muscle was actually a slow process (McVeigh and Tarrant, 1983). McVeigh and Tarrant (1983) determined the repletion rate of muscle glycogen of young Friesian bulls that were exposed to stress by mixing with other cattle for 1 hour, 3 hours, and 5 hours. The muscle glycogen level fell to 72% of the resting value after 1 hour, 55%, and 37%, respectively for the remaining two time points. A three-day recovery period, following glycogen depletion, showed only 84% repletion (McVeigh and Tarrant, 1983). Miller (2007) further stated that the replacement of muscle glycogen may take anywhere from a few days to a couple weeks.

As cattle acclimate to their environment, they will begin to accumulate stored glycogen. However, without proper time to acclimate, incidences of reduced meat quality may be observed. Scanga et al. (1998) also found that the sex of the animal plays an important role in incidences of DFD. The incidence of DFD in heifers was 0.30% and 0.14% greater during times of accumulated precipitation and frequent daily temperature fluctuations 1 to 3 days prior to harvest, when compared with steers and spayed heifers, respectively (Scanga et al., 1998). Scanga et al. (1998) also reported that steers treated with a combination implant of androgens and estrogens resulted in a 6% increase in DFD carcasses than steers treated solely with estrogen implants (Scanga et al., 1998).

In times of high temperatures, increased incidences of dehydration will occur which can affect meat quality through the shrinkage of myofibers (Gregory, 2010).

During the 20th century, the earth's surface temperature has risen 0.6°C and will continue to increase 0.06°C every decade and at this rate, generalized warming of the earth will take thousands of years to severely impact our surface temperatures (Gregory, 2010). In the short-term weather will become less predictable and therefore more volatile. The volatility of weather plays a large role in the stress of our livestock animals. Therefore, it is important to adapt to the changes in climate in order to maintain animal welfare and meat quality.

2.8b Perception of Meat Color

Quality cues can be grouped into intrinsic (color, and marbling) and extrinsic (price, origin, and quality labels) factors that affect the developing expectations of the general population (Font-i-Furnols and Guerrero, 2014). Consumers identify bright red colored beef as the standard for a high-quality meat product (Holman et al., 2017), while darker colored meat, as stated above, is the leading cause for consumer rejection (Miller, 2007). As a result, close to 15% of retail beef is discounted in price due to surface discoloration, which correlates to an annual loss of $1 billion dollars (Mancini and Hunt, 2005). Furthermore, Holman et al. (2017) found that of the 23 researched demographics, 88% of the people surveyed categorized meat color as either "important" or "very important". Visual perception of meat is determined through wavelengths that are reflected, absorbed, or scattered from the surface of the product, and because the human eye is trichromatic, the cones will have peak responses in the red (650nm – 700nm), green (490nm – 575nm), and blue (455nm – 490nm) spectra, while wavelengths that are absorbed or scattered are not perceptible to the eye (AMSA, 2012). Once light has penetrated the eye, these colors are relayed to the brain via the optical nerve and visual perception of the object's color, via cones, and lightness, via rods, can be obtained (AMSA, 2012). Meat color specifically is expressed through concentrations of water-soluble myoglobin proteins, which contains a 'globular' globin protein and a prosthetic heme that contains an iron atom within a porphyrin ring structure (Brewer, 2004).

The electron distribution of a unionized iron is as follows: Fe^0 = $1s^2 2s^2 2p^6 3p^6 4s^2 3d^6$ (Brewer, 2004). Upon ionization, iron loses electrons in the s-orbital, leaving 6 valence electrons in the d orbital in the ferrous state (Fe^{2+}) and 5 valence electrons in the ferric state (Fe^{3+}). Due to its electron deficiency, it will attract electronegative atoms of various ligands to the 6th ligand of myoglobin, while the imidazole nitrogen of histidine residue (His93) occupies the 5th, and the remaining 4 are ligated to the tetrapyrrole nitrogen's of heme, which form a hydrophobic heme pocket (Mancini and Hunt, 2005; Brewer, 2004). The 6th ligand is important, because it influences the electron configuration of both iron and heme, and as a result, the light absorbing characteristics and the color of the ligand-myoglobin complex (Brewer, 2004). When the myoglobin is in a ferrous state the 6th ligand can either bind to H_2O or O_2 and as a result creating meat with a dark red/purple (deoxymyoglobin) or a bright red cherry color (oxymyoglobin), respectively (AMSA, 2012; Mancini and Hunt, 2005; Brewer, 2004). Furthermore, in the ferric state, the 6th ligand of the tetrapyrrole ring is open, resulting in a heme that is slightly dome shaped. When this occurs the distal histidine (His64) is now unable to interact with the iron atom and a surface discoloration of dark grey to brown (metmyoglobin) will occur (Brewer, 2004).

As stated above, Diet has the ability to alter glycogen storage, chilling rate, and antioxidant accumulation, all of which can relate back to intrinsic color traits, pH, oxygen consumption, and metmyoglobin reducing activity (Mancini and Hunt, 2005). Oxidative damage is one of the major factors responsible for quality deterioration, resulting in meat remaining un-sold (Faustman et al., 2010). When muscle is displayed in high-oxygen modified atmospheric packaging, ferrous-oxymyoglobin (Fe^{2+}) will form and eventually be oxidize to form ferric-metmyoglobin iron (Fe^{3+}) through molecular superoxides (O_2^-), which can be visually represented by a muscle that changes from a bright red color to a dark red/brown color over a period of time (Chaijan, 2008). As superoxides accumulate, dismutation of these reactive species produces the prooxidant hydrogen peroxide (H_2O_2), which oxidizes the ferric iron and produces a hydroxyl radical in a reaction termed the Fenton reaction (Chaijan, 2008). Oxymyoglobin oxidation and lipid oxidation, which is mainly the oxidation of polyunsaturated fatty acids, are coupled because the oxidation of oxymyoglobin produces two prooxidants species, metmyoglobin and hydrogen peroxide, which facilitates lipid oxidation (Chaijan, 2008; Yin and Faustman, 1993).To summarize, lipid oxidation is the hydroxyl radical ($OH^\cdot$) oxidizing with unsaturated fatty acids at a methylene carbon in order to form fatty acyl radicals ($R^\cdot$), which reacts rapidly with atmospheric oxygen in order to form peroxyl radicals ($ROO^\cdot$) (Morrissey et al., 1998). Peroxyl radicals will preferentially oxidize with other unsaturated fatty acids, as seen by Horwitt (1986) who found that the rate of fatty acid oxidation containing 1, 2, 3, 4, 5 double bonds are 0.025, 1, 2, 4, 6, 8, respectively. They will then propagate a chain reaction producing lipid hydroperoxides (ROOH) and fatty acyl radicals (Morrissey et al., 1998). Finally, lipid hydroperoxides formed in the propagation reaction react with both copper (Cu^+) and ferrous iron to yield ferric iron, alkoxyl radicals ($RO^\cdot$), and a hydroxide (OH-). Lipid oxidation reduces the quality of meat through discoloration, and drip losses due to the conformational change of the prosthetic heme from the oxidation of the ferrous iron to ferric, which causes off-flavor, off-odor, texture defects, and potentially toxic compounds from peroxyl radical's propagation of the chain reaction in unsaturated fatty acids (Morrissey et al., 1998). As a result, color not only affects consumer perception atheistically, but can also be the initial indication of greater deleterious affects to muscle structure.

2.8c Shear Force

Meat tenderness influences consumer acceptability and has been found to be just as important as meat flavor (Reicks et al., 2010). Reicks et al. (2010) surveyed 1,310 consumers and concluded that tenderness had the greatest correlation (r = 0.84) to consumer acceptability. To measure meat tenderness, Warner Bratzler shear force (WBS) is a common method used to quantify the bite force needed to chew through a meat product. Miller et al. (2001) concluded that consumer acceptability increased as WBS values decreased and further found that the threshold from tough to tender was 4.9 kg (59% = "slightly tough) to 4.3 kg (86% = "slightly tender") of force, respectively.

Heat stress has been shown to increase muscle pH (Gardner et al., 2001; Węglarz, 2010) leading to consumer rejection due to discoloration (Miller, 2007); however, environmental stress factors may also affect the consumer's acceptability once purchased. Kadim et al. (2004) collected hot-boned muscle samples from the longissimus lumborum thoracis (LT) of beef cattle during the cool and hot seasons of Oman and concluded that muscle ultimate pH was greater in heat stressed cattle, while shear force was significantly lower. The increase in muscle pH led to a more optimum environment for endogenous enzymes including calpains to solubilize titin, filamin, and nebulin leading to a more tender product (Kadim et al., 2004).

Behrends et al. (2009) found an increase in WBS of strip steaks taken from weaned Bonsmara × Beefmaster steer calves who expressed agonistic behaviors at weaning and in feedlots. It was stated earlier, that heat stress increased the incidents of agonistic behavior (Foust and Headlee, 2017). Therefore, coupling results from Behrends et al. (2009), WBS values could increase for steers that express agonistic behaviors due to greater thermal exposure at weaning. Behrends et al. (2009) implemented a low intensity operation with only 35 days at a feedlot followed by 127 days on pasture. As a result of this low intensity operation, there was enough time to adapt and replenish muscle glycogen and maintain a low postmortem pH, preventing DFD characteristics and improved WBS values. Heat stress has been shown to improve meat quality through decreased WBS values; however, the deleterious effects on meat color will predominantly determine purchasing power.

Conclusion

As ambient temperatures begin to rise, due to climate change, the need for heat mitigation strategies will become more apparent, even in areas that historically have not required abatement strategies. Strategies such as shade and fans have been heavily researched in dairy and pasture fed operations, but there is a deficit in the number of studies that look specifically at the affect of fans or complete cover on feedlot performance. Understandably, complete cover may not be feasible for large feedlot operations, but many feedlots in the Southeast and other subtropical areas are smaller operations with less than 10,000 head. Quantification of heat stress has been recorded by using ambient temperature and relative humidity to calculate the THI. This THI quantification method has been used for six decades. Heat load index, on the other hand, is a similar method, but expands the model to also include black globe temperature and wind speed. The HLI quantification method is more dynamic compared to THI due to its ability to measure heat stress over a period of time using accumulated heat load units, and its ability to change heat load thresholds based on the phenotypic, genotypic, and management differences of each animal (group). Implementation of devices to calculate HLI and AHLU in real-time may play a key role in future heat abatement strategies. When evaluating HLI and AHLU the effect of black globe temperature was found to have the greatest impact out of the environmental stress factors, which further explains the need for proper shade structures or cover in order to alleviate the animal’s solar load and mitigate performance losses.

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CHAPTER 3

FINISHING BEEF UNDER COVER REDUCES HEAT LOAD AND IMPROVES EFFICIENCY DURING THE SUMMER IN THE SOUTHEASTERN UNITED STATES

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Abstract

Heat-stress in finishing cattle presents a significant risk to efficiency and economic viability, especially in the Southeastern United States. Forty-five Angus crossbred steers (450±25 kg) were blocked by weight and randomly assigned to environmental finishing treatments including covered with fan (**CWF**), covered without fan (**CNF**), or outside without shade (**OUT**). For 92 days steers were individually fed a typical feedlot ration. Environmental variables for the calculations of heat load index (**HLI**) and accumulated heat load units (**AHLU**) were collected throughout the study. Feed intake was recorded daily, and steers were weighed every 20 to 25 days. Once a treatment averaged the target weight of 613-kg, all steers were slaughtered, and carcass data were collected. Average maximal BG and HLI was lower for covered steers than OUT ($P<0.01$). Covered steers accumulated heat at an HLI of 93 while OUT steers accumulated at HLI of 87, therefore, average maximal AHLU were similar ($P=0.23$) between CWF and CNF and less than OUT ($P<0.01$). Average daily gains differed with CWF>CNF>OUT ($P\leq 0.03$), while G:F was similar between CWF and CNF ($P=0.22$), which were greater than OUT ($P<0.01$). Hot carcass weights (**HCW**) where heavier for CWF than OUT ($P<0.03$), but CNF was not different from either ($P\geq 0.23$). There was no difference for USDA Yield Grade ($P=0.38$), or marbling score ($P=0.71$). Steers finished under cover were more efficient than steers finished in open dry-lots; however, carcass traits remained similar across treatments. The addition of cooling fans further improved steer gains over time.

Key words: heat stress, feedlot, performance, carcass quality, carcass yield

3.1 INTRODUCTION

The Southeastern United States has been characterized as a humid, subtropical region with extended periods of high ambient temperatures, and relative humidity (West, 2003). In retrospect, heat stress has been extensively researched in order to determine the deleterious effect on multiple livestock industries including dairy (West, 2003; Collier et al., 2006), poultry (Sams, 1997), porcine (Boddicker et al., 2014), beef (Howden and Turnpenny, 1997), and ovine (Galan et al., 1999). Production losses attributed to heat stress including decreased performance, decreased reproduction, and increased mortality, have major economic impacts on the livestock industry totaling \$897 million, \$369 million, \$299 million, and \$128 million for the dairy, beef, porcine, and poultry industry, respectively (St-Pierre et al., 2003). In a survey performed by Onozaka et al (2010) consumers found locally grown products to be superior in freshness (70%), supporting the local economy (65%), and improved eating quality (62%). However, the incentive for producers to produce locally grown cattle in the Southeast has been historically muted due to adverse environmental climates (Onozaka et al., 2010). Southeastern feedlot operations are exposed to chronic heat stress for up to 7 months of the year vs. acute stress in other regions. Therefore, the gross economic impact, heat stress quantification and mitigation strategies are of interest to the food animal industry, especially operations in the Southeast.

The temperature humidity index (THI) system was established by Thom (1959) and is well documented in current research to quantify environmental variables for both humans and animals. Although THI is widely integrated in the literature, the model does not utilize variables critical to properly quantifying heat stress such as wind speed, solar radiation, or time, and does not properly assess heat load accumulation. Recognizing the deficiencies in THI, Gaughan et al. (2008) quantified heat load in beef cattle through a new regression model known as the heat load index (HLI). The HLI took into account black globe temperature (BG), relative humidity (RH), and wind speed (WS). Additionally, the HLI method further quantified heat load through accumulated heat load units (AHLU), which measures the time an animal is accumulating heat. The AHLU can be influenced through genetic and phenotypic influences and physical modifications of the animal's environment, allowing for an accurate assessment in a dynamic system. Heat produced internally through metabolic processes is exchanged into the environment through sensible (radiation, conduction, and convection) and insensible (evaporative) cooling mechanisms (Dahl et al., 2020; Garner et al., 1989).

Implementation of shades and fans has been shown to modify the environment through reduced solar radiation (Mader et al., 1999), and increased evaporative heat loss (Garner et al., 1989), respectively. Shade implementation in a feedlot operation has also been shown to improve live and carcass performance (Mitlohner et al., 2002; Blaine and Nsahlai, 2011; Johnson et al., 2015). However, fan utilization, in a feedlot operation, is rarely explored in the current literature, but has been found to improve average daily gains (ADG; Bond et al., 1957). The large scale of feedlot system prohibits finishing under solid structures; however, this may be a viable option for smaller scale operations in the Southeast and other subtropical areas.

Therefore, the objective of this study was to determine the effect that environmental stress factors have on feedlot performance and carcass characteristics in a Southeastern feedlot operation. Furthermore, integration of heat abatement strategies including covered finishing systems with and without forced airflow were analyzed to determine their validity in improving cattle performance and carcass characteristics.

3.2 MATERIALS AND METHODS

All procedures and guidelines that involved animals were approved by the University of Georgia Institutional Animal Care and Use Committee (A2018-01-017-Y1-A1).

3.2.1 Environmental Monitoring, Animal Performance, and Diet Management

In order to monitor and quantify the environmental stress factors at a micro-climatic level, each treatment had two Kestrel meters with weathervanes (5400AG cattle heat stress trackers; KestrelMeters; Boothwyn, PA) equally spaced in the treatment pens 2.4 m from the ground. Each Kestrel meter was programmed for each treatment using genotypic, phenotypic, and pen management factors following Gaughan et al. (2008; Table 3.2). The meters were set to capture the environmental factors including relative humidity (**RH**), black globe temperature (**BG**), and wind speed (**WS**) every 30 min. The Kestrel meters would also automatically calculate and record heat load index (HLI), and accumulated heat load units (**AHLU**) based on the criteria input. The values from the two meters in each pen were averaged for each timepoint for analysis.

In order to assess the heat load of each animal, panting scores (**PS**) were measured and recorded daily at 0900 h (**AM**) and 1600 h (**PM**) following Gaughan et al.

(2008; Table 3.3). Cattle who experience panting scores above 3.5 were removed from the study for 1 day and then placed back in their respected pen. As a result, 4 steers were moved to the sick pen, with adequate shade and cool water, due to excessive panting scores and allowed back to their treatments after 24 h. Furthermore, 1 steer was permanently removed from CWF due to urinary calculi and 2 were permanently removed from CNF due to lameness.

Forty-five crossbred Angus steers (450 ± 25 kg; 14 to 15 mo of age) were transported to the University of Georgia Beef Research Unit (Eatonton, GA, USA) and were blocked by weight (tru-test xr5000 scale; Valley Farm Supply, LLC.; New Providence, PA) and origin (n = 15 per treatment). Steers within blocks were randomly assigned to 1 of 3 treatments including covered with fan (**CWF**; DeLaval 1250 propeller dairy fans; 124.5 cm diameter; 439 rotations per minute; 39.1 m^3/hour/Watt; DeLaval; Tullamarine, AU), covered no fan (**CNF**), and outside drylot with no shade or fan availability (**OUT**). Steers assigned to CWF and CNF were housed in a covered barn with open sides. The finishing barn was oriented south-west to north-east and contains 10 pens with concrete flooring at a 2° slope from front to back (n = 3 steers per pen; 9.1 m × 9.1 m; 9.1m × 3 m per animal). The pens on the west side of the barn were equipped with fans and programed to start/stop at 24.4°C. Pens were constructed with metal panels and a 10 m feed alley was allocated towards the interior of the barn. A Calan Broadbent Feeding System (American Calan, Inc.; Northwood, New Hampshire) was integrated in order to administer feed to covered treatments. The fans were angled and tested with wind meters (Kestrel meters) to ensure that residual airflow from CWF did not impact CNF. Outside treatments were individually fed (*n* = 1 per pen) in outside pens (9.1m × 3.0 m per animal) due to limitations in Calan Gates. The outside pens were constructed 30 m from the eastern side of the barn to ensure afternoon shade from the barn did not reach the pens. All pens were equipped with automated water troughs and animals had *ad libitum* access to water at all times.

All steers were fed the same total mix (Godfrey's Feed, Madison, GA; Table 3.1). Feed was weighed and distributed daily (1000 h) to steers using an American Calan Data Ranger (American Calan, Inc.; Northwood, New Hampshire). Seven days prior to the study experiment steers were trained to use Calan gate feeders. Gates remained open for steers to adjust and then closed after five days and monitored to ensure cattle were properly trained. Cattle were fed 10 kg at the start with the addition of 1 kg every other day for 7 d. Orts were weighed back daily (0800 h) in order to calculate dry matter intake and gain:feed (G:F). Cattle were weighed on d 21, 46, 74, and 92 to track weight gain and calculate ADG. Feed samples were collected from the different feed loads and composited, ground (1-mm grind) in a Wiley Mill (Neobits inc.; Santa Clara, CA), and placed in a freezer (-20 ± 2°C) for dry matter analysis. Once thawed, Filter bag (F57 filter bags, ANKOM, Technology; Macedon, NY; $\mathbf{W_1}$) and sample with filter bag (0.45 g to 0.50 g; $\mathbf{W_2}$) weights were recorded and heat-sealed (1915, ANKOM Technology; $\mathbf{W_2}$). Neutral detergent fiber (**NDF**) and Acid Detergent fiber (**ADF**) were analyzed in an Ankom 2000 Automated Fiber Analyzer (SKU: A2000; Macedon, NY) using methods outlined in Ankom Technology (2006a; 2006b). The inclusion of 1 blank bag ($\mathbf{C_1}$) per run was utilized as an indicator of particle loss and bags were weighed after extraction (**W_3**). Neutral detergent fiber and acid detergent fiber were calculated using the following equation: $100 \times (W_3 - (W_1 \times C_1)) / W_2$.

3.2.2 Cattle Harvest and Carcass Analysis

When the first treatment group reached target weight (613 kg) all steers were transported (164 km) and harvested at a commercial packing plant under federal inspection (FPL Foods LLC, Augusta, GA). Steers were provided *ad libitum* access to water and cover 12 h prior to harvest during lairage at the packing plant.

Forty-eight hours postmortem the carcasses were ribbed between the 12^{th}-13^{th} rib and graded after 20 min by a USDA Meat Grader. After grading, rail data for yield and quality grade were manually collected including kidney pelvic heart fat (**KPH**), hot carcass weight (**HCW**), 12^{th} rib fat-thickness (**BF**), ribeye area (**REA**), marbling score (**MRB**), and maturity (skeletal and lean). Subjective lean and fat color were quantified using Japanese Beef Lean and Fat Color Standards (The Japan Ham & Sausage Cooperative Association; Tokyo, Japan). Objective lean and fat color (L*a*b*) were collected using a portable spectrophotometer (HunterLab; MiniScan EZ 4500L, Reston, VA; 10° viewing area, 2.54 cm aperture size; A illuminant) and calibrated using black, white, and saturated red tiles. Lean color was collected on the exposed surface of the longissimus lumborum thoraces, and external fat color was measured anterior to the cut surface. Objective color measurements were taken in triplicate and averaged for analysis.

3.2.3 Longissimus Lumborum Processing

After carcass data were collected the right longissimus lumborum (**LL**) was tagged to facilitate tracking through the fabrication process. During carcass fabrication, the right LL was removed to yield the boneless striploin (Institutional Meat Purchase Specification 180) from each carcass. Each striploin was vacuum packaged according to plant specifications and placed in coolers (0°C) for transport (169 km) to the University of Georgia Meat Science Technology Center (**MSTC**). Upon arrival at the MSTC the striploins were transferred to boxes and placed in dark storage (1±1°C) until 14 d postmortem. After 14 d postmortem, the striploins were unpackaged and twelve steaks were cut (2.54 cm thick) anterior to posterior for proximate analysis, slice shear (**SS**), sensory analysis (**SEN**) and shelf life following: one steak each for proximate, SS 14 d wet aging, SEN 14 d wet aging, SEN 21 d wet aging, SS 21 d wet aging, and then 7 steaks for shelf life. Samples for proximate analysis, slice shear force, and sensory were vacuumed sealed (B-620 series; 30-50 cm^3 O_2/m^2/24 h/101,325 Pa/ 23°C; Cryovac Sealed Air Corporation, Duncan, SC, USA). Proximate samples and 14 d postmortem samples were placed in frozen storage (-20 ± 2°C) while 21 d postmortem samples were boxed and placed back in cold storage for 7 additional days. After 21 d of postmortem aging the 21 d samples were also placed in frozen storage.

3.2.4 Color Stability during Retail Display and Lipid Peroxidation Analysis

The seven steaks for shelf life analysis were individually packaged in polystyrene trays (Cryovac® thermoformed polystyrene processor trays, Cryovac) with polyvinylchloride overwrap (PVC; O2 transmission = 23,250 ml/m2/24 h, 72 gauge; Pro

Pack Group, Oakland, NJ). Within a strip, the steaks were randomly assigned to 0, 1, 2, 3, 4, 5, or 6 days of retail display. All steaks were then placed in open top retail display cases (M1X, Hussmann Corp.; Bridgeton, MO) for 6 days under 24 h continuous warm-white fluorescent lighting (Octron/ECO; 30000K; F032/830/ECO; Sylvania Company, Versailles, KY; 1844 Lux). Temperature (-0.8°C) within the display cases was monitored and recorded using digital temperature loggers (TR-50U2, T & D Corp., Japan). Shelf life samples were rotated top to bottom and left to right daily. Objective color measures for reflectance between 400-700 nm and L*, a*, b* was recorded, in triplicate, daily (1500 ± 0100 h) on Day 6 samples (Hunter colorimeter Reston, Virginia). Spectral reflectance was used to calculate the proportions of oxymyoglobin, deoxymyoglobin, and metmyoglobin following AMSA (2012) guidelines adapted from Krzywicki (1979). Values for L*a*b* values were also used to calculate $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + \Delta b^*)^2]^2$, hue angle = arctangent (b*/a*), and chroma = $(a^{*2} + b^{*2})^{0.5}$ (AMSA, 2012). On their respective days the shelf life samples were placed in vacuum bags, sealed, and placed in frozen (-20 ± 2°C) storage for further lipid peroxidation analysis. Lipid peroxidation analysis was performed using a rapid, wet method following Buege and Aust (1978). Steaks were thawed for 12 h and trimmed of all external fat and connective tissue. Thiobarbituric acid/trichloroacetic acid (TBA/TCA) solutions were added to 0.50 grams of homogenized sample and incubated in boiling bath water for 20 min. After color formation, samples were placed in cool bath water (25°C) for 10 min and absorbance was read at 532 nm (Jasco V-630 Spectrophotometer, Jasco Inc., Easton, MA).

3.2.7 Proximate Analysis

For proximate analysis, each sample was allowed to thaw (2 ± 2°C) overnight. Once thawed, samples were removed from packaging, trimmed of external fat and connective tissue, minced, flash frozen in liquid nitrogen, and homogenized (Waring commercial blenders, Model 34BL97, Dynamics Corporation of America, New Hartford, CT). To determine moisture 3 ± 0.10 g of sample were weighed and transferred to a drying oven (90°C) for 24 h. Samples were placed in crucibles that were dried and placed in a desiccator to equalize prior to moisture and ash analysis as outlined in (AOAC, 1990). Moisture was determined using the following equation: ((wet sample weight – dry sample weight) / (wet sample weight)) × 100%. The dried samples from moisture analysis were then placed in an ash oven (Fisher Scientific; Hampton, NH; Isotemp muffle furnace) at 550°C for 24 h to determined ash content utilizing the following equation: ((Dry sample weight – Ash sample weight) / (Dry sample weight)) × 100%. To determine total lipid, 1 ± 0.1 g of homogenized sample were placed in filter bags (ANKOM XT4; ANKOM Technology; Macedon, NY) and lipid content was measured (Ankom XT15 Extraction System; Macedon, NY). Finally, homogenized samples (0.200 g – 0.299 g), were placed in foil and nitrogen content was analyzed using a Leco Nitrogen Analyzer (Model FP268, Leco Corporation, St. Joseph, MI, USA).

3.2.5 Sensory Analysis

For sensory analysis 8 trained panelists (AMSA, 2015) evaluated 16 samples each day spread across two sessions with 4 h between sessions. For each sensory session, eight samples were randomly removed (4 each from d 14 and 21 boxes) from the freezer, unpackaged and weighed. Samples were placed on poly trays with absorbent pads and allowed to thaw for 24 ± 2 h (4 ± 2°C). Once thawed, and before the panel session, each sample was weighed and a copper-constantan thermocouple (Omega Engineering, Stamford, CT) was inserted into the geometric center of each steak attached to a Digi-Sense 12-channel scanning thermometer (model 9200-00; Cole Palmer Vernon Hills, IL) to record internal temperature. The samples were cooked (Foreman Grill; Spectrum Brands, Inc.; Beachwood, OH) to achieve a final internal temperature of 71°C (AMSA, 2015). Once cooked the samples were weighed, wrapped in foil, and rested under a heat lamp to maintain temperature until sampling (maximum 10 min). Prior to serving, the samples were cut (1.27 × 1.27 x 2.54 cm) using a sample sizer. Two cubes per sample were placed in warmed, labeled jars in heated yogurt makers (Euro Cuisine, Inc.; Los Angeles, CA). The yogurt makers with the samples were then passed through a breadbasket door to the panelists in the sensory room. Samples were served unsalted and unspiced with water and unsalted soda crackers to cleanse pallet between each sample. The sensory room had positive airflow and contained eight individual booths with red lighting to conceal differences in sample color. In addition to the samples, panelists were also provided a warm-up sample. Each panelists assessed each sample on an 8-point hedonic scale for tenderness (initial and sustained; 1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, 8 = extremely tender), beef intensity (1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, 8 = extremely intense), and juiciness (1 = extremely dry, 2 = very dry, 3 =

moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juicy, 8 = extremely juicy) and a 6-point scale for off-flavor (1= none detected, 2 = threshold off-flavor, 3 = slightly intense, 4 = moderate off-flavor, 5 = very strong off-flavor, 6 = extreme off-flavor).

3.2.6 Shear Force Analysis

Slice Shear samples were weighed and cooked following the same methods as the sensory samples. Once cooked, the warm samples were cut into 2 slices from lateral end (1-cm thick, 5-cm long), parallel to the muscle fibers for slice shear force (AMSA, 2015). Each slice was sheared using an Instron Universal Testing Machine (Instron Dual Column Model 3365, Instron Corp., Norwood, MA; 51 kgf load cell, crosshead speed of 50 cm/min) with a slice shear head (0.11684 cm thickness). The peak force (kgf) for each slice was recorded (Bluehill software, Instron Corp., Norwood, MA) and averaged for each sample.

3.2.8 Statistical Analysis

Environmental data were analyzed as a general linear model with treatment as the fixed effect. Data from the two Kestrel units in each treatment were combined and averaged. Data were then analyzed by week daily maximum and minimum values (BG, RH, WS, HLI, and AHLU). All other data were analyzed as a completely randomized mixed model with treatment and time as the fixed effect(s) and animal (carcass) within treatment as the random term (JMP V13, SAS Inst.). For all analyses, animal or carcass was considered the observational and experimental unit. Feedlot performance data (weight, ADG, G:F), carcass characteristics, and proximate composition were analyzed for the main effects of treatment, time (where applicable) and the treatment by time interaction, and cumulative performance (ADG and G:F). Data for sensory analysis, slice shear force, and shelf life were analyzed as a split-plot where carcass was the whole-plot and steak within aging period or day of shelf life was the subplot. If an interaction occurred data were reanalyzed by day (period). Least squares means were separated by student's t pairwise comparisons. Mean differences were considered significant at $\alpha <$ 0.05.

3.3 RESULTS & DISCUSSION

3.3.1 Quantification of Environmental Stress Factors

Average maximum and minimum environmental stress values were quantified for 13 weeks, starting in the middle of June to the middle of September. Collection of the average maximum and minimum environmental variables showed a treatment and week effect for BG, RH, and WS ($P < 0.01$; Fig 3.2a, 3.2b, and 3.2c), as well as, HLI, and AHLU ($P < 0.01$; Fig 3.3a and 3.3b) and AM/PM PS ($P < 0.01$; Fig 3.4a and 3.4b), while a treatment × week effect ($P < 0.01$) was only observed for average maximum RH, WS, minimum and maximum AHLU values, and morning and afternoon panting scores ($P <$ 0.01). Steers exposed to OUT had a greater ($P < 0.01$) average maximum BG for all weeks of the experiment with an average increase of 15°C compared to both CWF and CNF steers; however, OUT steers had a lower ($P < 0.01$) minimum BG of 0.83°C and 0.96°C compared to CWF and CNF steers, respectively. A 2% increase ($P < 0.01$) in average maximum RH was found for CWF and OUT steers (Fig 3.2b) when compared to

CNF. Steers exposed to outside feedlots had a reduction in average minimum RH that was attributed to the increased airflow that was unavailable to the other two treatments (Fig 3.2c). The CNF treatment expressed the lowest ($P < 0.01$) WS of 3.72 kph, while CWF and OUT had WS of 8.48 and 10.80 kph, respectively (Fig 3.2c).

Barn cover alone reduced BG, but acted as a barrier and reduced WS. As a result, implementing fans in a covered finishing environment can reduce solar load, while maintaining proper convective cooling strategies. Steers in OUT were exposed to an average maximum HLI of 111.4, which was 23.2 and 19.1 units greater ($P > 0.01$) than CNF and CWF steers, respectively. Average maximum heat load index values for CNF steers were on average 4.14 greater ($P < 0.01$) than CWF values (Fig 3.3a). The average minimum HLI of CWF and CNF was 2.11 and 2.74 greater ($P < 0.01$), respectively, than the OUT environment. The greater minimum HLI may be due to the increase in RH, as well as a reduction of WS for CNF compared to the OUT environment. The OUT steers accumulated a greater amount of heat load compared to CWF and CNF steers. Average maximum and minimum AHLU were 397 and 356 units greater ($P < 0.01$) for OUT steers when compared to CWF and CNF treatments, respectively (Fig 3.3b). The greater accumulated heat load values can be explained by the constant exposure to solar radiation during the weeks of the study. Although OUT and CWF steers had similar RH and WS, the greater BG, as well as, the lower HLI threshold for OUT steers led to the greater accumulation of heat overtime. Exposure to greater BG was also related to OUT steers having greater ($P < 0.01$) AM (Fig 3.4a) and PM (Fig 3.4b) panting scores (PS) compared to CWF and CNF steers. Steers in the OUT treatment had an increase in average PM PS of 1.25 and 1.04 when compared to CWF and CNF steers, respectively (*P* < 0.01). In addition to increased PS for OUT steers, it was found that fans reduced the average PM PS by 0.22 (*P* < 0.01) compared to CNF steers. Steers in the OUT treatment had an increase in average AM PS of 0.68 and 0.50 when compared to CWF and CNF steers, respectively (*P* < 0.01). An increase (*P* < 0.01) in average AM PS of 0.19 was found in CNF steers compared to CWF. In addition to increases in mean PM PS, it was also observed that cattle were unable to properly dissipate heat during the night hours, resulting in an increase in mean AM PS, indicating OUT steers started the day at an elevated heat load. Therefore, OUT steers accumulated a significant amount of heat, while heat abatement strategies allowed steers to properly expend heat during the study.

When assessing HLI and AHLU there are three variables to consider, genotypic, phenotypic, and management practices. The BG, RH, and WS are dynamic variables that were manipulated through the addition of fans and cover. As a result of this environmental manipulation, changes to steer's AHLU and HLI were observed throughout all weeks of the study. Reduction in HLI can be explained by the gross reduction in radiant exposure leading to a lower BG. Similar BG reductions were found by Foust and Headlee (2017) for *Bos indicus* pregnant cows exposed to natural shading; furthermore, Hayes et al., (2017) found a reduction in BG, as well as an 11°C decrease in ground temperatures when finishing cattle were exposed to a two-tiered snow fence shaded structures. Therefore, conductive cooling methods may have played a role in maintaining animal performance. Gaughan et al., (2008) found a positive linear correlation between HLI and AHLU with PS (r^2=0.93 and 0.92, respectively). As a result, observed increases in PS for OUT steers was a result of greater heat load and inability of steers to properly dissipate heat. Gaughan et al. (2010) observed a 0.5 increase in mean PS when comparing Angus cattle exposed to an HLI between 86 and 96 compared to > 96; in the current study, barn covered steers on average had an average maximum mean HLI of 91, while OUT steers had an HLI of 110. Steers under cover for the current study had a PM PS reduction of 1.2 for CWF and 1.0 when compared to OUT steers. When assessing AM PS, OUT steers had PS that were on average 0.49 and 0.68 greater than CNF and CWF, respectively, which was similar to results found by Gaughan et al. (2010). Clarke and Kelly (1996) found a reduction of 40 breathes/minute in response to a reduction in solar load, which can be observed in the large reduction in PS in the current study. Mader et al., (1999) concluded that shade only changes the radiation balance of an animal, and not the humidity of the environment, which is in contrast with what was found in the current study. Although significant, only a 2% increase in average maximum RH was observed for covered steers and therefore may be caused by reduced airflow.

3.3.2 Animal Performance

A treatment × period effect was observed for live weight, ADG, and G:F ($P < 0.01$; Table 3.4), therefore, these data were reanalyzed by day or period. Initial body weight was similar among all 3 treatments on d 0, 21, 46, and 74; however, CWF steers were 37.10 kg heavier ($P < 0.01$) than OUT steers, while CNF steers were similar ($P \geq 0.17$) to both after 92 d. The difference in body weight after 92 d can be explained by greater total ADG for observed for CWF and CNF steers compared to OUT steers (Table

3.4). Cattle exposed to fans had an improved ($P < 0.02$) total ADG of 0.25 kg and 0.56 kg when compared to CNF and OUT steers, respectively. In addition to improved total ADG, total G:F for CWF and CNF steers was 0.04 kg and 0.03 kg greater ($P < 0.01$), respectively, than OUT steers. The reduced ADG and rate of G:F would have delayed finishing for OUT steers by approximately 20 days, to achieve the same finishing weight as CWF steers.

In previous research, shade and fan implementation has played a crucial role in reducing solar exposure and improved evaporative cooling, respectively (Garner et al., 1989). Beede and Collier (1986) observed a linear decrease in DMI when cattle were exposed to greater ambient temperatures leading to a similar reduction in ADG as seen in the current study. Furthermore, Grandin (2016) determined that reducing exposure to solar radiation improved both ADG and DMI, which can be seen in the improved performance of CWF steers. Blaine and Nsahlai (2010) found that shade improved ADG by 0.15 kg, while in the current experiment CWF and CNF had an increase of 0.54 and 0.33 kg. Furthermore, Blaine and Nsahlai (2010) observed improvements in efficiency of 0.41 feed:gain, which was similar to efficiency values observed in covered steers compared to OUT. Mitlohner et al (2002) observed an increase in ADG and gain:feed by 0.10 and 0.006 when cattle were placed under shade. However, Mitlohner et al. (2002) observed an increase in DMI of 0.28 kg/d, however OUT steers in the current experiment had similar DMI with CWF and greater than CNF steers. Therefore, nutrient partitioning was utilized for maintaining thermoregulation instead of growth. In addition to shade, fans have been utilized in both dairy and beef cattle operations to reduce panting (Magrin et al., 2016) and improve ADG (Bond et al., 1957). Identical results of fans improving ADG was found in research performed by Bond (1957), who found that fans improved ADG by 0.47 kg and 0.24 kg in both years of their feedlot study. Performance values of ADG were similar on d 21 and d 74, while covered steers had improved values for the remaining periods. However, when assessing all periods for gain:feed, similarities were only found on d 92. As a result, difference in live weight by d 92 can be attributed by the differences in efficiency and average daily gain. When assessing the days needed to finish, CNF and OUT steers would have needed an additional 5 to 20 days on feed to achieve target weight, respectively.

3.3.3 Carcass Quality and Yield

A treatment effect was observed for HCW ($P < 0.03$; Table 3.5), while no difference was found for yield grade ($P > 0.44$), REA ($P > 0.62$), back fat ($P > 0.44$), KPH ($P > 0.93$), and dressing percentage ($P > 0.60$). No treatment effect differences were observed for quality grade factors including, marbling ($P > 0.83$), and overall maturity ($P > 0.91$). Additionally, no treatment differences (P > 0.07) were observed for any subjective or objective color measures. Based on marbling scores and maturity values, the carcasses would have graded Average Choice, which was aligned with USDA graders call.

Steers exposed to fans met target weight first, which explains the difference in HCW. Although HCW differed across treatments, quality and yield data did not differ. Similar results by Clarke and Kelly (1996) found that shade (10 m^2/head) had no significant influence on carcass yield or quality. In contrast, Mitlöhner et al., (2002) showed a 10.8% reduction in dark cutter and a 19.6% increase in choice quality grade and greater for cattle that were exposed to heat abatement strategies. When assessing changes in carcass characteristics, it was expected to observe improvements in covered steers when compared to outside with no cover. The lack of difference can be explained by the location to which the study was conducted. The trial ran by Mitlöhner et al., (2002) was located in Texas, while the current experiment was conducted in Georgia. The acute heat stress environment of Texas may have prevented cattle from adapting to the environment, while chronic heat stress allowed steers to adapt. Furthermore, Mitlöhner (2001) and Mitlöhner (2002) found no difference in yield characteristics, except HCW, as observed in the current study. Greater levels of catecholamines are found in moments of heat stress (Foust and Headlee, 2017) and as a result may lead to a depletion of muscle-stored glycogen, resulting in greater postmortem pH leading to an increase in dark cutters (Moberg, 2000; Muchenje et al., 2009); however, no changes in color were observed in the current study. Therefore it can be speculated that overall, shade and fan implementation improved rate of gain and as a result greater HCW. Furthermore, the lack in carcass yield and quality characteristics lead to a lack of difference found in carcass L*, a*, b*. However, Kadim et al. (2004) observed an increase in lean L*, a*, b* values for the longissimus thoracis when cattle were exposed to the hot compared to cool environments of Muscat. Muscat's acute heat stress environment may have attributed to the changes in carcass color, however the chronic environment in the current research may have lead to similar carcass color characteristics as seen by similarities in quality and yield.

3.3.4 Cost Benefit Analysis

A treatment effect was observed for feed cost (*P* = 0.01) and net profit/loss (*P* < 0.01; Table 3.6). Steers in OUT were less efficient than steers in CWF and OUT. Feed cost differences followed the difference found in DMI. Steers in CNF had lower DMI values when compared to OUT, while no differences were observed between CWF and OUT. Although OUT steers had greater DMI, the decrease in feed efficiency lead to increased feed costs. No difference (*P* > 0.27) was observed for gross carcass value, which was expected by similarities in carcass quality characteristics. Therefore, the similarities (*P* = 0.45) in feeder values and similarities in carcass values lead to the conclusion that differences in net profit/loss were influenced by changes in feed cost. As a result, cover successfully improved animal value by $145.55 and $140.27 per head for CWF and CNF, respectively, when compared to OUT steers.

3.3.5 Color Stability during Retail Display

No treatment × day interaction effects (*P* > 0.07) or treatment main effects (P > 0.24; Table 3.7) were observed for objective color analysis over the 6 d of simulated retail display. However, a day effect (*P* < 0.01) was found for L*a*b* color values, hue, chroma, ΔE, all 3 forms of myoglobin, and lipid peroxidation (Table 3.8).

Color and the dynamic properties of myoglobin are vital to change in meat quality. The day effect observed in the study for all shelf life variables is expected due to physiological changes that normally occur in postmortem muscles. Without external factors (i.e. oxidative stress), 0.2% of oxygen consumed will be converted to ROS that bind to atmospheric oxygen and deplete oxygen resources that naturally bind to myoglobin in order to form oxymyoglobin, however an increase in oxidative stress may lead to a rapid increase in ROS and act as a catalyst for color change (Rhoads et al., 2013). Oxidative stress occurs when free radical production exceeds the antioxidant defense system as a result of diet, breed, and most importantly preslaughter handling procedures (Xing et al., 2019). Although cattle in the outside treatment were exposed to chronic heat stress, it seems as though oxidation values remained similar across treatments as seen by the progression of lipid peroxidation throughout shelf life. The ratio of ROS and SOD will continue to increase postmortem and lead to the natural change in color as seen in the current study.

3.3.6 Proximate Analysis

No treatment effect for protein, lipid, moisture, and ash was observed for proximate analysis (Table 3.9; $P > 0.39$). Proximate analysis was conducted on the first steak from the collected shortloin at the 13th rib. Given that were no differences among treatments for ribeye area, marbling score, or color (as an indicator of pH and therefore water holding capacity) at the 12th-13th rib junction, differences in proximate composition were not expected.

3.3.7 Slice Shear force and Sensory Analysis

No treatment main effects ($P > 0.43$), day of aging effect ($P = 0.08$), or treatment × day of aging effect ($P > 0.27$) were observed for shear force (Table 3.10). Furthermore, no treatment main effect ($P > 0.43$) or treatment × day of aging effect ($P > 0.07$) were observed for sensory analysis, while a day of aging effect was observed for initial ($P < 0.01$) and sustained tenderness ($P = 0.01$; Table 3.11) with steaks aged for 21 d being more tender than those aged for 14 d. No treatment main effect ($P > 0.07$), or treatment × day of aging ($P > 0.27$) effect were observed for thaw loss and cook loss; however a day of age effect was observed for day of aging for thaw loss ($P = 0.04$), with steaks aged for 14 days having greater thaw loss compared to those aged for 21 days.

When assessing tenderness, no treatment and day of aging effect was observed. The lack of significance and the similarities in marbling score most likely allowed steaks to reach similar tenderness by the natural degradation of proteins through postmortem proteinases as seen by Wulf et al. (1996). The lack of difference between d 14 and 21 of aging diminished as was also observed by Choat et al. (2006). Therefore, steaks were allowed to achieve tenderness by d 14 of again, which translated to similar shear force values. However, greater tenderness values were observed in sensory analysis, which may be a result of the near significant change in tenderness from d 14 and 21. Although d 14 steaks had greater thaw loss values, only a 0.51% change was observed. The lack of significance for the remaining sensory values can also be explained by the lack of difference observed in proximate analysis. Miller (2007) states that the replacement of muscle glycogen may take anywhere from a few days to a couple weeks. Steers in the current study were on feed for 13 weeks, therefore metabolic substrates were allowed to replenish overtime as adaption to chronic heat stress ensued. As stated in the shelf life study steers were able to adapt physiologically to their environment, which lead to similarities in postmortem analysis.

3.4 Conclusion

The addition of fans and cover as heat abatement strategies does not affect carcass quality or sensory data, but did positively impact feed efficiency and final live and carcass weights. It can be speculated that the chronic heat stressed environment of the Southeastern United States allowed for steers to adapt and therefore maintain carcass yield and quality characteristics. Although carcass values remained similar, implementation of cover and improved efficiencies resulted in a positive net profit, while outside resulted in net losses per head. It is important to note that when applying profits in the current study to small/medium feedlot operation scenarios, the importance of heat abatement strategies becomes even more apparent. It was also concluded that heat stress did not lead to oxidative stress, as seen by no differences in shelf life between treatments. Steers that are exposed to chronic stress can lead to a desensitization also known as a "flooding effect" as explained by Hart and Hart, (1985). Cattle who are in natural production systems will only have diurnal states of heat stress rather than chronic stress; however, steers will continue to accumulate heat overtime if proper mitigation techniques are not applied as seen in the OUT steers. As seen in the current experiment, maintaining growth and profit in a Southeastern feedlot operation is possible with proper heat abatement strategies. Retaining operations in the Southeast will lead to an increase in locally grown beef supply that will fill the current demand. Furthermore, additional research into methods to combat the subtropical climate of the region of the Southeastern region can further incentivize producers.

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Table 3.1: Composition of diet for feedlot steers

Ingredient	Percent dry matter basis
Cracked corn	46.00
Distiller grain with solubles	24.00
Soy hulls	14.00
Ground hay	10.00
Molasses	2.00
Calcium carbonate	1.50
TM Godefrey's[1]	1.25
Sodium bicarbonate	1.00
Ammonium chloride	0.20
Analyzed Nutrient Composition, % DM[2]	
Hay	
Acid detergent fiber	55.25
Neutral detergent fiber	35.57
Cracked corn	
Acid detergent fiber	23.54
Neutral detergent fiber	23.00

[1]Trace Mineral Godfrey's feed, Ca 29.65%, Cl 0.15%, Mg 0.27%, S 8.20%, Co 769.00 mg/kg, Cu 15,361.01 mg/kg, I 1,441 mg/kg, Fe 12,

030.00 mg/kg, Mn 56,732.00 mg/kg, Se 288.00 mg/kg, Zn 72,000.03 mg/kg.

[2]Nutrient composition analyzed using Ankom 2000 Fiber Analyzer.

Table 3.2: Management and cattle profile adjustments for Kestrel units

	Treatment[1]		
Trait	CWF	CNF	OUT
Pen management			
Manure class	1	1	3
Shade	3 m^2 to 5 m^2	3 m^2 to 5 m^2	None
Water temperature	20°C to 30°C	20°C to 30°C	30°C to 35°C
Extra water	No	No	No
Heat rations	No	No	No
Manure clear	Yes	Yes	No
Cattle profile			
Genotype	*Bos taurus*	*Bos taurus*	*Bos taurus*
Coat color	Black	Black	Black
Days on feed[2]	0 to 80	0 to 80	0 to 80
Health status	Healthy	Healthy	Healthy

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; OUT = outside drylot steers without shade or fans.

[2]Days on feed adjusted at d 80 to “80 to 130”.

Table 3.3: Panting score with breathing conditions

Score[1]	Breathing Condition
0	No panting
1	Slight panting, mouth closed, no drool, easy to see chest movements
2	Fat panting, drool present, no open mouth
2.5	As for 2, but occasional open mouth panting, tongue not extended
3	Open mouth and excessive drooling, neck extended, head held up
3.5	As for 3 but tongue out slight and occasionally fully extended for short periods of time
4	Tongue fully extended for prolonged periods with excessive drooling and neck extended
4.5	As for 4 but head held down. Cattle "breathe" from flank and drooling may cease

[1]Adapted from Gaughan et al. (2008).

Table 3.4: Least squares means for the main effect of environmental treatment on feedlot performance

Trait	Treatment[1]			SEM	*P*-value
	CWF	CNF	OUT		
Weight, kg					
d 0	445	447	458	6.48	0.29
d 21	487	485	493	7.21	0.69
d 46	546	542	526	8.27	0.18
d 74	596	590	569	9.15	0.08
d 92	620[a]	606[ab]	583[b]	10.12	0.01
ADG, kg					
d 21	2.03	1.63	1.64	0.13	0.06
d 46	2.34[a]	2.21[a]	1.34[b]	0.14	< 0.01
d 74	1.74	1.70	1.52	0.12	0.31
d 92	1.32[a]	0.89[b]	0.75[b]	0.14	0.01
Total	1.89[a]	1.68[b]	1.35[c]	0.06	< 0.01
G:F, kg					
d 21	0.17[a]	0.14[ab]	0.14[b]	0.01	0.04
d 46	0.16[a]	0.16[a]	0.09[b]	0.01	< 0.01
d 74	0.12[ab]	0.12[a]	0.10[b]	0.01	0.04
d 92	0.09	0.07	0.06	0.01	0.06
Total	0.14[a]	0.13[a]	0.10[b]	0.01	< 0.01

Total DMI[2], kg/hd/d	14.20[a]	12.95[b]	14.80[a]	0.40	< 0.01

[abc]Within a row, means without a common superscript differ (*P* < 0.05).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; OUT = outside drylot steers without shade or fans.

[2]Dry matter intake kg/hd/d for steers across 92 d finishing period.

Table 3.5: Least squares means for the main effect of environmental treatment on carcass yield and quality

	Treatment[1]				
Trait	CWF	CNF	OUT	SEM	*P*-value
Live weight, kg	613	601	577	9.09	0.06
Hot carcass weight, kg	370.93[a]	362.13[ab]	348.75[b]	6.06	0.03
Dressing, %	60.48	60.27	60.40	0.38	0.60
Kidney, pelvic, heart fat, %	2.00	2.12	2.07	0.20	0.93
Ribeye area, cm^2	87.40	85.39	84.86	2.03	0.62
Backfat, cm	1.11	1.28	1.25	0.10	0.40
Yield grade	2.50	2.77	2.60	0.15	0.44
Marbling[2]	502.86	519.29	528.57	30.53	0.83
Skeletal maturity[3]	141.43	133.57	137.14	3.82	0.36
Lean maturity[3]	126.43	130.71	128.57	2.96	0.60
Overall maturity[3]	134.29	132.86	134.29	2.63	0.91
Subjective color[4]					
Lean color	2.64	1.79	2.57	0.32	0.12
Fat color	1.29	1.79	1.71	0.16	0.07
Objective color					
Lean					
L*	42.59	43.54	42.19	0.82	0.47
a*	29.85	29.50	29.46	0.47	0.79

b*	21.71	21.33	21.26	0.44	0.72
Fat					
L*	79.16	79.18	79.62	0.26	0.70
a*	8.44	8.64	8.27	0.40	0.49
b*	18.05	18.55	18.66	0.40	0.47

[ab]Within a row, means without a common superscript differ (*P* < 0.05).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; OUT = outside drylot steers without shade or fans.

[2]Measured based on AMSA (2013) beef marbling: 300 = slight, 400 = small, 500 = modest.

[3]Measured based on AMSA (2013) maturity: 100 = A maturity, 500 = E maturity.

[4]Subjective lean and fat color quantified using Japanese beef lean and fat color standards.

Table 3.6: Least squares means for the main effect of environmental treatment on cost-benefit analysis

	Treatment[1]				
Trait	CWF	CNF	OUT	SEM	*P*-value
Feeder value, \$/hd[2]	1,057.14	1,058.47	1,091.29	21.40	0.45
Feed cost, \$/hd/d[3]	3.46[ab]	3.25[b]	3.71[a]	0.11	0.01
Gross carcass value, \$/hd[4]	1,491.39	1,476.78	1,423.37	32.02	0.27
Net profit/loss, \$/hd[5]	89.64[a]	84.36[a]	-55.91[b]	29.20	< 0.01

[ab]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; OUT = outside drylot steers without shade or fans.

[2]Feeder value was calculated using market price for steers at \$0.59/kg/hd.

[3]Feedlot cost for steers fed 92 d, \$/hd/d.

[4]Carcass value based on USDA AMS grid NW_LS410.

[5]Net profit/loss = Gross carcass value – (Feeder value + Cost of feed).

Table 3.7: Least squares means for the main effect of environmental treatment on color stability during retail display on objective color and lipid oxidation for aerobically packaged steaks in retail display across 6 days

	Treatment[1]				
Trait	CWF	CNF	OUT	SEM	*P*-value
L*	42.49	43.42	42.45	0.57	0.40
a*	26.16	26.02	26.65	0.49	0.62
b*	20.68	20.43	20.73	0.37	0.83
Hue angle[2]	38.62	38.33	38.06	0.38	0.56
Chroma[2]	33.37	33.10	33.78	0.59	0.70
Delta E[2]	8.68	9.46	8.62	0.41	0.24
Dmb, %[3]	6.04	5.59	5.61	0.25	0.36
Omb, %[3]	64.69	66.24	66.04	0.85	0.37
Mmb, %[3]	29.27	28.17	28.35	0.67	0.45
MDA, mg/kg[4]	0.10	0.11	0.11	0.01	0.97

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; OUT = outside drylot steers without shade or fans.

[2]Calculated according to AMSA (2012).

[3]Calculated using equations found as outlined by Krzywicki (1979); Dmb = deoxymyoglobin, Omb = oxymyoglobin, Mmb = metmyoglobin.

[4]Malondialdehyde concentration calculated using equations as outlined by Buege and Aust (1978).

Table 3.8: Least squares means for the main effect of day of display on shelf life objective color and lipid oxidation for aerobically packaged steaks in retail display across 6 days

	Day of Display								
Trait	0	1	2	3	4	5	6	SEM	*P*-value
L*	46.74^{a}	43.28^{b}	42.62^{c}	42.99^{bc}	41.47^{d}	41.14^{d}	41.27^{d}	0.36	< 0.01
a*	32.77^{a}	30.55^{b}	28.47^{c}	26.01^{d}	24.41^{e}	22.25^{f}	19.55^{g}	0.35	< 0.01
b*	24.30^{a}	23.43^{b}	21.97^{c}	20.25^{d}	19.41^{e}	18.16^{f}	16.80^{g}	0.25	< 0.01
Hue[1]	36.55^{e}	37.50^{d}	37.68^{d}	37.88^{d}	38.61^{c}	39.39^{b}	40.77^{a}	0.10	< 0.01
Chroma[1]	40.90^{a}	38.51^{b}	35.96^{c}	32.89^{d}	31.18^{e}	28.73^{f}	25.97^{g}	0.44	< 0.01
Delta E[1]	-	5.22^{a}	6.94^{b}	9.23^{c}	11.39^{d}	13.60^{e}	16.10^{f}	0.60	< 0.01
Dmb, %[2]	2.57^{e}	4.23^{d}	5.43^{c}	5.77^{c}	7.00^{b}	7.56^{a}	7.61^{a}	0.18	< 0.01
Omb, %[2]	74.09^{a}	73.25^{a}	69.99^{b}	62.64^{c}	63.61^{c}	60.11^{d}	56.00^{e}	0.66	< 0.01
Mmb, %[2]	23.34^{e}	22.52^{e}	24.57^{d}	31.59^{b}	29.38^{c}	32.33^{b}	36.39^{a}	0.53	< 0.01
MDA, mg/kg[3]	0.04^{c}	0.06^{c}	0.07^{c}	0.11^{b}	0.12^{b}	0.16^{a}	0.16^{a}	0.01	< 0.01

[abcdefg]Within a row, means without common superscript differ ($P < 0.05$).

[1]Calculated according to AMSA (2012).

[2]Calculated using equations found as outlined by Krzywicki (1979); Dmb = deoxymyoglobin, Omb = oxymyoglobin, and Mmb = metmyoglobin.

[3]Malondialdehyde concentration calculated using equations found as outlined by Buege and Aust (1978).

Table 3.9: Least squares means for the main effect of environmental treatment on proximate values

	Treatment[1]				
Trait	CWF	CNF	OUT	SEM	*P*-value
Protein, %	22.37	22.03	22.36	0.21	0.39
Lipid, %	6.63	6.55	6.72	0.80	0.99
Moisture, %	69.95	69.70	70.20	0.54	0.79
Ash, %	1.01	1.01	1.02	0.01	0.81

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; OUT = outside drylot steers without shade or fans.

Table 3.10: Least squares means for the main effect of environmental treatment for cooking characteristics, slice shear force, and sensory analysis on steaks wet-aged 14 and 21 days postmortem

	Treatment[1]				
Trait	CWF	CNF	OUT	SEM	*P*-value
Thaw loss, %	3.27	2.71	2.12	0.34	0.08
Cook loss, %	17.96	18.28	18.67	0.67	0.69
Slice shear, N	15.45	14.57	15.20	0.99	0.58
Initial tenderness[2]	5.10	5.22	5.11	0.16	0.84
Sustained tenderness[2]	5.46	5.60	5.45	0.16	0.74
Overall juiciness[2]	4.62	4.55	4.65	0.13	0.87
Beef flavor[2]	4.91	4.90	4.89	0.10	0.99
Off-flavor[3]	1.67	2.40	1.86	0.37	0.37

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; OUT = outside drylot steers without shade or fans.

[2]1 = extremely tough, bland, and dry, 2 = very tough, bland, dry, 3 = moderately tough, bland, and dry, 4 = slightly tough, bland, and dry, 5 = slightly tender, intense and juicy, 6 = moderately tender, intense, and juicy, 7 = very tender, intense, and juicy, 8 = extremely tender, intense, and tender.

[3]1 = none detected, 2 = threshold off-flavor, 3 = slightly intense, 4 = moderately intense, 5 = very strong off-flavor, 6 = extreme off-flavor.

Table 3.11: Least squares means for the main effect of day of age for cooking characteristics, slice shear force, and sensory analysis on steaks wet-aged 14 and 21 days postmortem

	Day of age			
Trait	14	21	SEM	*P*-value
Thaw loss, %	2.65	2.14	0.22	0.04
Cook loss, %	18.44	18.16	0.50	0.69
Slice shear, N	15.43	14.71	0.50	0.08
Initial tenderness[2]	5.01[b]	5.27[a]	0.10	< 0.01
Sustained tenderness[2]	5.39[b]	5.62[a]	0.10	0.01
Overall juiciness[2]	4.57	4.64	0.09	0.45
Beef flavor[2]	4.84	4.97	0.08	0.16
Off-flavor[3]	1.60	2.22	0.32	0.20

[ab]Within a row, means without a common superscript differ ($P < 0.05$).

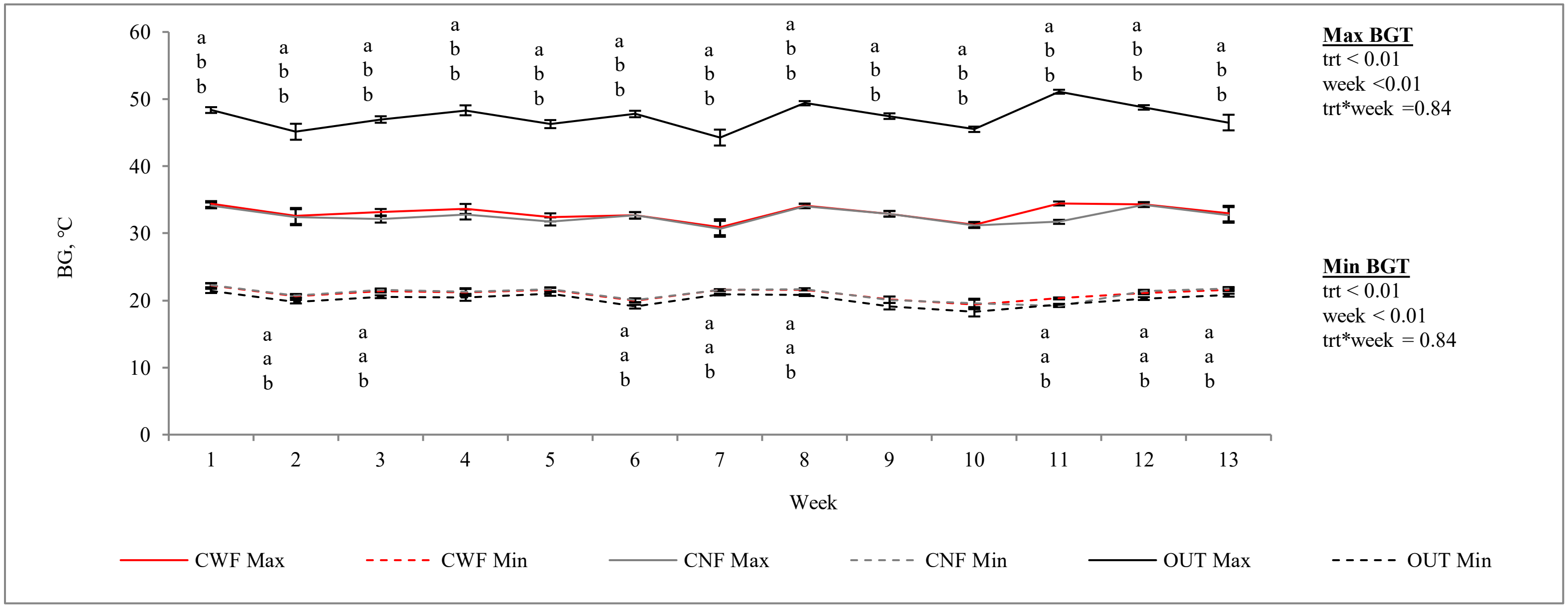
[2]1 = extremely tough, bland, and dry, 2 = very tough, bland, dry, 3 = moderately tough, bland, and dry, 4 = slightly tough, bland, and dry, 5 = slightly tender, intense and juicy, 6 = moderately tender, intense, and juicy, 7 = very tender, intense, and juicy, 8 = extremely tender, intense, and tender.

[3]1 = none detected, 2 = threshold off-flavor, 3 = slightly intense, 4 = moderately intense, 5 = very strong off-flavor, 6 = extreme off-flavor.

Figure 3.1:

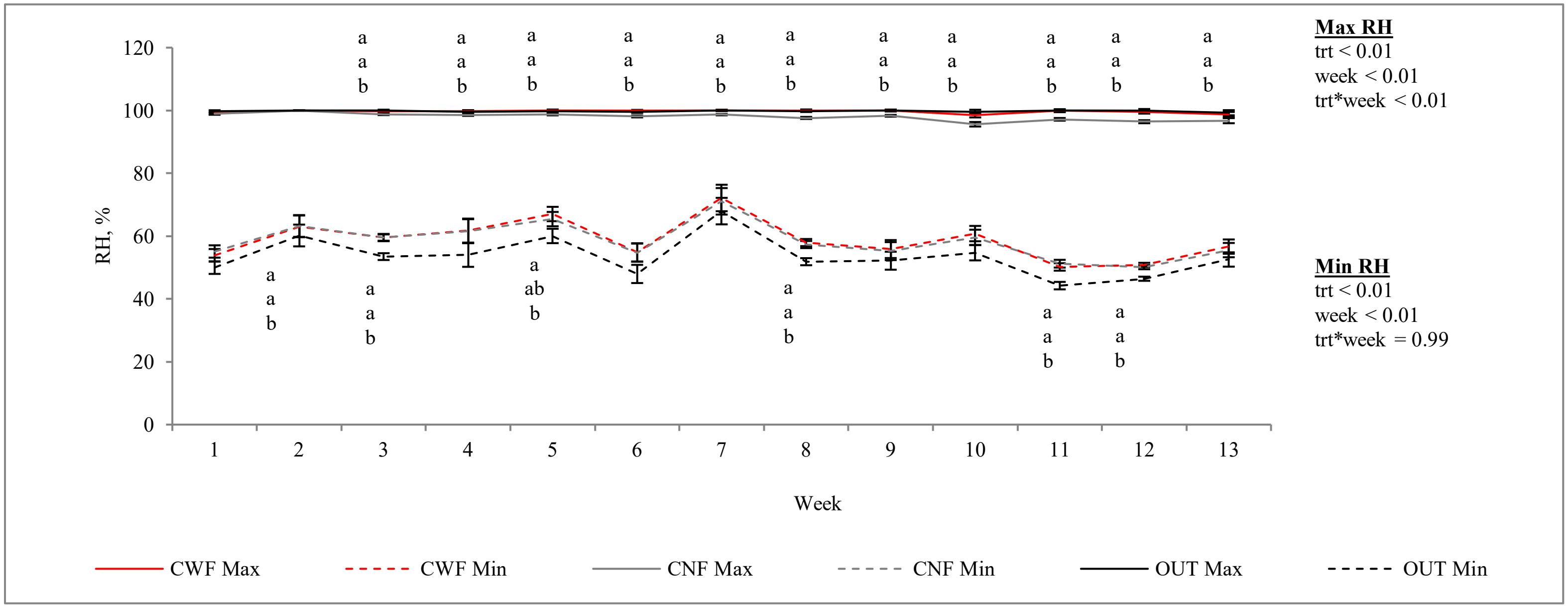
Figure 3.1: Environmental stress factors included: relative humidity (**RH**), black globe temperature (**BG**), wind speed (**WS**), heat load index (**HLI**), and accumulated heat load units (**AHLU**), were measured using Kestrel devices (5400AG cattle heat stress trackers; KestrelMeters; Boothwyn, PA). Each treatment was assigned 2 Kestrel units placed 2.4 m from ground level and values were averaged.

A.

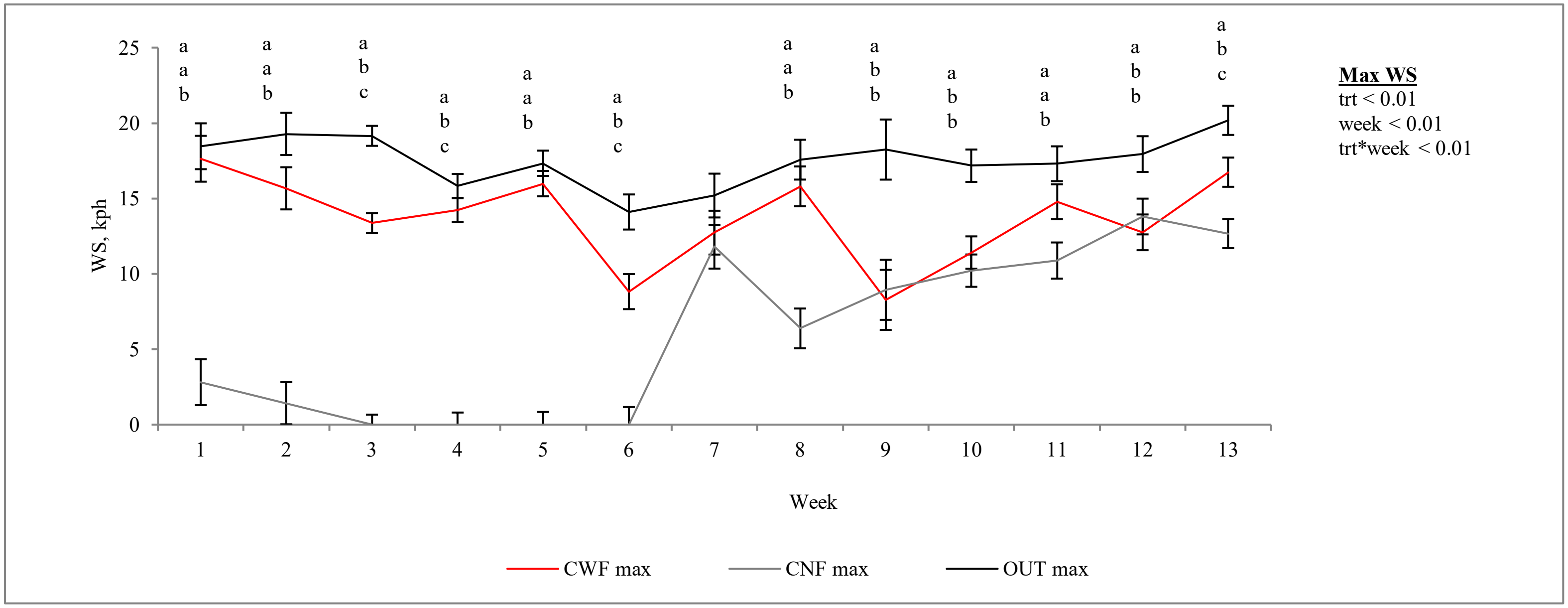


BG, °C
Week
Max BGT
trt < 0.01
week <0.01
trt*week =0.84
Min BGT
trt < 0.01
week < 0.01
trt*week = 0.84
CWF Max
CWF Min
CNF Max
CNF Min
OUT Max
OUT Min

B.


Max RH
trt < 0.01
week < 0.01
trt*week < 0.01
Min RH
trt < 0.01
week < 0.01
trt*week = 0.99
RH, %
Week
CWF Max
CWF Min
CNF Max
CNF Min
OUT Max
OUT Min

C.



WS, kph
Week
CWF max
CNF max
OUT max
Max WS
trt < 0.01
week < 0.01
trt*week < 0.01

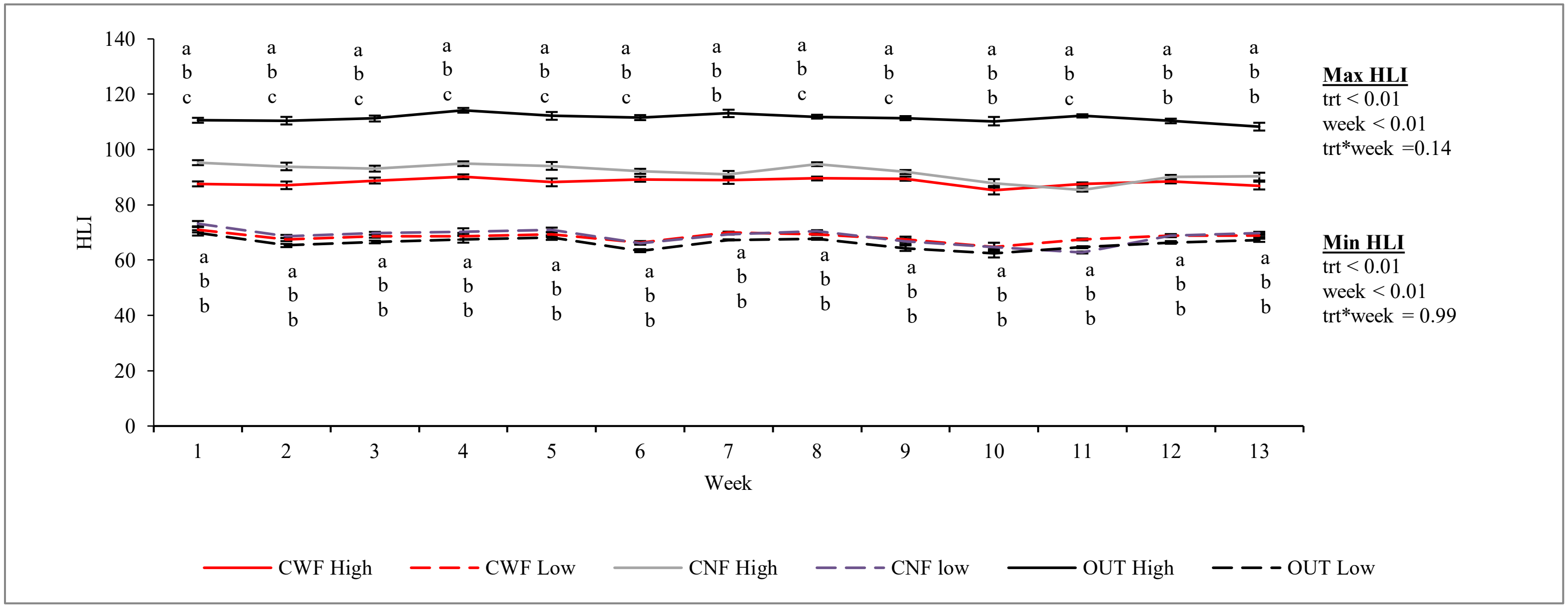
Figure 3.2

Figure 3.2a: Effect of CWF: covered with fan, CNF: covered with no fan, and OUT: outside drylot with no shade or fans on black globe temperature (BG). Solid lines refer to the average maximum BG, while dashed lines refer to the average minimum BG. The BG values were quantified by Kestrel 5400AG cattle heat stress trackers (5400AG cattle heat stress trackers; KestrelMeters; Boothwyn, PA). Each treatment was assigned 2 Kestrel units placed 2.4 m from ground level and values were averaged. ^{abc}Significant means between treatments within week were denoted by the difference in letters (P < 0.05).

Figure 3.2b: Effect of CWF: covered with fan, CNF: covered with no fan, and OUT: outside drylot with no shade or fans on relative humidity (RH). Solid lines refer to the average maximum RH, while dashed lines refer to the average minimum RH. The RH values were quantified by Kestrel 5400AG cattle heat stress trackers (5400AG cattle heat stress trackers; KestrelMeters; Boothwyn, PA). Each treatment was assigned 2 Kestrel units placed 2.4 m from ground level and values were averaged. ^{abc}Significant means between treatments within week were denoted by the difference in letters (P < 0.05).

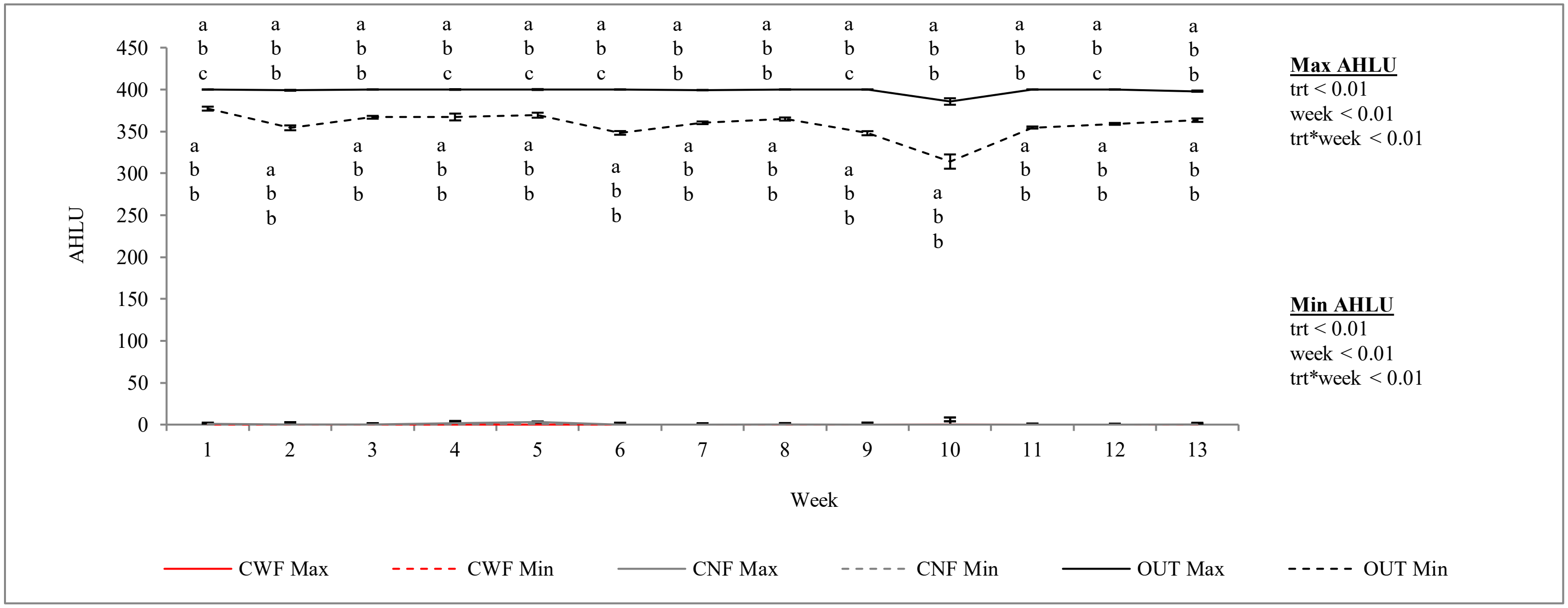
Figure 3.2c: Effect of CWF: covered with fan, CNF: covered with no fan, and OUT: outside drylot with no shade or fans on wind speed (WS). Solid lines refer to the average maximum WS, while average minimum WS was not included due to lack of significance. The WS values were quantified by Kestrel 5400AG cattle heat stress trackers (5400AG cattle heat stress trackers; KestrelMeters; Boothwyn, PA). Each treatment was assigned 2 Kestrel units placed 2.4 m from ground level and values were averaged. [abc]Significant means between treatments within week were denoted by the difference in letters ($P < 0.05$).

A.



140
120
100
80
60
40
20
0
HLI
1 2 3 4 5 6 7 8 9 10 11 12 13
Week
Max HLI
trt < 0.01
week < 0.01
trt*week =0.14
Min HLI
trt < 0.01
week < 0.01
trt*week = 0.99
CWF High
CWF Low
CNF High
CNF low
OUT High
OUT Low

B.



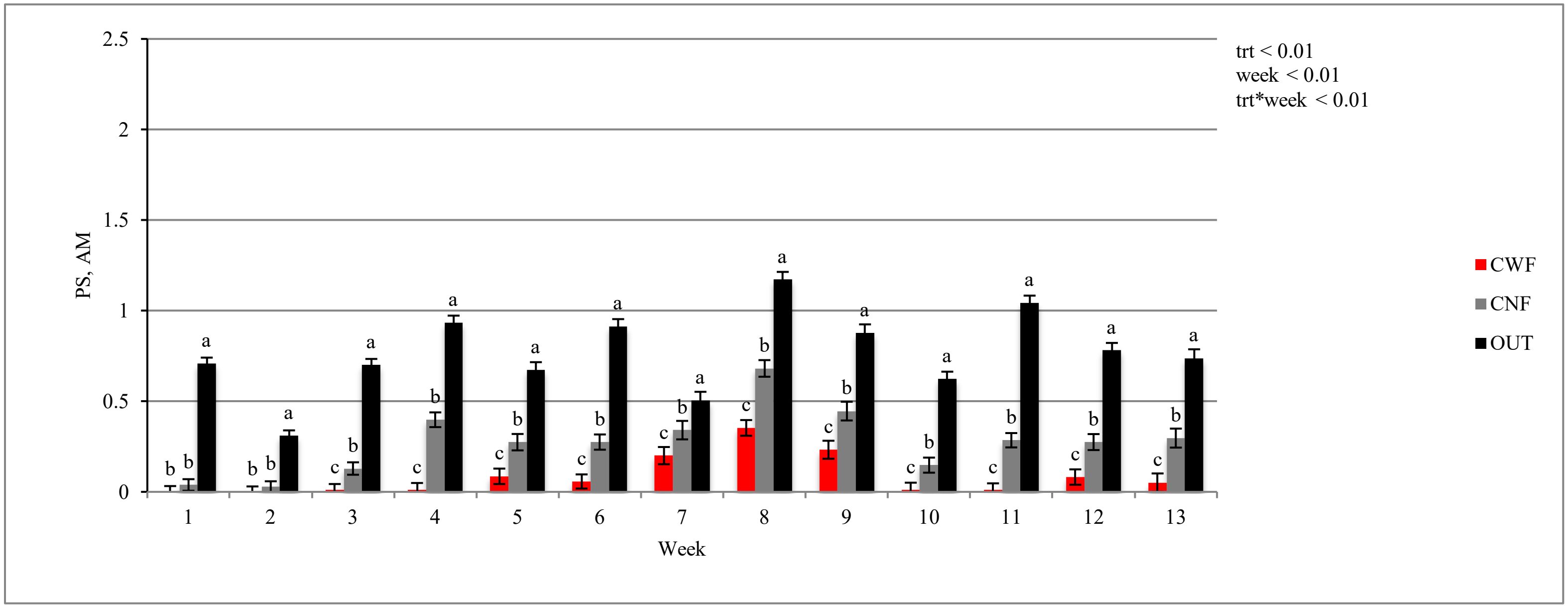
450
400
350
300
250
200
150
100
50
0
AHLU
1
2
3
4
5
6
7
8
9
10
11
12
13
Week
Max AHLU
trt < 0.01
week < 0.01
trt*week < 0.01
Min AHLU
trt < 0.01
week < 0.01
trt*week < 0.01
CWF Max
CWF Min
CNF Max
CNF Min
OUT Max
OUT Min

Figure 3.3

Figure 3.3a: Effect of CWF: covered with fan, CNF: covered with no fan, and OUT: outside drylot with no shade or fans on Heat Load Index (HLI). Solid lines refer to the average maximum HLI, while average minimum HLI was not included due to lack of significance. The HLI values were quantified by Kestrel 5400AG cattle heat stress trackers (5400AG cattle heat stress trackers; KestrelMeters; Boothwyn, PA). Each treatment was assigned 2 Kestrel units placed 2.4 m from ground level and values were averaged. HLI was calculated utilizing the following equations: $HLI_{BG>25}=8.62+(0.38\times RH)+(1.55\times BG)-(0.5\times WS)+e^{(2.4-WS)}$ and $HLI_{BG<25}=10.66+(0.28\times RH)+(1.3\times BG)-WS$. [abc]Significant means between treatments within week were denoted by the difference in letters ($P < 0.05$).

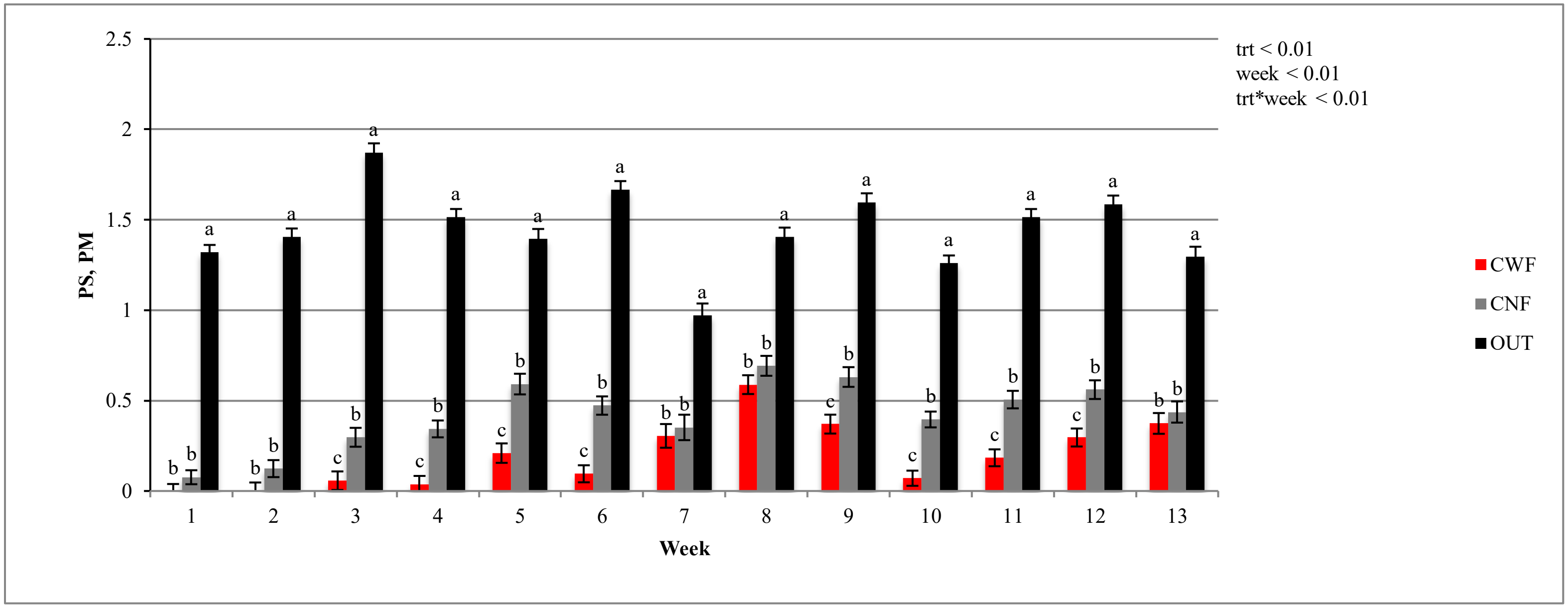
Figure 3.3b: Effect of CWF: covered with fan, CNF: covered with no fan, and OUT: outside drylot with no shade or fans on Heat Load Index (HLI). Solid lines refer to the average maximum HLI, while average minimum HLI was not included due to lack of significance. The HLI values were quantified by Kestrel 5400AG cattle heat stress trackers (5400AG cattle heat stress trackers; KestrelMeters; Boothwyn, PA). Each treatment was assigned 2 Kestrel units placed 2.4 m from ground level and values were averaged. [abc]Significant means between treatments within week were denoted by the difference in letters ($P < 0.05$).

A.



2.5
2
1.5
1
0.5
0
PS, AM
trt < 0.01
week < 0.01
trt*week < 0.01
CWF
CNF
OUT
1
2
3
4
5
6
7
8
9
10
11
12
13
Week

B.



2.5
2
1.5
1
0.5
0
PS, PM
1
2
3
4
5
6
7
8
9
10
11
12
13
Week
trt < 0.01
week < 0.01
trt*week < 0.01
CWF
CNF
OUT

Figure 3.4

Figure 3.4a: Effect of CWF: covered with fan, CNF: covered with no fan, and OUT: outside drylot with no shade or fans on panting scores (PS) recorded daily at 1000 (AM) using a method outlined by Gaughan et al. (2008; 0 = no panting; 2 = fast panting, drool present; 4 = open mouth with tongue fully extended for prolonged periods). Panting scores were averaged per week and [abc]significant means between treatments within week were denoted by the difference in letters ($P <$ 0.05). Pulled steers included in analysis.

Figure 3.4b: Effect of CWF: covered with fan, CNF: covered with no fan, and OUT: outside drylot with no shade or fans on panting scores (PS) recorded daily at 1700 (PM) using a method outlined by Gaughan et al. (2008; 0 = no panting; 2 = fast panting, drool present; 4 = open mouth with tongue fully extended for prolonged periods). Panting scores were averaged per week and [abc]significant means between treatments within week were denoted by the difference in letters ($P <$ 0.05). Pulled steers included in analysis.

CHAPTER 4

EVALUATION OF HEAT STRESS ON PERFORMANCE AND CARCASS CHARACTERISTICS DURING THE SUMMER IN THE SOUTHEASTERN UNITED STATES

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[1]Sims, W. M., J. G. Williams, R. L. Stewart Jr., S. Tao, R. W. Mckee, L. F. G. D. Menezes, C. L. Thomas, and A. M. Stelzleni. To be submitted to *Translational Animal Science*.

Abstract

Eighty crossbred Angus steers were blocked by weight (463 ± 36 kg) and assigned to four treatments to evaluate the use of summer heat mitigation strategies in a Southeastern Georgia feedlot operation. Treatments included: cover with fans (**CWF**), covered with no fans (**CNF**), outside steers with optional shade (**SHADE**), and outside drylot with no shade (**OUT**). Performance traits were measured for each group until the first treatment group achieved a target weight of 636 kg. Steers that met target weight and ½ of remaining treatments ($N = 50$) were considered 1st harvest. Remaining steers were monitored for performance until target weight was met (target weight). Steers were harvested and carcass characteristics were collected for all steers. Cover was successful in reducing ($P < 0.01$) black globe temperature (**BG**), heat load index (**HLI**), and accumulated heat load units (**AHLU**). The reduction in thermal stress resulted in lower ($P < 0.01$) morning (**AM**) and evening (**PM**) panting scores for CWF, CNF, and SHADE steers. Steers under cover had improved performance traits including: average daily gain (**ADG**), gain-to-feed (**G:F**), and percent gain, while SHADE and OUT were lower ($P < 0.01$). Hot carcass weight (**HCW**) values were greater ($P < 0.01$) for covered steers at first harvest. When given sufficient time to achieve target weight, animal performance traits remained greater ($P < 0.01$) for covered steers; however, all carcass characteristics were similar for all treatments. Cover was shown to mitigate heat load and panting scores, while also improving animal performance traits, and carcass characteristics.

KEYWORDS: thermal stress, mitigation, performance, carcass characteristics

4.1 Introduction

When exposed to heat stress, cattle are able to adapt physiologically, behaviorally, and immunologically (Brown-Brandl et al., 2005). Although adaptation is necessary, performance losses such as decreased: Dry matter intake (**DMI**), average daily gain (**ADG**), and increased mortality may accrue overtime (Johnson et al., 2015). Cattle exposed to greater amounts of solar radiation have expressed lower carcass yield, quality grades, and increased incidences of dark cutters (Mitlohner et al., 2002). In a survey performed by Onozaka et al (2010) consumers found locally grown products to be superior in freshness (70%), supporting the local economy (65%), and improved eating quality (62%). However, the incentive for producers to produce locally grown cattle in the Southeast has been historically muted due to adverse environmental climates (Onozaka et al., 2010). Therefore, an incentive to market locally grown beef in the Southeast will need to have strategies to monitor and prevent excessive heat load events that occur frequently. The new heat load index quantifies heat stress over a period of time, and may further demonstrate the practicality of heat abatement strategies in a feedlot operation (Gaughan et al., 2008).

Various Temperature Humidity Index (**THI**) methods have been developed and utilized for over 6 decades. The THI method integrates dry bulb temperature in combination with wet bulb temperature, relative humidity, or dew point (Gaughan et al., 2008) in order to measure heat stress in both humans and animals. Though THI is used heavily in current heat stress literature (Gaughan et al., 1999; St-Pierre et al., 2003), the new HLI integrates solar radiation and wind speed, while quantifying heat stress over a period of time as accumulated heat load units (**AHLU**); therefore, mitigation of heat load through a reduced exposure to solar load and improved wind speed may decrease HLI and improve overall performance. Shade has been found to improve final body weight, ADG, hot carcass weight (**HCW**), and decrease overall heat load (Blaine and Nsahlai, 2011). In addition to shade, Bond et al., (1957) determined the increase in ADG when fans are integrated into a beef cattle operation. Cattle exposed to temperatures greater than 35°C expressed greater ultimate pH leading to darker carcass characteristics (Scanga et al., 1998). Solid structures would be ideal; however, this may not be practical for a large-scale operation and but may be a viable option for smaller scale operations in the Southeast and other subtropical areas.

The objective of this study was to determine the effect of shade or complete cover with and without fans on reducing HLI in order to improve steer performance and carcass characteristics in a Southeastern US Georgia feedlot operation. Results in Chapter 3 showed improvements in profitability when complete cover was utilized. Although complete cover improved net profits, the capital needed may be an issue for some producers. Therefore, it is important to compare cover with lower cost and more practical heat abatement strategies such as optional shading structures.

4.2 MATERIALS AND METHODS

All procedures and guidelines were approved by the University of Georgia Institutional Animal Care and Use Committee (A2019-01-017-Y2-A2).

4.2.1 Environmental Monitoring, Animal Performance, and Diet Management,

Each treatment was assigned two Kestrel meters with weathervanes (5400AG cattle heat stress trackers; KestrelMeters; Boothwyn, PA) equally spaced in the treatment pens in order to quantify climatic environments. Kestrel meters were placed at the midline of the pen rails 2.4 m from the ground near the one-third and two-thirds marks. All Kestrel meters were programmed for each treatment using genotypic, phenotypic, and management factors following Gaughan et al. (2008; Table 4.2). Meters were set to record the environmental stress factors included relative humidity (**RH**), black globe temperature (**BG**), wind speed **(WS)** were measured every 30 min. Kestrel devices calculated heat load index (**HLI**), and accumulated heat load unit (**AHLU**) values using the aforementioned climatic variables.

In order to assess the heat load of each animal, panting scores (**PS**) were measured and recorded daily at 1000 (**AM**) and 1500 (**PM**) using methods outlined by Gaughan et al. (2008).

Eighty crossbred Angus steers (463 ± 36 kg; 14 to 15 mo of age) were transported to the University of Georgia Beef Research Unit (Eatonton, GA, USA) and were blocked by weight (tru-test xr5000 scale; Valley Farm Supply, LLC.; New Providence, PA). Steers were randomly assigned to 1 of 4 treatments including: covered with fan (**CWF**; DeLaval 1250 propeller dairy fans; 124.5 cm diameter; 439 rotations per minute; 39.1 m^3/hour/Watt; DeLaval; Tullamarine, AU), covered no fan (**CNF**), outside drylot with optional shade (**SHADE**; 80% UV block shade cloth, 3.05 m × 3.66 m per animal), or outside drylot with no shade or fan (**OUT**). Steers assigned to CWF and CNF were housed in a covered barn with opened sides. The finishing barn was oriented southwest to northeast with 10 pens that had concrete flooring at a 2° slope from front to back (4 steers per pen; 9.1 m × 9.1 m; 9.1m × 3 m per animal). Sand bedding was spread across barn pens to enhance footing. Fans were installed on the west side of the barn (CWF) and were programed to start/stop at 24.4°C. Pens were constructed with metal panels and a 10 m feed alley allocated towards the interior of the barn. A Calan Broadbent Feeding System (American Calan, Inc.; Northwood, New Hampshire) was integrated in order to administer feed to covered treatments. Airflow was tested using Kestrel meters to ensure no residual flow impacted CNF. Outside treatments were pair fed (n = 2 per pen; N = 20 per treatment) in outside pens (5.5 m × 6.1 m; 5.5 m × 3.0 m per animal) due to limitations in Calan Gates. Automated water troughs were installed in all pens (including SHADE and OUT treatments) and animals had *ad libitum* access to water. The study was further separated into two separate parts. The first part of the study collected data from steers that were able to achieve target weight, as well as, half of the steers from all remaining treatments (n = 50). Four separate weight periods were recorded on d 25, 52, 78, and 85. The second part of the study allowed the remaining steers to achieve target weight. Therefore, six separate weight periods were recorded on d 25, 52, 78, 85, 92, and 127.

A total mixed ration (Godfrey's Feed, Madison, GA; Table 4.1) was fed to all steers. Feed was weighed and distributed (1000 am) to covered steers using an American Calan Data Ranger (American Calan, Inc.; Northwood, New Hampshire), while outside feed was weighed using a floor scale (Prime Scales, PS-IN202; Ontario, CA). Ten days prior to the study, steers under cover were trained to use Calan gate feeders by being brought up feed starting with 10 kg and increasing 1 kg every 10 days. Gates remained open for steers to adjust and then closed on day six and steers were monitored to ensure they were properly trained. Pair fed steers (OUT and SHADE) were fed out of feed bunks (Behlen; Columbus, NE) allowing for 152 linear cm per steer. Starting d -10, while covered steers were being trained to Calan gates, pair fed steers were brought up on feed similar to covered steers.

Feed samples were taken during the first 4 weigh periods, ground (1-mm grind) in a Wiley Mill (Neobits inc.; Santa Clara, CA), and placed in a freezer (-20°C ± 2°C) for dry matter analysis. Once thawed, Filter bag (F57 filter bags, ANKOM, Technology; Macedon, NY; $\mathbf{W_1}$) and sample with filter bag (0.45 g to 0.50 g; $\mathbf{W_2}$) weights were recorded and heat sealed (1915, ANKOM Technology; $\mathbf{W_2}$). Neutral detergent fiber (**NDF**) and Acid Detergent fiber (**ADF**) were analyzed in an Ankom 2000 Automated Fiber Analyzer (SKU: A2000; Macedon, NY) using methods outlined in Ankom Technology (2006a; 2006b). The inclusion of 1 blank bag ($\mathbf{C_1}$) per run was utilized as an indicator of particle loss and bags were weighed after extraction ($\mathbf{W_3}$). Neutral detergent fiber and acid detergent fiber were calculated using the following equation: $100 \times (W_3 - (W_1 \times C_1)) / W_2$.

Feed bunk scores were assessed daily, prior to feed delivery, on a 4-point bunking system (0 = no feed in bunk, 2 = 25% to 50% of pervious feed remained, 4 = feed remained untouched) as outlined in the Iowa Beef Center: Feed Bunk Management (2015). The amount of feed was adjusted as needed after two consecutive days of a bunk score less than 0.5 or greater than 1.5. Residual feed was weighed back weekly after the final bunk score was recorded.

4.2.2 Steer Harvest and Carcass Analysis

When the first group achieved 636 kg, that treatment and half of the other treatments were transported (164 km) to a commercial packing plant and slaughtered under federal inspection (FPL Foods LLC, Augusta, GA) for the 1st harvest. Once individual treatments met target weight, steers were transported (74 km) to the University of Georgia Meat Science and Technology Center (**MSTC**; Athens, GA) for 3 separate harvest sessions performed under federal inspection. Prior to transportation, weights were recorded and mud scores were measured in accordance with the 2016 National Beef Quality Assurance (**NBQA**; Eastwood et al., 2017). Steers were provided ad libitum access to water and cover during lairage 12 h prior to harvest.

After 48 hours postmortem, carcasses were ribbed between the 12th and 13th rib. Yield and quality grade were collected including kidney pelvic heart fat (**KPH**), hot carcass weight (**HCW**), 12th rib fat-thickness (**BF**), ribeye area (**REA**), marbling score (**MRB**), and maturity (skeletal and lean). Subjective lean and fat color were quantified using Japanese Beef Lean and Fat Color Standards (The Japan Ham & Sausage Cooperative Association; Tokyo, Japan). Objective lean and fat color (L*a*b*) were collected using a portable spectrophotometer (HunterLab; MiniScan EZ 4500L portable spectrophotometer, Reston, VA; 10° viewing area, 2.54 cm aperture size; A illuminant) and calibrated using black, white, and saturated red tiles. Surface of the longissimus lumborum thoraces was used to quantify lean color, while external fat color was measured anterior to the cut surface. Objective color measurements were taken in triplicate and averaged for analysis. Muscle pH was collected at the 12th to 13th rib using a HANNA pH meter (edge® Multiparameter pH meter; HANNA Instruments; Woonsocket, Rhode Island) with edge® digital electrodes.

4.2.3 Longissimus Lumborum Processing

At first harvest, the right longissimus lumborum (LL) was tagged to track samples through the fabrication process. The right LL was removed from each carcass to yield the boneless striploin (Institutional Meat Purchase Specification 180). Each striploin was vacuum packaged according to plant specifications and then placed in coolers (0°C). Samples were transported (169 km) to the University of Georgia Meat Science Technology Center (**MSTC**). Upon arrival at the MSTC, striploins were unpackaged and seven steaks were cut (2.54 cm thick) anterior to posterior for proximate analysis, slice shear (**SS**), and sensory analysis (**SEN**) Steaks for slice shear force and sensory analysis followed SS 2 d wet aging, SEN 2 d wet aging, SS 7 d wet aging, SEN 7 d wet aging, SS 14 d wet aging, and SEN 14 d wet aging. Samples for proximate analysis and day 2 postmortem aging were vacuum packaged (B-620 series; 30-50 cm^3 $O_2/m^2/24$ h/101,325 Pa/ 23°C; Cryovac Sealed Air Corporation, Duncan, SC, USA) and placed in frozen storage (-20 ± 2°C). The remaining samples were vacuum packaged, placed in boxes, and held in dark storage (1 ± 1°C) until 7 and 14 d postmortem after which they were transferred to frozen storage until further analysis. For steers retained until reaching target weight, all data and sample collection procedures were the same as for the first group with the exception that the longissimus lumborum was not vacuum packaged prior to fabrication since transportation was not required. All samples were held in frozen storage until all samples were collected and frozen for at least 2 weeks.

4.2.4 Proximate Analysis

Samples were thawed (2 ± 2°C) overnight and trimmed of all fat and connective tissue, minced, and flash frozen in liquid nitrogen and homogenized (Waring commercial blenders, Model 34BL97, Dynamics Corporation of America, New Hartford, CT). Samples were placed in crucibles that were dried overnight (90°C) and placed in a desiccator to equalize for 10 min prior to moisture and ash analysis as seen in methods outlined in AOAC (1990). Three grams of sample (± 0.10 g) were weighed and transferred to a drying oven (90°C) for 24 h and moisture was determined using the following: ((wet sample weight – dry sample weight) / (wet sample weight)) × 100%. The dried samples from moisture analysis were then placed in an ash oven (Fisher Scientific; Hampton, NH; Isotemp muffle furnace) at 550°C for 24 h to determined ash content utilizing the following equation: ((Dry sample weight – Ash sample weight) / (Dry sample weight)) × 100%. To determine total lipid, 1 ± 0.1 g of homogenized sample were placed in filter bags (ANKOM XT4; ANKOM Technology; Macedon, NY) and lipid content was analyzed (Ankom XT15 Extraction System; Macedon, NY). Homogenized samples (0.200 g – 0.299 g), in triplicate, were placed in foil and nitrogen content was analyzed using a Leco Nitrogen Analyzer (Model FP268, Leco Corporation, St. Joseph, MI, USA). Protein was quantified by multiplying N content by 6.25. Protein content is not shown because analysis was stopped due to conflicts with CDC COVID-19 guidelines.

4.2.5 Sensory Analysis

Eight trained panelists (AMSA, 2015) participated in evaluating 16 samples each day spread across two sessions with 4 h between each session. Two samples were randomly selected from d 2, 7, and 14 boxes from a freezer, unpackaged and weighed. Samples were placed on poly trays with absorbent pads and allowed to thaw for 24 ± 2 h (4 ± 2°C). Once samples were thawed, and before serving to panelists, samples were weighed once more and a copper-constantan thermocouple (Omega Engineering, Stamford, CT) was inserted into the geometric center of each steak attached to a Digi-Sense 12-channel scanning thermometer (model 9200-00; Cole Palmer Vernon Hills, IL) to record internal temperatures. Samples were cooked (Foreman Grill; Spectrum Brands, Inc.; Beachwood, OH) to achieve a final internal temperature of 71°C (AMSA, 2015). Samples were weighed once more for cooked weighed, wrapped in foil and rested under a heat lamp prior to serving in order to maintain temperature (maximum 10 min). Once cooked, samples were cut (1.27 × 1.27 × 2.54 cm) using a sample sizer. Samples were cut into two cubes and placed in warmed, labeled jars in heated yogurt makers (Euro Cuisine, Inc.; Los Angeles, CA). Samples were served unsalted and unspiced with water and unsalted soda crackers to cleanse pallet between each sample. Sensory room contained 8 individual booths with positive airflow, and red lighting to conceal differences in steak color. Warm-up samples were also provided to each panelist during each session. Panelists were given an 8-point hedonic scale for tenderness (initial and sustained; 1 =

extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, 8 = extremely tender), beef intensity (1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, 8 = extremely intense), and juiciness (1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juicy, 8 = extremely juicy) and a 6-point scale for off-flavor (1= none detected, 2 = threshold off-flavor, 3 = slightly intense, 4 = moderate off-flavor, 5 = very strong off-flavor, 6 = extreme off-flavor) during each session. Sensory analysis data is not shown as the sensory panel had to be stopped due to conflicts with CDC COVID-19 guidelines.

4.2.6 Slice Shear Force Analysis

Slice Shear samples were weighed and cooked using same methods described in the sensory section. Once samples were cooked, 2 slices were cut from the lateral end (1-cm thick, 5-cm long), parallel to the muscle fibers (AMSA, 2015). Each slice was sheared using an Instron Universal Testing Machine (Instron Dual Column Model 3365, Instron Corp., Norwood, MA; 51 kgf load cell, crosshead speed of 50 cm/min) with a slice shear head (0.11684 cm thickness). The peak force (kgf) for each slice was recorded (Bluehill software, Instron Corp., Norwood, MA) and averaged for each sample.

4.2.7 Statistical Analysis

Environmental data were analyzed as a general linear model with treatment as the fixed effect. Data from the two Kestrel units in each treatment were combined and averaged. Data were then analyzed by week daily maximum and minimum values (BG, RH, WS, HLI, and AHLU). All other data were analyzed as a completely randomized mixed model with treatment and time as the fixed effect(s) and animal (carcass) within treatment as the random term (JMP V13, SAS Inst.). For all analyses, animal or carcass was considered the observational and experimental unit for covered treatments. For live animal performance measures, the pen was considered the experimental unit and observational unit for G:F and DMI, while steer was the observational unit for weight and ADG. Since the treatment was ability to seek shade for carcass characteristics and beyond the carcass was considered the experimental unit and observational unit. Feedlot performance data (weight, ADG, G:F), carcass characteristics, and proximate composition were analyzed for the main effects of treatment, time (where applicable) and the treatment by time interaction, and cumulative performance (ADG and G:F). Data for sensory analysis, slice shear force, and shelf life were analyzed as a split-plot where carcass was the whole-plot and steak within aging period or day of shelf life was the subplot. If an interaction occurred data were reanalyzed by day (period). Least squares means were separated by student's t pairwise comparisons. Mean differences were considered significant at $\alpha < 0.05$.

4.3 Results and Discussion

4.3.1 Quantification of Environmental Variables

There was a treatment × week interaction ($P < 0.01$) for maximum and minimum BG (Fig 4.1a). Although optional shade was implemented, average maximum BG values between SHADE and OUT were not different ($P = 0.81$), but were greater ($P < 0.01$) than covered steers, while no difference was observed between the two covered environments ($P = 0.64$). Covered with no fan had greater ($P < 0.03$) average minimum BG when compared to SHADE and OUT treatments, while CWF was only greater ($P = 0.02$) than SHADE. Steers exposed to SHADE and OUT treatments had an average maximum BG of 45°C, which was 13°C greater ($P < 0.01$) than CWF and CNF environments; however, it was observed that covered steers had an average minimum BG that was 1.6°C greater ($P < 0.03$) than OUT and SHADE environments.

Treatment ($P < 0.01$) and week ($P < 0.01$) main effects were observed for maximum and minimum RH, but there were no treatment × week interactions for minimum RH ($P = 0.99$); however, an interactions were observed for maximum RH (Fig 4.1b; $P < 0.01$). Steers in OUT and SHADE environments experienced RH 2-4% greater ($P < 0.01$) than the maximum RH of the covered steers; however, CNF were exposed to 4% and 2% greater ($P < 0.01$) average minimum RH compared to OUT and SHADE, respectively. The average minimum RH in CWF was 2% greater ($P < 0.01$) than OUT, while no difference was observed for remaining treatments.

There was a treatment × week interaction ($P < 0.01$) for maximum WS (Fig 4.1c). Steers in CWF had a greater ($P < 0.01$) average maximum WS of 2 km/h compared to CNF and OUT, while OUT had a greater ($P < 0.01$) maximum WS of 3 km/h. Weeks 3, 4, and 5 were removed from results due to malfunctions in Kestrel devices.

There were treatment × week interactions for average maximum HLI ($P < 0.01$), while average minimum HLI only had treatment and week main effects ($P < 0.01$; Fig 4.2a). Steers in OUT and SHADE environments had similar ($P = 0.18$) average maximum

HLI but were greater ($P < 0.01$) compared to both covered environments, while CNF was greater ($P < 0.05$) than CWF. Steers in OUT and SHADE environments had a maximum HLI that was 18 and 22 units greater ($P < 0.01$) than CWF and CNF, while CNF had an HLI 3 units greater than CWF. Although SHADE steers were exposed to optional shade structures, a reduction ($P < 0.01$) in average maximum HLI values, when compared to OUT steers, were only found in week 10 of the study. Fan and cover implementation for CWF and CNF steers successfully reduced ($P < 0.01$) average maximum HLI values; however, CNF treatments were shown to experience greater ($P = 0.03$) minimum HLI of 1.48 units when compared to SHADE steers.

There were treatment × week interactions for maximum and minimum AHLU ($P < 0.01$; Fig 4.2b). Steers in OUT and SHADE had greater ($P < 0.01$) average maximum AHLU than covered steers, while no difference ($P = 0.98$) was observed for covered treatments; furthermore, OUT had greater ($P < 0.01$) average maximum AHLU than SHADE. No difference ($P = 0.99$) in average minimum AHLU was observed for covered treatments, while OUT was greater ($P < 0.01$) than SHADE; furthermore, SHADE and OUT were greater ($P < 0.01$) than covered environments. Steers exposed to OUT and SHADE had a greater HLI, leading to an average maximum AHLU 342 and 305 units greater than CWF and CNF, respectively. Although SHADE experienced greater AHLU, shade structures were successful in reducing units by 36 compared to OUT steers. Average minimum AHLU were similar to average maximum units with SHADE and OUT steers accumulating 248 and 284 units more, respectively, than CWF and CNF steers.

There were treatment × week interactions for AM and PM PS (*P* < 0.01; 4.3a and 4.3b, respectively). Steers exposed to SHADE or OUT environmental treatments experienced greater HLI. The increase in HLI values led to greater AHLU and soon led to greater panting scores. Covered steers had similar (*P* = 0.20) average AM PS; however, OUT and SHADE expressed AM panting scores greater (*P* < 0.01) than covered steers. Steers in OUT treatments had AM PS greater (*P* < 0.01) than SHADE. Average PM PS were different (*P* < 0.01) across all treatments; OUT expressed the greatest (*P* < 0.01) average PM PS followed by SHADE, CNF, and then CWF. Outside steers without shade expressed AM panting scores that were 0.08 and 0.03 greater than covered and shaded steers, respectively. Steers given optional shade had panting scores that were 0.04 and 0.05 greater than CNF and CWF, respectively. Steers in the OUT treatment expressed the greatest average PM PS of 0.94, while SHADE, CNF, and CWF had lower average PM PS of 0.38, 0.21, and 0.06, respectively.

Shade and fans have been shown to reduce solar load (Mader et al., 1999) and improve convective cooling (Garner et al., 1989), respectively. It is well documented in current literature that improved animal performance such as increased ADG and DMI has been observed with the implementation of management factors including fans (Bond et al., 1957; Marchesini et al., 2018) and shade (Mitlöhner et al., 2001). There are three management strategies for attenuating thermal stress: 1) physical modification of the environment, such as reduction of solar radiation by shade, 2) genetic development of lower maintenance breeds that are not as sensitive to heat stress and, 3) improved nutritional management (Beede and Collier, 1986).

Environments with complete cover provided the greatest mitigation against increased HLI and AHLU. Optional shade implementation slightly reduced HLI values while improving the rate of heat load dissipation as seen in the reduced AHLU values towards the ending weeks of the study. The difference observed between SHADE and CWF/CNF environments was a result of the large reduction in solar exposure in covered steers having 100% solar block at all times. Foust and Headlee (2017) concluded that solar exposure increases shade-seeking behavior. Therefore, as BG increases, cattle will begin to seek shade to reduce overall heat accumulation. In the current study, SHADE steers were able to seek 80% UV blockage during the periods of BG spikes potentially allowing them to better maintain thermal balance when compared to OUT steers. Monitors were not placed under shade, which could explain the lack of difference in BG, RH, HLI, and AHLU between SHADE and OUT treatments during the beginning and middle weeks of the study. The HLI threshold values for SHADE steers were changed to 92, however, BG throughout the study were so great that the reductions in excessive heat load for SHADE steers were only observed towards the ending weeks of the study. The increase in RH for covered steers can be explained by the lack of airflow and open environment during the nighttime. Fans were programed to turn off during cooler temperatures, therefore outside steers may have had improved airflow due to exposure to open environements. Mader et al. (1999) stated that shade only changes the radiation balance of the animal and has no affect on air temperature or humidity. Although relative humidity was found to be different between environments, the differences were minimal and likely had little impact on the differences found in HLI or AHLU.

The increase in panting scores can be explained by the greater exposure to increased HLI leading to an accumulation of heat. Gaughan et al (2008) found a positive linear correlation with increased HLI and AHLU leading to an increase panting scores ($r^2 = 0.93$ and $r^2 = 0.92$, respectively). As a result, outside steers were unable to effectively dissipate heat, which led to the increase in mean AM and PM panting scores. Similar results were found by Moons et al. (2015), who concluded that steers exposed to greater BG, with no shade availability, had increased respiration rates and panting scores. Furthermore, Moons et al. (2015) observed that the addition of shade for both beef and dairy cows did not reduce panting scores, which is in contrast with the current study. Shaded structures were found to decrease mean panting scores in the evening and afternoon hours. Lees et al. (2020) concluded that mean panting scores of unshaded Angus increased by 0.71 when shade was not provided. The current study found similar results with OUT steers expressing mean PM panting scores of 0.94. Fans did not significantly reduce panting scores throughout the study, which is in contrast with Magrin et al. (2016) who observed a decrease in panting score for Charolais bulls. As observed in chapter 3, OUT steers with no shade or fans had a mean PM PS of 1.41, while OUT steers in the current study had mean PM PS of 0.94, which is a 0.47 reduction. Furthermore, CNF and CWF steers in chapter 3 had a 0.20 and 0.13 increase in PM PS when compared to steers in the current chapter. Steers in chapter 3 were assessed during the months of July to September, while steers reported in this study were assessed during the transitional period of summer to fall (August to December). Therefore, heat load abatement strategies may be critical during the late spring and early summer months, while late summer to early fall strategies may vary.

4.3.2 Animal Performance

Considering all steers, there was no difference in weight between treatments on d 0, 25, 52, or 78 ($P \geq 0.06$). Since CNF reached an average of 636 kg on d 85 that was considered the first terminal point with all of CNF and half of the other treatments (randomly selected) being sent to harvest. Comparing the weights of the terminal steers on d 85 (Weight at first harvest, Table 4.3), treatment differences were observed for initial weight ($P \geq 0.06$). A treatment effect was observed for final live weight, total ADG, total percent gain, gain:feed, bunk scores, and cost of gain ($P < 0.01$). Due to improved performances, CNF steers achieved target weight first and had live weights that were similar ($P = 0.43$) to CWF, while greater ($P < 0.01$) than outside steers. Covered steers had greater ($P < 0.01$) total ADG, percent gain, and gain:feed when compared to outside treatments. No differences ($P = 0.07$) in ADG, percent gain, and gain:feed were observed between covered treatments and no differences ($P = 0.15$) were observed between outside treatments. A treatment effect was observed for cost of gain with covered steers having lower ($P < 0.01$) cost of gain values than outside steers, while no differences ($P = 0.57$) between covered treatments and between outside treatments ($P = 0.87$) were observed. Steers in OUT had greater ($P < 0.02$) bunk scores compared to all treatments, while covered and SHADE steers were similar ($P = 0.11$). Steers in CWF had an ADG that was 0.54 and 0.73 kg greater than SHADE and OUT, respectively. The

CNF treatment had an ADG that was 0.66 and 0.85 kg greater than SHADE and OUT, respectively. An increase in 0.04 and 0.05 gain:feed was observed for CWF when compared to SHADE and OUT, respectively. Furthermore, CNF steers had an increase of 0.05 and 0.06 for G:F when compared to SHADE and OUT. The differences in ADG and G:F led to covered steers having greater percent gains. Covered steers had an 8 % to 10% increase in percent gain when compared to outside steers. Cost of gain was reduced by \$0.79 and \$0.84/kg for CWF and CNF steers, respectively, compared to OUT, while a reduction of \$0.77 and \$0.82/kg was observed compared to SHADE.

Similar results were concluded when assessing the performance of steers that achieved target weight. A treatment effect was observed for ADG and gain:feed with greater ($P < 0.01$) ADG, and G:F values at target weight for covered treatments compared to outside. The percent gain values were similar ($P > 0.10$) for covered and OUT steers, however, values were lower ($P < 0.03$) for SHADE steers compared to all three treatments. Steers in OUT exhibited greater ($P < 0.02$) bunk scores compared to SHADE, while no differences ($P > 0.07$) were observed for CWF, CNF, and SHADE. Remaining steers of CWF finished on d 92, while OUT steers finished on d 127. An unexpected reduction in ADG and scheduling issues resulted in SHADE steers being processed prior to achieving finishing weight. It was projected from an average of previous ADG values that SHADE steers would have required 14 additional days to finish (d 106), which explains the differences observed in percent gain. Steers exposed to OUT climatic conditions required 4,235 kg or \$1,058.75 worth of additional feed, compared to CNF steers, in order to achieve target weight. Although not significant, optional shade was successful in reducing the cost of gain by $0.66/kg of weight when compared to OUT, while CWF and CNF reduced ($P < 0.01$) cost of gain by $1.35 and $1.61/kg, respectively.

As temperatures begin to rise, energy that was originally utilized for growth will be redirected into thermoregulation in order to maintain homeostasis (Blain and Nsahlai, 2010). Protection form solar radiation can reduce the radiant heat load on an animal by 30% (Mader et al., 1999) and aid in maintaining animal performance (Mitlöhner et al., 2002; Blain and Nsahlai, 2010). As stated, it was projected that SHADE steers would have finished on d 106, which was 21 d prior to OUT steers. Similar results were found by Mitlöhner et al. (2001), who concluded that optional shade structures reduced the amount of time to finish by 20 d when compared to cattle not under cover. Furthermore, the implementation of fans improved performance when compared to SHADE/OUT steers, however, improvements were not different than CNF steers. Similar results were concluded by Magrin et al. (2016), who found that fans had no effect on the performance of finishing young bull calves. However, Bond (1957) found that fan implementation improved total ADG by 0.47 kg and 0.24 kg for across two years, while total ADG only increased by 0.18 and 0.07 kg for CWF compared to CNF at first harvest and target weight, respectively. The addition of fans however, improved cleanliness due to greater air movement that dried the pens surface resulting in fewer cleanouts or application of additional bedding materials. Similar results were stated by Magrin et al. (2016) who found a reduction in litter moister with ceiling fan implementation. Mitlöhner et al. (2002) and Blain and Nsahlai (2010), found that shade improved ADG by 0.15 kg and

0.10 kg/day, however optional shading in the current experiment did not differ from OUT, while complete cover improved total ADG.

4.3.3 Carcass Characteristics

First, carcass characteristics were collected for steers at first harvest and analyzed for treatment effects (Table 4.4). Steers in SHADE had greater ($P < 0.01$) mud scores compared to CWF steers, while no difference ($P > 0.06$) was observed for all other treatments. Hot carcass weights of covered steers were heavier ($P < 0.05$) than OUT, while CNF, CWF and SHADE were similar ($P > 0.06$). Steers in outside drylots with no shade or fans had lower ($P < 0.04$) yield grade than CNF steers, while all remaining treatments were similar ($P > 0.05$). There were no differences in any other traits contributing to yield grade including REA ($P > 0.17$), BF ($P >0.17$), and KPH ($P > 0.09$). Steers in the CNF treatment had live weights 35 kg and 55 kg greater than SHADE and OUT, respectively. There were no differences in MRB ($P > 0.12$), lean maturity ($P > 0.14$), skeletal maturity ($P > 0.41$), and overall maturity ($P > 0.28$) between all treatments. Furthermore, there was no differences in subjective lean ($P > 0.12$) and fat ($P > 0.30$) color, as well as, muscle pH ($P > 0.18$) across all treatments.

A treatment effect was also observed for several carcass characteristics for steers slaughtered at a target weight of 636 kg (Table 4.5). Mud scores were similar ($P > 0.12$) within outside and covered treatments; however, outside steers were greater ($P < 0.01$) than covered. No differences ($P > 0.36$) were observed for HCW between treatments. Steers exposed to SHADE had greater ($P < 0.01$) dressing percent than all 3 treatments, while no difference ($P > 0.09$) was observed between remaining treatments. The CNF and SHADE had a lower ($P < 0.01$) lean maturity than OUT and CWF, while there was no difference between OUT and CWF ($P = 0.99$). Outside treatments had similar ($P = 0.58$) overall maturity, while expressing greater ($P > 0.01$) overall maturity than CNF steers. Steers in CWF had similar ($P > 0.06$) overall maturity to all treatments. Steers in OUT environments had greater ($P < 0.01$) muscle pH compared to covered steers, while SHADE were similar ($P > 0.09$) to all treatments. When assessing fat and lean color, CNF steers had lighter ($P < 0.01$) fat L* values, while all 3 remaining treatments were similar ($P > 0.33$). The SHADE and CWF treatments had similar ($P = 0.24$) fat a* values but lower ($P < 0.02$) than OUT and greater ($P > 0.04$) than CNF. Furthermore, OUT carcasses expressed greater ($P < 0.01$) fat a* values than CNF. Steers in OUT and SHADE expressed greater ($P < 0.02$) fat b* values than CNF treatments, while all other treatments were not different ($P > 0.15$). As for lean color, CNF had the greatest ($P < 0.02$) lean L* values than all treatments, while all remaining treatments did not differ ($P > 0.63$). No differences ($P > 0.05$) were observed for lean a* and b* values across all treatments.

Covered steers had improved live weights at first harvest, which lead to greater HCW and yield grades. Although, yield characteristics were greater for covered steers, similar carcass quality characteristics were observed between treatments. Similar results were concluded by Mader et al. (1999), who found similar marbling values between steers with and without shade cover. Furthermore, Mader et al. (1999) did not observe differences in BF and KPH, which was similar to results in the current study. Although there were no differences in marbling and maturity at first harvest, OUT steers would have averaged a Select quality grade, while a Choice quality grade for the remaining three treatments. Similar results were concluded by Mitlohner et al. (2002), who found an improvement in meat quality when shade was implemented. It is important to note that the animal's physiological response, in states of stress, is to mobilize muscle stored glucose (Gregory, 2010). In addition to glucose mobilization, it has been found that thermal stress will cause a redirection of blood flow from major organ systems to peripheral tissues, resulting in reduced nutrient absorption, gut motility, and even reproduction (Oakes et al., 1976). In addition to partitioning energy, Rhoads et al. (2013) concluded that heat stress leads to a restriction in diet, as seen by OUT steers at target weight, and result in depositing muscle protein rather than muscle lipid. However, steers adapting to the chronic heat may cause the lack of difference in BF and MRB. It is well documented that seasonal changes can affect meat quality characteristics (Kadim et al., 2004; Węglarz, 2010). Cattle exposed to increased temperatures have been reported to express greater proportions of dark, firm, and dry (DFD) characteristics (Kreikemeier & Unruh, 1993; Miller, 2007). Kadim et al. (2004) found that the pH of steers exposed to warm seasons ranged from 5.74 – 6.93. However, the current study found that postmortem pH for steers at 1st harvest did not exceed a pH of 5.50 and resulted in steers exhibiting no DFD characteristics. It is likely that the reductions in DMI and gains led to a minor reduction in energy stores in the form of back fat and marbling at 1st harvest, which lead to a decrease in glycolytic potential and therefore altered biochemical and histochemical characteristics that influenced lean L* values (Xing et al., 2019). Furthermore, Kadim (2004) observed greater lean L*, a*, and b* values for cattle fed in hot season compared to cold. In the current study, only L* values differed at target weight and can may be explained by the physiological changes that occur during seasonal transitions.

No differences in HCW were observed between all treatments at target weight. However, dressing percent for SHADE steers became greater than the remaining 3 treatments, which is similar to results found by Rana et al. (2014), who observed an increase in dressing percent when cattle were exposed to heat load reduction strategies. This increase in dressing percent for SHADE steers may be due to the significant drop in BG towards the 10^{th} week of the study, which allowed steers to recover from the prior thermal stresses and maintain growth. Steers that were exposed to OUT conditions expressed greater muscle pH values, which can be explained by the environmental change from spring to winter. Shifts in climatic conditions have been shown to increase incidences of DFD (Kadim et al., 2004; Węglarz, 2010). Although OUT carcasses did not show signs of DFD, the increase in muscle pH may have continued if steers remained on feed for a longer period. McVeigh and Tarrant (1983) found that once a stressful event has subsided, muscle glycogen could take weeks to replenish. The OUT steers remained on feed for an additional 46 days, which was an ample amount of time to grow and store muscle glycogen, leading to increased HCW and dressing percentages compared to steers at 1^{st} harvest. Maturity values were lower for CNF steers most likely due to the reduction in days until they were harvested. Steers in the CNF environment were processed after 85 d on feed, while the CWF/SHADE and OUT treatments were given an additional 7 to 46 d to reach target weight. This is also the reason why little to no difference in maturity was seen for steers at first harvest, because processing of all animals occurred on d 85.

4.3.4 Proximate analysis

No treatment effects were observed for percent: lipid ($P = 0.91$), moisture ($P = 0.17$), or ash ($P = 0.16$), for steers at first harvest (Table 4.6). Similar results were obtained from steers that achieved target weight, which expressed similar lipid ($P = 0.74$), moisture ($P = 0.67$), and ash ($P = 0.13$) percentages (Table 4.7).

4.3.5 Cost-Benefit Analysis

A treatment main effect was observed for gross carcass value ($P < 0.01$) and net profit/loss ($P < 0.01$) values for steers at first harvest (Table 4.8). Although carcass quality values and feed cost did not differ amongst treatments, steers in CNF were able to achieve target weight and therefore the improvements to HCW translated to greater mean gross carcass values. The improvements in HCW led to a lower net loss for CNF steers compared to SHADE and OUT, while similar to CWF.

A treatment main effect was not observed for steers that achieved target weight (Table 4.9). As steers were able to meet target weight, carcass yield values normalized and therefore resolved any differences that were observed in steers at first harvest. Although no differences were observed for net profit/loss, covered steers had a lower net loss than outside steers.

As a result, a delay to market weight lead to lower carcass gross values for steers at first harvest; however, when steers were allowed to achieve target weight, carcass values were able to stabilize, but at the expense of additional days on feed. Therefore, if additional pricing factors were quantified, we may observe greater differences between cover and outside steers.

4.3.6 Slice Shear Force Analysis

There was no interaction (*P* = 0.91) for treatment and day of aging as seen in tables 4.10, 4.11, 4.12, and 4.13. for first harvest treatment and day of age, as well as, target weight treatment and day of age, respectively. No differences were observed between treatment shear force (*P* > 0.46), percent thaw loss (*P* > 0.18), or percent cook loss (P > 0.26) values for steers at first harvest; however, a day of aging effect was observed between d 2, 7, and 14 for shear force (*P* < 0.01) and percent thaw loss (*P* < 0.01). Steaks wet-aged for 2 d were less tender (*P* < 0.01) than d 7 and 14, while no differences (*P* = 0.25) were detected between d 7 and 14. Thaw loss was different (*P* < 0.01) between all days of aging with d 2 having the greatest percent thaw loss, followed by d 7 and 14. A treatment effect (*P* < 0.01) was observed at target weight, with CNF having tenderer (*P* < 0.01) steaks than all three treatments, while no treatment effects were observed for thaw loss (*P* > 0.31) or cook loss (*P* > 0.18). Furthermore, day of aging was similar to first harvest with steaks being less tender (*P* < 0.01) at d 2 compared to d 7 and 14, while no differences (*P* = 0.26) were detected between d 7 and 14. Thaw loss was different (*P* < 0.01) across all days of aging with d 2 having the greatest thaw loss, followed by d 7 and 14, while no differences (*P* > 0.05) were observed for cook loss across days of aging.

When assessing tenderness, no treatment effects were observed for first harvest steers; however, a day of aging effect was observed for both first harvest and steers that achieved target weight. Wulf et al. (1996) noted a decrease in Warner-Bratzler shear force between d 0 and 7, while values began to stabilize between d 14 and 21. Similar results can be concluded in the current study due to increases in calcium dependent proteinases such as μ-calpain activity early in postmortem proteolysis. As wet aging continued value differences began to diminish at d 14 as observed by Wulf et al. (1996).

A treatment effect was observed for steers at target weight. Steaks that were harvested were taken from steers that were on feed for different amounts time. May et al. (1992) concluded that steers on feed for 100 d had lower shear force values compared to steers at d 84 and d 140. For the current study CNF steers were fed for 85 d, while CWF, SHADE, and OUT were fed for 92, 92, and 127 d, respectively. The differences between treatments were observed for CNF having lower shear force values than the 3 remaining treatments. Although the results presented in the current study contradict the observations of May et al. (1992), the differences can be explained by the location of harvest. The CNF steers were harvested at a commercial facility, which utilized electrical stimulation practices, while the remaining steers were transported to the MSTC where no electrical stimulation was used.

At first harvest, all steers in CNF achieved target weight and were harvested at FPL foods LLC, while remaining treatments continued and were transported to the UGA MSTC for processing. The critical difference between both of these facilities is the practice of electrical stimulation (ES). While steers that were transported to FPL were exposed to ES prior to muscle collection, steers transported to the MSTC were not. Electric stimulation has been shown to increase the frequency of I-band fractures and accelerate the degradation of structural proteins (titin, neubulin, desmin, and troponin-T) in the longissimus dorsi muscle (Ho et al., 1996). Results found by Savell et al. (1979) concluded that electrical stimulation had less panel-detectable connective tissue and improved tenderness of grain-fed steer steaks. Similarities can be drawn to the current study, which found improved objective tenderness values from steaks that were harvested from FPL Foods LLC. It can be concluded that thermal stress did not play a major role in the overall composition of the longissimus dorsi muscle; however, additional testing may be needed to identify the significant change in shear force.

4.4 Conclusions:

The use of heat mitigation strategies successfully improved animal performance, as well as, carcass yield characteristics. Optional shade implementation may be a viable option during short-term stress events; however, geographic locations that are known to have long and severe thermal stress events may need to integrate systems with 100% cover from solar radiation. Although optional shading may provide minimal relief, chronic conditions of the Southeastern regions of the United States may need to utilize complete cover to improve performance. The addition of fans did not further improve animal performance, therefore may not be a necessity to mitigate thermal load. However, fans improved performance traits in steers fed towards the beginning of summer as seen in chapter 3. Therefore, fan implementation may be needed based on the time of the year. Future research into heat abatement strategies for Southeastern feedlots may be needed in order to assess the economical benefits for producers. Steers at first harvest had improved net profit values, however values did not differ at target weight. Mitigation strategies improved animal performance and reduced the amount of days needed on feed to achieve market weight. Therefore, locally grown beef cattle operations can be sustained in the Southeastern United States with proper heat abatement strategy models in place.

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Table 4.1: Composition of diet for feedlot steers

Ingredients	Percent dry matter basis
Ground corn	46.00
Corn distiller grains	24.00
Soy hulls	5.00
Peanut hulls	5.00
Molasses	2.00
Calcium carbonate	1.50
NaCl	1.00
TM Godfrey's[1]	1.25
Sodium bicarbonate	1.00
Ammonium chloride	0.20
Vitamin A, D, & E	0.05
Rumensin 90	0.02
Analyzed nutrient composition, % DM basis	
Dry matter	89.01
Crude protein	13.12
Neutral detergent fiber[2]	26.36
Acid detergent fiber[2]	14.00

[1]Trace mineral Godfrey's feed; Ca 19.65%, S 8.20%, Mg 0.27%, Co 769.00 mg/kg, Cu 15,361.01 mg/kg, I 1,441.00 mg/kg, Fe 12,030.00 mg/kg, Mn 57,632.00 mg/kg, Se 288.00 mg/kg, Zn 72,000.03 mg/kg.

[2]Calculated using Ankom 2000 Fiber Analyzer.

Table 4.2: Management and cattle profile adjustments for Kestrel units

	Treatment[1]			
Trait	CWF	CNF	SHADE	OUT
Pen management				
Manure class	1	1	3	3
Shade	3 m^2 to 5 m^2	3 m^2 to 5 m^2	3 m^2 to 5 m^2	None
Water temperature	20°C to 30°C	20°C to 30°C	30°C to 35°C	30°C to 35°C
Extra water	No	No	No	No
Heat rations	No	No	No	No
Manure clear	Yes	Yes	No	No
Cattle profile				
Genotype	*Bos taurus*	*Bos taurus*	*Bos taurus*	*Bos taurus*
Coat color	Black	Black	Black	Black
Days on feed[2]	0 to 80	0 to 80	0 to 80	0 to 80
Health status	Healthy	Healthy	Healthy	Healthy

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

[2]Days on feed adjusted at d 80 to “80 to 130”.

Table 4.3: Least squares means for the main effect of environmental treatment on feedlot performance

Trait	Treatment[1]				SEM	*P*-value
	CWF	CNF	SHADE	OUT		
Live weight, kg						
d 0[2]	452	454	479	471	8.36	0.06
d 25[2]	511	518	519	498	9.06	0.36
d 52[2]	557	568	562	543	9.57	0.30
d 78[2]	610	615	611	583	10.29	0.13
Weight at first harvest, kg[3]	625[ab]	637[a]	601[bc]	581[c]	10.16	< 0.01
Weight at target weight, kg[4]	636	637	613	636	15.10	0.59
Average daily gain, kg						
d 25[2]	2.38[a]	2.56[a]	1.60[b]	1.08[c]	0.17	< 0.01
d 52[2]	1.71	1.85	1.60	1.64	0.16	0.71
d 78[2]	2.00	1.81	1.89	1.56	0.13	0.09
d 85[2]	2.22[a]	3.09[a]	-0.89[b]	-0.28[b]	0.33	< 0.01
Total at first harvest, kg[3]	2.08[a]	2.15[a]	1.44[b]	1.29[b]	0.07	< 0.01
Total at target weight, kg[4]	1.97[a]	2.15[a]	1.43[b]	1.31[b]	0.10	< 0.01
Gain, %						
d 25[2]	12.31[a]	11.62[a]	7.64[b]	5.36[c]	0.80	< 0.01
d 52[2]	8.17	8.85	7.59	8.20	0.74	0.69
d 78[2]	8.53	7.65	8.00	6.94	0.52	0.18

d 85[2]	3.43[a]	2.46[a]	-0.93[b]	-0.37[b]	0.39	< 0.01
Total at first harvest, %[3]	28.12[a]	28.81[a]	20.27[b]	18.71[b]	0.88	< 0.01
Total at target weight, %[4]	28.81[a]	28.80[a]	21.65[b]	25.97[a]	1.39	< 0.01
Total at first harvest[3]						
Dry matter intake, kg/hd/d	10.55	10.36	10.57	9.43	0.49	0.29
Gain:feed	0.15[a]	0.16[a]	0.10[b]	0.10[b]	0.01	< 0.01
BS[5]	0.57[b]	0.55[b]	0.53[b]	0.62[a]	0.02	< 0.01
Cost of gain, $/kg	1.64[b]	1.59[b]	2.41[a]	2.43[a]	0.10	< 0.01
Total at target weight[4]						
Dry matter intake, kg/hd/d	9.27[b]	10.36[a]	9.88[ab]	6.43[c]	0.55	< 0.01
Gain:feed	0.15[a]	0.16[a]	0.11[b]	0.10[b]	0.01	< 0.01
BS[5]	0.60[a]	0.55[bc]	0.50[c]	0.58[ab]	0.03	< 0.01
Cost of gain, $/kg	1.84[b]	1.59[b]	2.54[a]	3.19[a]	0.23	< 0.01
Additional days on feed	7	0	7	42	-	-

[abc]Within a row, means without a common superscript differ (*P* < 0.05).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

[2]All steers were analyzed (CWF = 20, CNF = 20, SHADE = 20, OUT = 20)

[3]Performance collected on steers that achieved target weight (CNF = 20) and ½ of the three remaining treatments (CWF = 10, SHADE = 10, OUT = 10).

[4]Performance collected on all steers that achieved target weight (CNF = 20 (85 d), CWF = 10 (92 d), SHADE = 10 (92 d), OUT = 10 (127 d)).

[5]Bunk scores collected using a 4-point system as outlined in the Iowa Beef Center: Feed Bunk Management (2015).

Table 4.4: Least squares means for the main effect of environmental treatment on carcass yield and quality from steers at first harvest (85 d)

	Treatment[1]					
Trait	CWF	CNF	SHADE	OUT	SEM	*P*-value
Mud score[2]	2.42[b]	2.71[ab]	3.20[a]	2.91[ab]	0.19	0.01
Hot carcass weight, kg	349.78[a]	353.59[a]	334.89[ab]	327.62[b]	7.77	0.03
Dressing, %	58.30	57.89	58.05	58.74	0.63	0.73
Kidney, pelvic, heart fat, %	2.95	3.23	2.95	3.00	0.13	0.22
Ribeye area, cm^2	71.55	73.72	69.61	69.36	2.56	0.43
Backfat, cm	1.12	1.17	1.05	0.90	0.04	0.17
Yield grade	3.00[ab]	3.11[a]	2.89[ab]	2.70[b]	0.16	0.04
Marbling[3]	443	467.50	427	398	23.55	0.12
pH	5.45	5.45	5.45	5.42	0.02	0.60
Skeletal maturity[4]	145	145	144	142	2.93	0.85
Lean maturity[4]	137	138	133	139	2.81	0.43
Overall maturity[4]	141	142	139	141	2.25	0.75
Lean color[5]	3.10	3.20	3.60	3.40	0.22	0.37
Fat color[5]	1.30	1.30	1.50	1.50	0.16	0.59
Objective color						
Lean color						
L*	46.05	45.28	43.99	42.28	1.28	0.13
a*	27.56	29.13	28.13	29.40	0.81	0.31

b*	19.81	21.16	20.15	21.27	0.72	0.29
Fat color						
L*	79.74	80.74	78.85	79.71	0.63	0.10
a*	6.45	6.21	7.15	6.61	0.32	0.14
b*	16.89	16.60	17.63	17.32	0.48	0.31

[ab]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

[2]Mud scores collected in accordance with 2016 National Beef Quality Assurance (NBQA; 1 = none, 2 = small, 3 = moderate, 4 = large, 5 = extreme).

[3]Measured based on AMSA (2013) beef marbling: 300 = slight, 400 = small, 500 = modest

[4]Measured based on AMSA (2013) maturity: 100 = A maturity, 500 = E maturity.

[5]Subjective lean and fat color quantified using Japanese beef lean and fat color standards.

Table 4.5: Least squares means for the main effect of environmental treatment on carcass yield and quality from steers that achieved target weight for CWF (92 d), CNF (85 d), SHADE (92 d), and OUT (127 d) steers

	Treatment[1]					
Trait	CWF	CNF	SHADE	OUT	SEM	*P*-value
Mud score[2]	2.20^{b}	2.71^{b}	3.50^{a}	4.06^{a}	0.27	< 0.01
Hot carcass weight, kg	362.79	353.59	364.31	362.90	9.40	0.73
Dressing, %	59.37^{b}	57.89^{b}	61.92^{a}	59.35^{b}	0.70	< 0.01
Kidney, pelvic, heart fat, %	3.05	3.23	3.25	3.30	0.13	0.52
Ribeye area, cm^2	71.94	73.72	74.42	72.29	2.86	0.91
Backfat, cm	1.28	1.17	1.18	1.10	0.04	0.17
Yield grade	3.30	3.11	3.30	3.20	0.16	0.70
Marbling[3]	476.00	467.50	484.00	466.00	29.47	0.96
pH	5.45^{b}	5.45^{b}	5.48^{ab}	5.51^{a}	0.01	< 0.01
Skeletal maturity[4]	145	145	155	150	3.67	0.13
Lean maturity[4]	152^{a}	138^{b}	143^{b}	152^{a}	2.74	< 0.01
Overall maturity[4]	149^{ab}	142^{b}	149^{a}	151^{a}	2.55	0.01
Lean color[5]	3.10	3.20	3.00	3.70	0.28	0.31
Fat color[5]	1.00	1.30	1.30	1.10	0.13	0.18
Objective color						
Lean color						
L*	42.11^{b}	45.28^{a}	41.65^{b}	40.84^{b}	1.19	< 0.01

a*	30.94	29.13	30.52	30.61	0.57	0.05
b*	22.81	21.16	22.38	22.58	0.53	0.06
Fat color[6]						
L*	79.05^{b}	80.74^{a}	79.34^{b}	78.61^{b}	0.53	< 0.01
a*	7.26^{b}	6.21^{c}	7.79^{b}	9.03^{a}	0.38	< 0.01
b*	17.21^{ab}	16.60^{b}	18.31^{a}	18.71^{a}	0.59	0.02

[abc]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

[2]Mud scores collected in accordance with 2016 National Beef Quality Assurance (NBQA; 1 = none, 2 = small, 3 = moderate, 4 = large, 5 = extreme).

[3]Measured based on AMSA (2013) beef marbling: 300 = slight, 400 = small, 500 = modest

[4]Measured based on AMSA (2013) maturity: 100 = A maturity, 500 = E maturity.

[5]Subjective lean and fat color quantified using Japanese beef lean and fat color standards.

Figure 4.6 Least squares means for the main effect of environmental treatment on proximate analysis from steaks from steers at first harvest (85 d)

	Treatment[1]					
Trait	CWF	CNF	SHADE	OUT	SEM	*P*-value
Protein, %[2]	-	-	-	-	-	-
Lipid, %	3.50	3.89	3.99	3.71	0.52	0.91
Moisture, %	71.68	71.40	72.08	72.62	0.44	0.17
Ash, %	1.62	1.65	1.45	1.52	0.06	0.16

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

[2]Protein analysis was not analyzed due to complications with COVID-19.

Figure 4.7 Least squares means for the main effect of environmental treatment on proximate analysis from steaks from steers that achieved target weight for CWF (92 d), CNF (85 d), SHADE (92 d), and OUT (127 d) steers

	Treatment[1]					
Trait	CWF	CNF	SHADE	OUT	SEM	*P*-value
Protein, %[2]	-	-	-	-	-	-
Lipid, %	3.80	3.89	4.47	4.40	0.56	0.74
Moisture, %	71.78	71.40	70.99	71.65	0.49	0.67
Ash, %	1.55	1.65	1.41	1.41	0.06	0.13

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

[2]Protein analysis was not analyzed due to complications with COVID-19.

Table 4.8: Least squares means for the main effect of environmental treatment on cost-benefit analysis from steers at first harvest (85 d)

	Treatment[1]					
Trait	CWF	CNF	SHADE	OUT	SEM	*P*-value
Feeder value, \$/hd[2]	1,264.12	1,272.96	1,279.20	1,271.14	32.68	0.99
Feed cost, \$/hd/d[3]	3.27	3.44	3.35	3.00	0.18	0.18
Gross carcass value, \$/hd[4]	1,333.08[b]	1,521.45[a]	1,349.91[b]	1,344.92[b]	47.74	< 0.01
Net profit/loss, \$/hd[5]	-209.14[ab]	-44.06[a]	-427.08[b]	-363.13[b]	95.00	< 0.01

[ab]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

[2]Feeder value was calculated using market price for steers at \$0.59/kg/hd.

[3]Feed cost for steers fed 85 d, \$/hd/d.

[4]Carcass value based on USDA AMS grid NW_LS410.

[5]Net profit/loss = Gross carcass value – (Feeder value + Cost of feed).

Table 4.9: Least squares means for the main effect of environmental treatment on cost-benefit analysis from steers that achieved target weight for CWF (92 d), CNF (85 d), SHADE (92 d), and OUT (127 d) steers

	Treatment[1]					
Trait	CWF	CNF	SHADE	OUT	SEM	*P*-value
Feeder value, \$/hd[2]	1,281.96	1,272.96	1,273.09	1,267.37	34.07	0.99
Feed cost, \$/hd/d[3]	3.32	3.44	3.64	3.38	0.19	0.59
Gross carcass value, \$/hd[4]	1,559.29	1,521.45	1,554.00	1,563.36	53.48	0.90
Net profit/loss, \$/hd[5]	-27.49	-44.06	-107.15	-265.15	81.57	0.10

[ab]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

[2]Feeder value was calculated using market price for steers at \$0.59/kg/hd.

[3]Feed cost for steers fed to target weight; CWF = 92d, CNF = 85 d, SHADE = 92 d, OUT = 127 d.

[4]Carcass value based on USDA AMS grid NW_LS410.

[5]Net profit/loss = Gross carcass value – (Feeder value + Cost of feed).

Figure 4.10 Least squares means for the main effect of environmental treatment on shear force, % thaw loss, and % cook loss for steaks wet-aged for 2, 7, and 14 d from steers at first harvest for CWF, CNF, SHADE, and OUT steers (85 d)

	Treatment[1]					
Trait	CWF	CNF	SHADE	OUT	SEM	*P*-value
Slice shear, N	17.57	17.65	17.22	18.16	0.99	0.93
Thaw loss, %	4.27	3.72	4.11	4.49	0.46	0.56
Cook loss, %	12.80	13.87	13.90	13.46	0.81	0.68

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

Figure 4.11 Least squares means for the main effect of day of age on shear force, % thaw loss, and % cook loss for steaks wet-aged for 2, 7, and 14 d from steers that at first harvest for CWF (92 d), CNF (85 d), SHADE (92 d), and OUT (127 d) steers[1]

	Day of Age				
Trait	2	7	14	SEM	*P*-value
Slice shear, N	19.57[a]	16.88[b]	16.32[b]	0.52	< 0.01
Thaw, %	5.34[a]	4.37[b]	2.50[c]	0.23	< 0.01
Cook, %	14.11	12.73	13.91	0.62	0.22

[abc]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

Table 4.12: Least squares means for the main effect of environmental treatment on shear force, % thaw loss, and % cook loss for steaks wet-aged for 2, 7, and 14 d from steers that achieved target weight for CWF (92 d), CNF (85 d), SHADE (92 d), and OUT (127 d) steers

	Treatment[1]					
Trait	CWF	CNF	SHADE	OUT	SEM	*P*-value
Slice shear, N	22.02[a]	17.64[b]	22.78[a]	21.25[a]	1.18	< 0.01
Thaw loss, %	4.27	3.72	3.25	3.59	0.34	0.74
Cook loss, %	15.66	13.99	14.02	15.66	0.98	0.35

[ab]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

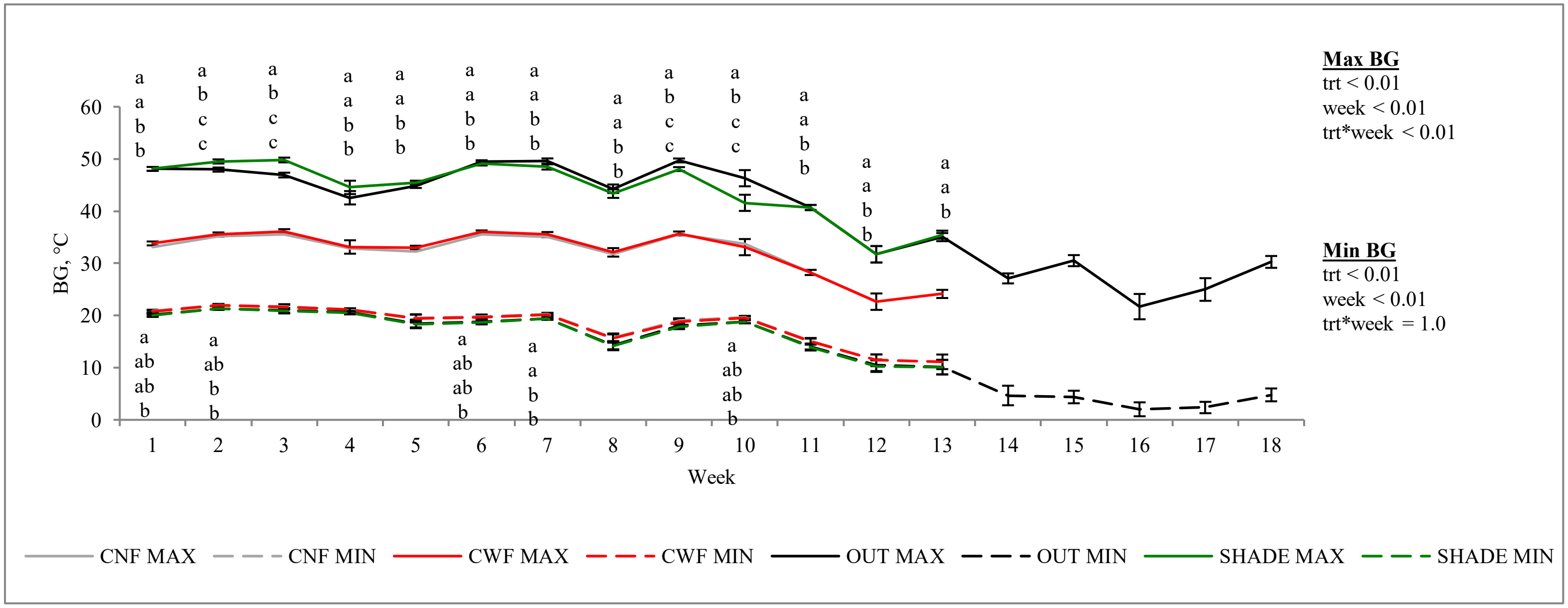
Table 4.13: Least squares means for the main effect of day of age on shear force, % thaw loss, and % cook loss for steaks wet-aged for 2, 7, and 14 d from steers that achieved target weight for CWF (92 d), CNF (85 d), SHADE (92 d), and OUT (127 d) steers[1]

	Day of Age				
Trait	2	7	14	SEM	*P*-value
Slice shear, N	24.13[a]	18.99[b]	18.17[b]	0.76	< 0.01
Thaw, %	4.80[a]	3.46[b]	2.38[c]	0.23	< 0.01
Cook, %	15.37	13.36	15.38	0.69	0.05

[abc]Within a row, means without a common superscript differ ($P < 0.05$).

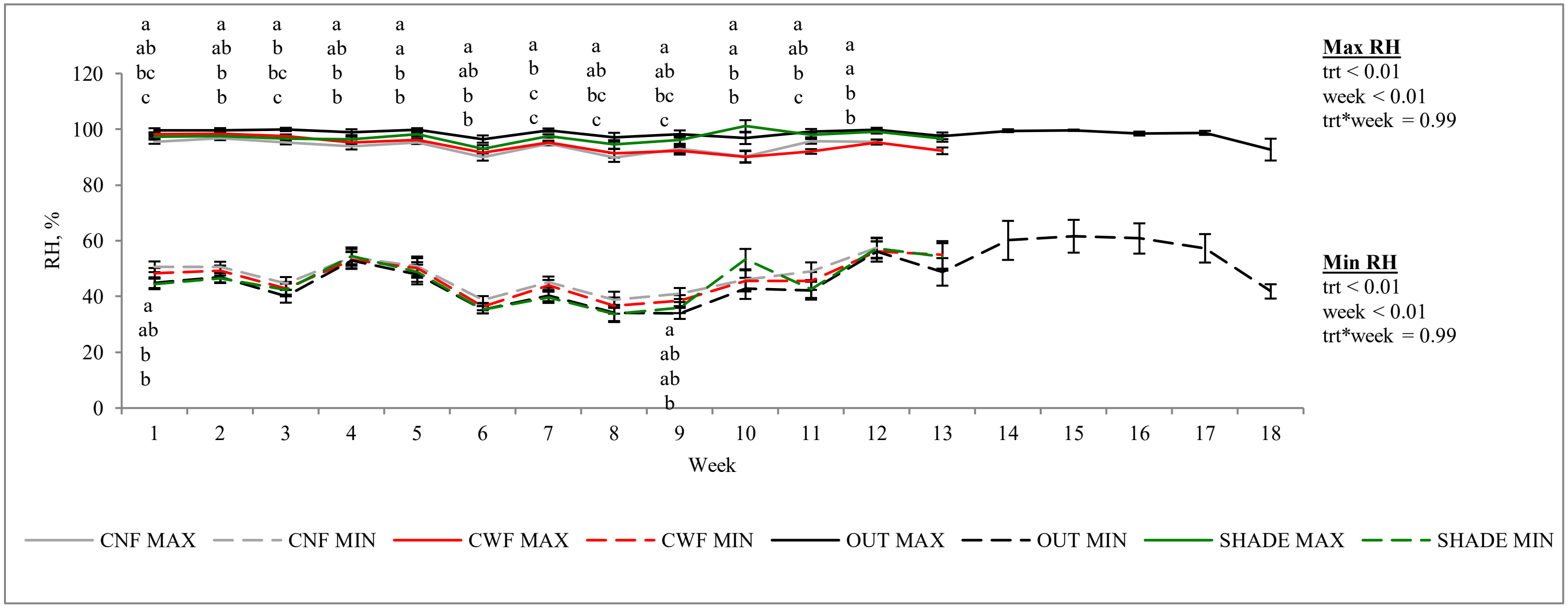
[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

A.

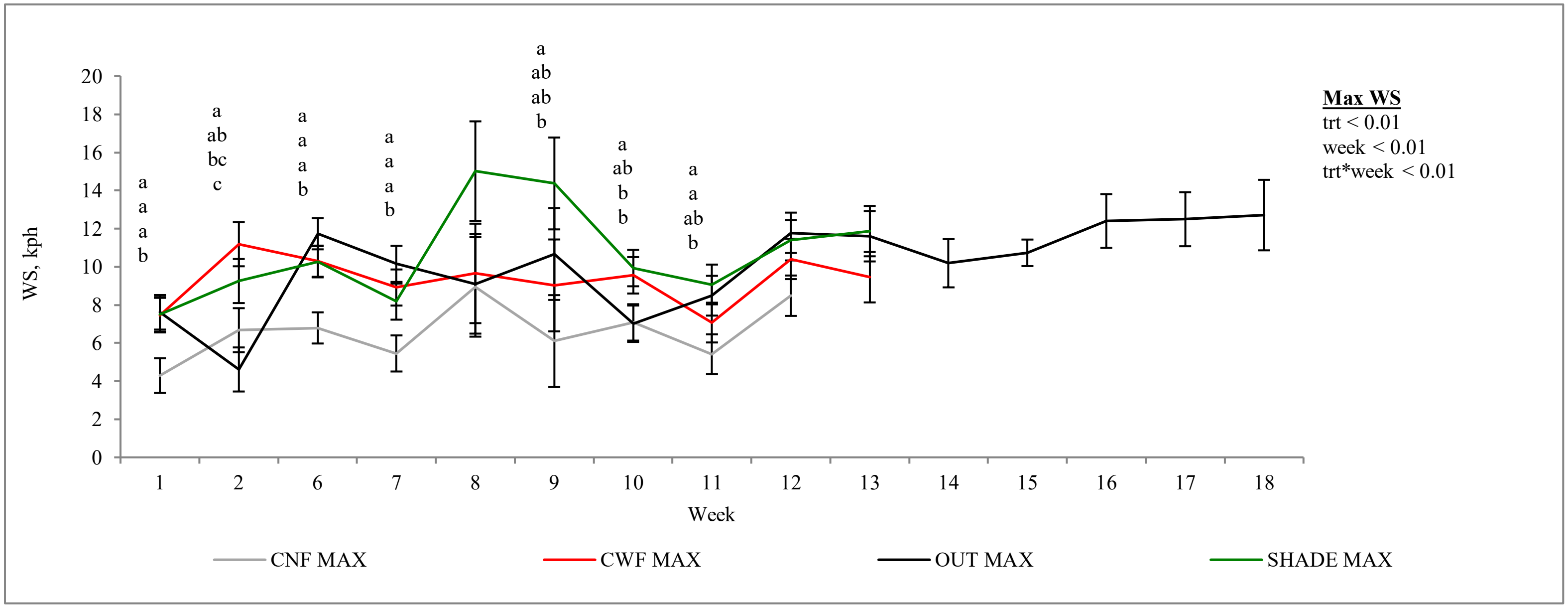


Max BG
trt < 0.01
week < 0.01
trt*week < 0.01
Min BG
trt < 0.01
week < 0.01
trt*week = 1.0
BG, °C
Week
CNF MAX
CNF MIN
CWF MAX
CWF MIN
OUT MAX
OUT MIN
SHADE MAX
SHADE MIN

B.


Max RH
trt < 0.01
week < 0.01
trt*week = 0.99
Min RH
trt < 0.01
week < 0.01
trt*week = 0.99
RH, %
Week
CNF MAX
CNF MIN
CWF MAX
CWF MIN
OUT MAX
OUT MIN
SHADE MAX
SHADE MIN

C.



20
18
16
14
12
10
8
6
4
2
0
WS, kph
1
2
6
7
8
9
10
11
12
13
14
15
16
17
18
Week
a a a b
a ab bc c
a a a b
a a a b
a ab ab b
a ab b b
a a ab b
Max WS
trt < 0.01
week < 0.01
trt*week < 0.01
CNF MAX
CWF MAX
OUT MAX
SHADE MAX

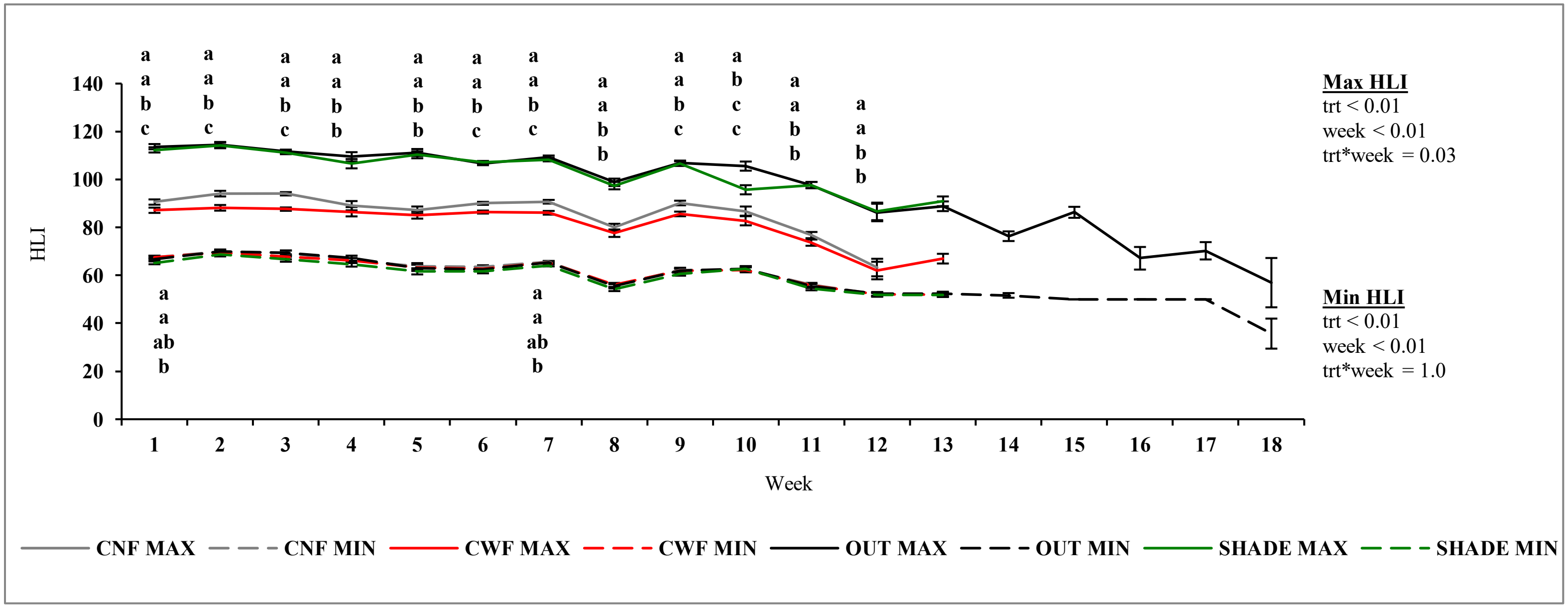
Figure 4.1

Figure 4.1a: Effect of CWF: covered with fan; CNF: covered with no fan; SHADE: optional shade without fan; OUT: outside drylot with no shade or fans on black globe temperature (BG). Solid lines refer to the average maximum BG, while dashed lines refer to the average minimum BG. The BG values were quantified by Kestrel 5400AG cattle heat stress trackers (5400AG cattle heat stress trackers; KestrelMeters; Boothwyn, PA). Each treatment was assigned 2 Kestrel units placed 2.4 m from ground level and values were averaged. [abc]Significant means between treatments within week were denoted by the difference in letters ($P < 0.05$). Treatment, week, and treatment by week interactions were calculated for the first 12 weeks of the study.

Figure 4.1b: Effect of CWF: covered with fan; CNF: covered with no fan; SHADE: optional shade without fan; OUT: outside drylot with no shade or fans on relative humidity (RH). Solid lines refer to the average maximum RH, while dashed lines refer to the average minimum RH. The RH values were quantified by Kestrel 5400AG cattle heat stress trackers (5400AG cattle heat stress trackers; KestrelMeters; Boothwyn, PA). Each treatment was assigned 2 Kestrel units placed 2.4 m from ground level and values were averaged. [abc]Significant means between treatments within week were denoted by the difference in letters ($P < 0.05$). Treatment, week, and treatment by week interactions were calculated for the first 12 weeks of the study.

Figure 4.1c: Effect of CWF: covered with fan; CNF: covered with no fan; SHADE: optional shade without fan; OUT: outside drylot with no shade or fans on wind speed (WS). Solid lines refer to the average maximum WS, while minimum WS was not included due to lack of significance. Weeks 3, 4, and 5 were not included due to a malfunction in the Kestrel device. The WS values were quantified by Kestrel 5400AG cattle heat stress trackers (5400AG cattle heat stress trackers; KestrelMeters; Boothwyn, PA). Each treatment was assigned 2 Kestrel units placed 2.4 m from ground level and values were averaged. [abc]Significant means between treatments within week were denoted by the difference in letters ($P < 0.05$). Treatment, week, and treatment by week interactions were calculated for the first 12 weeks of the study.

A.



HLI
Week
Max HLI
trt < 0.01
week < 0.01
trt*week = 0.03
Min HLI
trt < 0.01
week < 0.01
trt*week = 1.0
CNF MAX
CNF MIN
CWF MAX
CWF MIN
OUT MAX
OUT MIN
SHADE MAX
SHADE MIN

B.

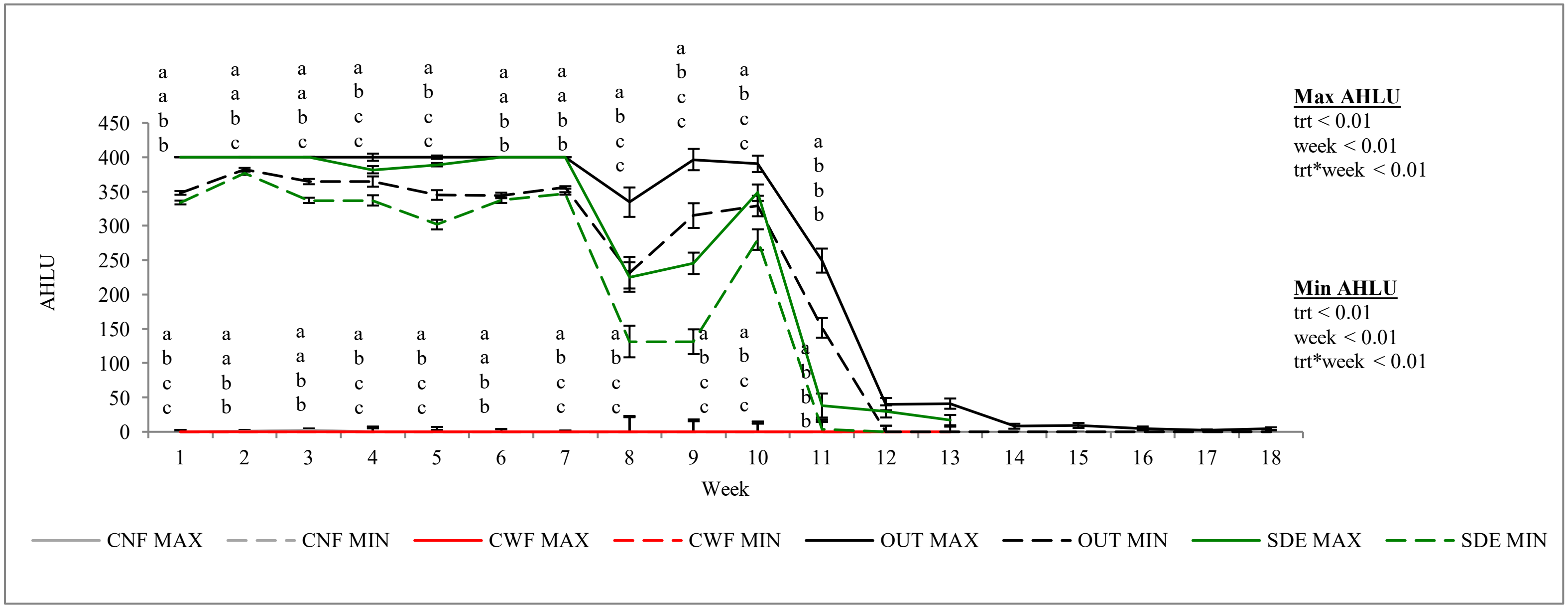
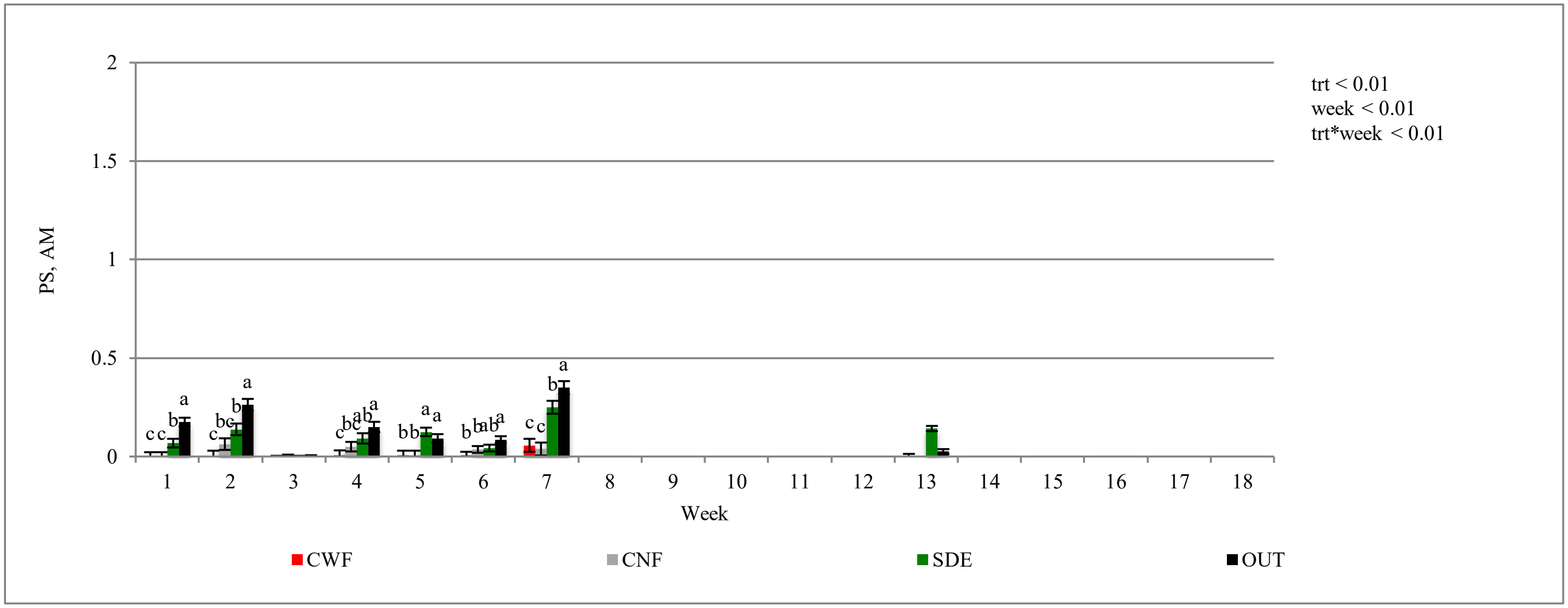

AHLU
Week
Max AHLU
trt < 0.01
week < 0.01
trt*week < 0.01
Min AHLU
trt < 0.01
week < 0.01
trt*week < 0.01
CNF MAX
CNF MIN
CWF MAX
CWF MIN
OUT MAX
OUT MIN
SDE MAX
SDE MIN

Figure 4.2

4.2a: Effect of CWF: covered with fan; CNF: covered with no fan; SHADE: optional shade without fan; OUT: outside drylot with no shade or fans on Heat Load Index (HLI). Solid lines refer to the average maximum HLI, while dashed lines refer to the average minimum HLI. The HLI values were quantified by Kestrel 5400AG cattle heat stress trackers (5400AG cattle heat stress trackers; KestrelMeters; Boothwyn, PA). Each treatment was assigned 2 Kestrel units placed 2.4 m from ground level and values were averaged. [abc]Significant means between treatments within week were denoted by the difference in letters ($P < 0.05$). Treatment, week, and treatment by week interactions were calculated for the first 12 weeks of the study.

4.2b: Effect of CWF: covered with fan; CNF: covered with no fan; SHADE: optional shade without fan; OUT: outside drylot with no shade or fans on accumulated heat load units (AHLU). Solid lines refer to the average maximum AHLU, while dashed lines refer to the average minimum AHLU. The AHLU values were quantified by Kestrel 5400AG cattle heat stress trackers (5400AG cattle heat stress trackers; KestrelMeters; Boothwyn, PA). Each treatment was assigned 2 Kestrel units placed 2.4 m from ground level and values were averaged. [abc]Significant means between treatments within week were denoted by the difference in letters ($P < 0.05$). Treatment, week, and treatment by week interactions were calculated for the first 12 weeks of the study.

A.



2
1.5
1
0.5
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PS, AM
1
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16
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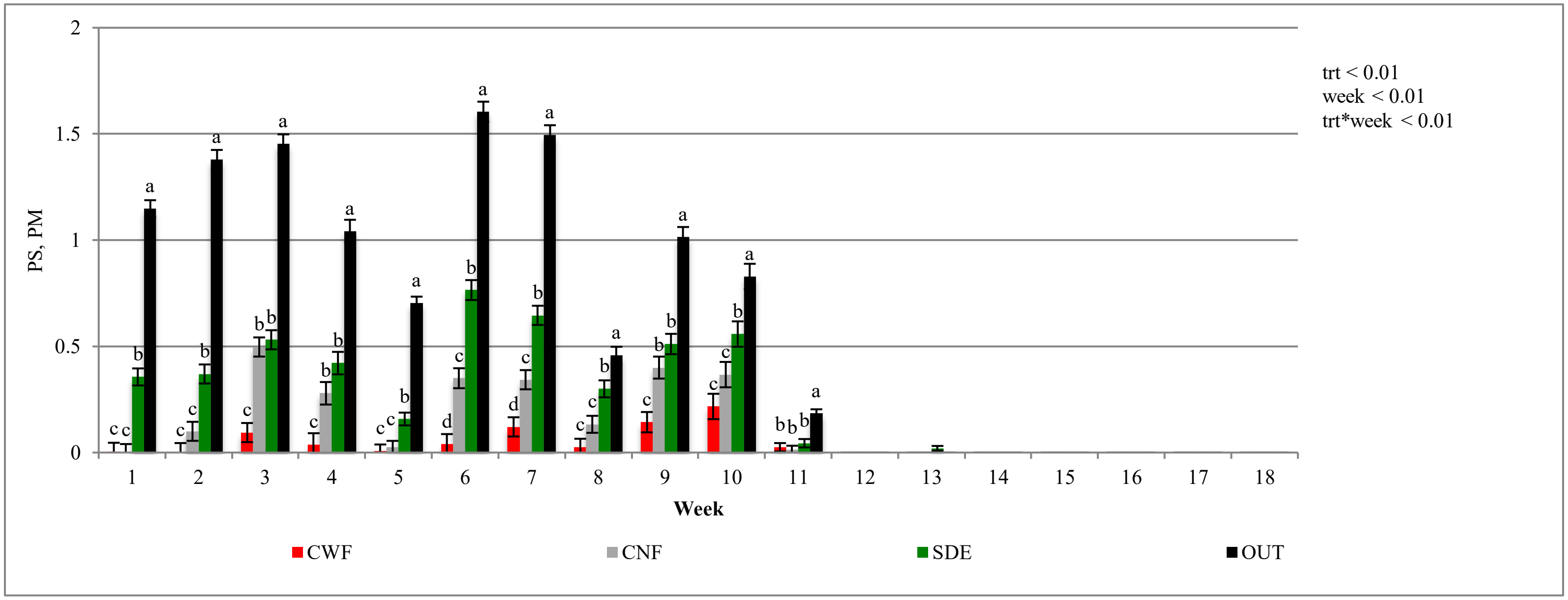
18
Week
trt < 0.01
week < 0.01
trt*week < 0.01
CWF
CNF
SDE
OUT

B.



2
1.5
1
0.5
0
PS, PM
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Week
trt < 0.01
week < 0.01
trt*week < 0.01
CWF
CNF
SDE
OUT

Figure 4.3

Figure 4.3a: Effect of CWF: covered with fan; CNF: covered with no fan; SHADE: optional shade without fan; OUT: outside drylot with no shade or fans on panting scores (PS) recorded daily at 1000 (AM) using a method outlined by Gaughan et al. (2008; 0 = no panting; 2 = fast panting, drool present; 4 = open mouth with tongue fully extended for prolonged periods). Panting scores were averaged per week and [abc]significant means between treatments within week were denoted by the difference in letters ($P < 0.05$). Treatment, week, and treatment by week interactions were calculated for the first 12 weeks of the study.

Figure 4.3b: Effect of CWF: covered with fan; CNF: covered with no fan; SHADE: optional shade with no fan; OUT: outside drylot with no shade or fans on panting scores (PS) recorded daily at 1700 (PM) using a method outlined by Gaughan et al. (2008; 0 = no panting; 2 = fast panting, drool present; 4 = open mouth with tongue fully extended for prolonged periods). Panting scores were averaged per week and [abc]significant means between treatments within week were denoted by the difference in letters ($P < 0.05$). Treatment, week, and treatment by week interactions were calculated for the first 12 weeks of the study.

CHAPTER 5

CONCLUSIONS

This research assessed the implementation of heat mitigation strategies in animal feedlot productions systems located in geographical locations, such as the Southeastern United States, that are known for chronic thermal stressors. Cover and fans were shown to significantly reduce thermal stress and improve overall performance traits such as: average daily gain, percent gain, feed efficiency and reduce the days needed to finish. Due to the intense thermal stress of a Southeastern Georgia feedlot, optional shading was unable to reduce thermal stress and resulted in similar performance traits to steers in outside drylots with no shade or fan implementation.

No differences in carcass quality characteristics were observed for both chapters. This may be due to the exposure of chronic heat load events, which lead to outside steers adapting to the environment. Improved performance traits lead to an increase in HCW, which translated to improved gross carcass values. When steers were able to achieve target weight, no differences in gross carcass values were observed. Therefore, 100% solid cover from solar radiation may be critical to combat chronic stress, while optional shading may not be sufficient in Southeastern feedlot operations.

APPENDIX A

Table 4.3: Least squares means for the main effect of environmental treatment on performance from steers that achieved target weight for CWF (92 d), CNF (85 d), SHADE (92 d), and OUT (127 d) steers with one sick steer removed from CWF

	Treatment[1]					
Trait	CWF	CNF	SHADE	OUT	SEM	*P*-value
Total						
Live weight	649	637	613	636	14.90	0.35
Average daily gain	2.13^{a}	2.15^{a}	1.43^{b}	1.31^{b}	0.08	< 0.01
Gain, %	30.38^{a}	28.81^{a}	21.65^{c}	25.97^{b}	1.11	< 0.01
Dry matter intake, kg/hd/d	9.64^{a}	10.36^{a}	9.88^{a}	6.43^{b}	0.48	< 0.01
Gain:feed	0.14^{ab}	0.16^{a}	0.11^{bc}	0.10^{c}	0.01	< 0.01
BS[2]	0.55	0.55	0.50	0.58	0.05	0.77
Cost of gain, $/kg	1.62^{c}	1.60^{c}	2.54^{b}	3.19^{a}	0.17	< 0.01

[abc]Within a row, means without a common superscript differ (*P* < 0.05).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

[2]Bunk scores collected using a 4-point system as outlined in the Iowa Beef Center: Feed Bunk Management (2015).

Table 4.5: Least squares means for the main effect of environmental treatment on carcass yield and quality from steers that achieved target weight for CWF (92 d), CNF (85 d), SHADE (92 d), and OUT (127 d) steers with one sick steer removed from CWF

	Treatment[1]					
Trait	CWF	CNF	SHADE	OUT	SEM	*P*-value
Mud score[2]	2.22[b]	2.71[b]	3.50[a]	4.06[a]	0.28	< 0.01
Hot carcass weight, kg	371.85	353.59[a]	364.31	362.90	9.07	0.39
Dressing, %	59.71[b]	57.89[c]	61.92[a]	59.35[bc]	0.73	< 0.01
Kidney, pelvic, heart fat, %	3.05	3.23	3.25	3.30	0.13	0.52
Ribeye area, cm^2	74.05	73.72	74.42	72.29	2.87	0.95
Backfat, cm	1.33	1.17	1.05	0.90	0.09	0.37
Yield grade	3.33	3.11[a]	3.30	3.20	0.17	0.65
Marbling[3]	474.44	467.50	484.00	466.00	31.40	0.97
pH	5.45[b]	5.45[b]	5.48[ab]	5.51[a]	0.02	< 0.01
Skeletal maturity[4]	144	145	143	152	3.90	0.13
Lean maturity[4]	151[a]	138[b]	143[b]	152[a]	2.89	< 0.01
Overall maturity[4]	148[a]	142[b]	149[a]	151[a]	2.69	0.01
Lean color[5]	2.89	3.20	3.00	3.70	0.28	0.17
Fat color[5]	1.00	1.30	1.30	1.10	0.13	0.21
Objective color						
Lean color						
L*	42.11[b]	45.28[a]	41.65[b]	40.84[b]	1.24	< 0.01

a*	30.94[a]	29.13[b]	30.52[ab]	30.61[a]	0.57	0.04
b*	22.81[a]	21.16[b]	22.38[ab]	22.58[a]	0.55	0.04
Fat color						
L*	79.06[b]	80.74[a]	79.34[b]	78.61[b]	0.55	< 0.01
a*	7.26[b]	6.21[c]	7.79[b]	9.03[a]	0.40	< 0.01
b*	17.21[ab]	16.60[b]	18.31[a]	18.71[a]	0.61	0.02

[abc]Within a row, means without a common superscript differ (*P* < 0.05).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

[2]Mud scores collected in accordance with 2016 National Beef Quality Assurance (NBQA; 1 = none, 2 = small, 3 = moderate, 4 = large, 5 = extreme).

[3]Measured based on AMSA (2013) beef marbling: 300 = slight, 400 = small, 500 = modest.

[4]Measured based on AMSA (2013) maturity: 100 = A maturity, 500 = E maturity.

[5]Subjective lean and fat color quantified using Japanese beef lean and fat color standards.

Figure 4.7 Least squares means for the main effect of environmental treatment on proximate analysis from steaks from steers that achieved target weight for CWF (92 d), CNF (85 d), SHADE (92 d), and OUT (127 d) steers with one sick steer removed from CWF

	Treatment[1]					
Trait	CWF	CNF	SHADE	OUT	SEM	*P*-value
Protein, %[2]	-	-	-	-	-	-
Lipid, %	4.08	3.89	4.47	4.40	0.58	0.82
Moisture, %	71.50	71.40	70.99	71.65	0.49	0.78
Ash, %	1.58	1.65	1.41	1.41	0.09	0.14

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

[2]Protein analysis was not analyzed due to complications with COVID-19.

Table 4.9: Least squares means for the main effect of environmental treatment on cost-benefit analysis from steers that achieved target weight for CWF (92 d), CNF (85 d), SHADE (92 d), and OUT (127 d) steers with one sick steer removed from CWF

	Treatment[1]					
Trait	CWF	CNF	SHADE	OUT	SEM	*P*-value
Feeder value, $/hd[2]	1,280.79	1,272.96	1,273.09	1,267.37	34.07	0.99
Feed cost, $/hd/d[3]	3.45	3.44	3.64	3.38	0.19	0.59
Gross carcass value, $/hd[4]	1,595.89	1,521.45	1,554.00	1,563.36	53.48	0.90
Net profit/loss, $/hd[5]	-2.53	-44.06	-107.15	-265.15	80.76	0.07

[ab]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

[2]Feeder value was calculated using market price for steers at $0.59/kg/hd.

[3]Feed cost for steers fed to target weight; CWF = 92d, CNF = 85 d, SHADE = 92 d, OUT = 127 d.

[4]Carcass value based on USDA AMS grid NW_LS410.

[5]Net profit/loss = Gross carcass value – (Feeder value + Cost of feed).

Table 4.12: Least squares means for the main effect of environmental treatment on shear force, % thaw loss, and % cook loss for steaks wet-aged for 2, 7, and 14 d from steers that achieved target weight for CWF (92 d), CNF (85 d), SHADE (92 d), and OUT (127 d) steers with one sick steer removed from CWF

	Treatment[1]					
Trait	CWF	CNF	SHADE	OUT	SEM	*P*-value
Slice shear, N	22.08[a]	17.64[b]	22.75[a]	21.26[a]	1.22	< 0.01
Thaw loss, %	3.57	3.70	3.24	3.60	0.34	0.72
Cook loss, %	15.49	13.97	13.99	15.67	1.00	0.40

[ab]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.

Table 4.13: Least squares means for the main effect of day of age on shear force, % thaw loss, and % cook loss for steaks wet-aged for 2, 7, and 14 d from steers that achieved target weight for CWF (92 d), CNF (85 d), SHADE (92 d), and OUT (127 d) steers with one sick steer removed from CWF[1]

	Day of Age				
Trait	2	7	14	SEM	*P*-value
Slice shear, N	24.00[a]	19.06[b]	18.15[b]	0.77	< 0.01
Thaw, %	4.80[a]	3.50[b]	2.39[c]	0.24	< 0.01
Cook, %	15.29	13.31	15.37	0.72	0.05

[abc]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CWF = steers 100% cover with fans; CNF = steers under 100% cover no fans; SHADE = outside drylot steers with optional shade; OUT = outside drylot steers without shade or fans.