EFFECTS OF CATTLE HIDE COLOR AND CHANGING ENVIRONMENTAL CONDITIONS AT NORTHERN LATITUDES ON FEEDER CATTLE PERFORMANCE AND BEHAVIOR

by

Katie J. Friede

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Animal and Range Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

August 2025

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to all my family and friends for their unwavering support and encouragement throughout my master’s program. I couldn’t have done it without all of you cheering me on and providing me with a much-needed laugh at the end of some very long days. I am immensely grateful to Dr. Darrin Boss for not only providing me with this opportunity, but for his guidance and support in my completion of this degree. I would like to thank the faculty and staff at the Northern Agricultural Research Center, as well as their resources and facilities necessary for this research. NARC and the Hi Line are very special places that have presented me with many opportunities I couldn’t have dreamed of and I am forever grateful for them. I would like extend my gratitude to my major professor, Dr. Sam Wyffels, for being a part of my academic journey. The opportunity to work under your guidance have been invaluable to my growth. I also want to acknowledge and thank Dr. Hannah DelCurto-Wyffels and Dr. Tim DelCurto for not only serving on my committee, but for being great mentors and teachers throughout both my undergraduate and graduate journey at Montana State – the courses you taught me years ago inspired me to think and dream bigger than I thought possible. I want to thank Dr. Hannah Speer for always making time to help me with whatever I threw at her. I am deeply grateful you were always just across the hall! Thanks to Dr. Megan Van Emon for helping with data collection on this project and your overall support. Lastly, I want to thank my husband Kade. I truly could not have done this without you and “Thank you” doesn’t begin to cover all the times you let me cry on your shoulder when I was learning to write code in R, being my audience as I practiced a presentation for the 400th time, or the much-needed comic relief. You have always believed in me so much that it has allowed me to believe in myself.

TABLE OF CONTENTS

1. LITERATURE REVIEW: THE ROLE OF HIDE COLOR AND ENVIRONMENT ON BEEF CATTLE THERMOREGULATION, PERFORMANCE AND BEHAVIOR ... 1

Simple Summary ... 1
Abstract ... 1
Beef Cattle Feedlot Sector ... 2
Factors Affecting Beef Cattle Performance ... 3
    Breed ... 3
    Feed Intake ... 8
    Environment ... 10
    Heat Stress ... 13
    Cold Stress ... 18
    Solar Radiation in Relation to Coat Color ... 21
Potential Implications on Beef Cattle Selection with the Consideration of Coat Color ... 27
Future Research Needs ... 28
Conclusion ... 30

2. HIDE COLOR INFLUENCE ON FEEDLOT STEER GROWTH, PERFORMANCE, AND CARCASS TRAITS ... 31

Introduction ... 31
Materials and Methods ... 33
    Study 1 ... 34
    Study 2 ... 38
    Statistical Analysis ... 41
Results ... 42
    Study 1 ... 42
    Study 2 ... 49
Discussion ... 56
    Average daily gain & Gain to Feed ... 56
    Hair Depth ... 58
    Tag Scores ... 59
    Cattle Surface Temperature ... 60
    Carcass Characteristics ... 62
Conclusion ... 63

3. THE INFLUENCE OF HIDE COLOR AND NORTHERN LATTITUDE CLIMATES ON FEED INTAKE BEHAVIOR OF BEEF STEERS ... 65

Introduction ... 65

TABLE OF CONTENTS CONTINUED

- Materials and Methods 67
  - Study 1 68
  - Study 2 69
  - Statistical Analysis 71
- Results 72
  - Study 1 72
  - Study 2 75
- Discussion 78
  - Average Daily Intake 78
  - Average Daily Intake g/kg BW 80
  - Coefficient of variation of intake 81
  - Time Spent Eating 84
  - Eating Rate 85
- Conclusion 88

4. CONCLUSIONS AND MANAGEMENT CONSIDERATIONS 90

REFERENCES CITED 93

LIST OF TABLES

Table Page

1. Table 2.1. Nutrient composition of finishing diet in Study 1, conducted at NARC in 2023. 36
2. Table 2.2. Weather conditions recorded during Study 1, conducted at 1NARC in 2023. 38
3. Table 2.3. Nutrient composition of finishing diet in Study 2, conducted at 1NARC in 2024. 39
4. Table 2.4. Weather conditions recorded during Study 2, conducted at 1NARC in 2024. 40
5. Table 2.7. Coat depth measurements (mm) across different treatment periods in Study 1, conducted at 1NARC in 2023. 45
6. Table 2.9. Ribeye area and 12th rib fat among treatments in Study 1, conducted at 1NARC in 2023. 47
7. Table 2.10. Carcass characteristics of steers at harvest in Study 1, conducted at 1NARC in 2023. 48
8. Table 2.11. Performance metrics of steers by treatment group in Study 2, conducted at 1NARC in 2024. 50
9. Table 2.12. 1Tag scores across different treatment periods in Study 2, conducted at 2NARC in 2024. 51
10. Table 2.13. Coat depth measurements (mm) across different treatment periods in Study 2, conducted at 1NARC in 2024. 52
11. Table 2.14. Steer Surface Temperature (°C) across different treatment periods in Study 2, conducted at 1NARC in 2024. 53
12. Table 2.15. Ribeye area and 12th rib fat among treatments in Study 2, conducted at 1NARC in 2024 54
13. Table 2.16. Carcass characteristics of steers at harvest in Study 2, conducted at 1NARC in 2024 55
14. Table 3.1. Effects of Coat Color on Intake Behavior Across Periods in Study 1, conducted at 1NARC in 2023 74

TABLES CONTINUED

Table Page

15. Table 3.2. Effects of Coat Color on Intake Behavior Across Periods in Study 2, conducted at 1NARC in 2024 77

ABSTRACT

This study investigates the influence of hide color on beef steer intake behavior and performance metrics under varying environmental conditions. Conducted at the Northern Agricultural Research Center near Havre, Montana, the two studies were conducted in consecutive years: 2023 (Study 1) and 2024 (Study 2). Angus-based yearling steers of Red, White, and Black hide color were placed into the feedlot from February to July (140 days) to measure the influence of climatic conditions on feeder cattle behavior and performance. In both studies, steers were assigned to one of four treatment groups: Red hided, Red Angus steers (REDANG), Black hided, Angus steers (BLKANG), White hided steers (Charolais sires bred to Angus cows; CHARANG), and Black hided steers (Simmental sires bred to Angus cows; SIMANG). Steers were fitted with electronic ear tags and monitored using Vytelle electronic feed bunks to measure feed intake and behavior on a finishing feedlot diet. Cattle surface temperature was measured weekly, on the same day of the week at two consistent times of day for a duration of 20 weeks. Results indicated a treatment by period interaction for average daily intake (ADI) for both studies ($P<0.01$). In Study 1, REDANG steers had higher ADI than SIMANG in several periods (Period 3: $P<0.01$; Period 4: $P=0.04$; Period 5: $P\leq0.03$). In Study 2, BLKANG steers showed greater ADI than other treatments in multiple periods (Period 1: $P<0.01$; Period 3: $P\leq0.03$; Period 4: $P\leq0.02$). Additionally, hide color influenced surface temperature, with CHARANG steers consistently cooler than other treatments ($P<0.01$) and BLKANG, SIMANG, and REDANG steers averaging 2.85°C greater than CHARANG steers in Study 1. In Study 2, BLKANG and SIMANG had higher surface temperatures ($P\leq0.02$) than other treatments. Despite these differences, no significant treatment effects on average daily gain (ADG) were observed ($P\geq0.24$). Due to the effect of hide color on cattle surface temperature observed, there may be a potential impact on the steers ability to manage their body temperature under varying environmental conditions, however, there was no clear effect on performance and behavior at the scale presented in this study. Therefore, further research is required to determine the impact of hide color on cattle thermoregulation, the interaction with environment and potential management considerations.

CHAPTER ONE

LITERATURE REVIEW: THE ROLE OF HIDE COLOR AND ENVIRONMENT ON BEEF CATTLE THERMOREGULATION, PERFORMANCE AND BEHAVIOR

Simple Summary

Beef cattle are raised in diverse regions of the world with temperatures fluctuating widely from extreme cold and hot environments. These exceedingly hot and cold environments can adversely affect beef cattle productivity and welfare, resulting in significant economic loss. While some research has been done on the influence of climatic conditions on feeder cattle welfare, limited work has been done that assesses the relationship of hide color and extreme environmental changes on cattle thermoregulation, and in particular, its effect on animal performance and intake behavior. This review examines research on the role of hide color and environment on beef cattle thermoregulation, performance and behavior.

Abstract

Beef cattle are raised in various production systems and environments that may lack the essential resources such as shelter and shade for cattle to maintain thermoneutrality. This is particularly prevalent in the beef industry's feedlot sector, where infrastructure often fails to provide adequate protection from environmental stressors. As thermal challenges in livestock production systems are one of the main causes of animal stress, understanding how livestock respond to environmental changes is imperative to proper management. While the mechanisms of cattle thermoregulation are fairly well understood, there is a scarcity of research on how hide

coloration might influence feedlot cattle acclimation through solar warming (albedo). This review identifies the available research on hide color albedo and the behavioral changes of cattle in response to dynamic environmental stressors and addresses areas for potential research on cattle hide color and its relation to performance.

Beef Cattle Feedlot Sector

The main objective of a finishing feedlot is to sustainably produce market-ready cattle that yield tender, highly marbled beef, delivering an excellent eating experience for consumers, while minimizing production costs and maximizing growth efficiency (O'Quinn et al., 2018, Smith & Carpenter 1974). Cattle in the feedlot are fed a high grain/low-forage diet until they develop adequate fat cover and meet the USDA standards for slaughter, which include being free of drug residues, ambulatory, and showing no signs of neurological disorders (USDA, 2023). Feedlots have historically been located in the Great Plains region of the United States due to the area's temperate climate and proximity of feedstuffs that comprise the feedlot cattle diet. Over 72% of feedlot production occurs in the 5-state area of Nebraska, Texas, Kansas, Iowa, and Colorado (USDA, 2018). As of January 1st, 2024, cattle in the U.S. on feed intended for slaughter totaled 11.9 million head (NASS, 2024).

Over the past 60 years feedlots have expanded across parts of North America's Southwest, upper Mid-West, and the Pacific Northwest regions (USDA, 2023). This is due to the development and availability of low-cost feedstuffs, such as food byproducts (Drouillard, 2018). This expansion of the feedlot sector into Northern and Southern Latitudes has become an important addition to the food chain (Drouillard, 2018). Consequently, it has presented a new set of thermal challenges as cattle are now located in varied extreme environments which ultimately has an impact on their health and productivity (Muzzo et al., 2025). In addition, feedlot populations have a high turnover rate of cattle that are shipped from various climates (Cernicchiaro et al., 2021). If cattle are unable to quickly alter their metabolisms to acclimate to the stress of the sudden changes in environmental conditions, a high death loss rate can be experienced (Hall et al., 2012). This introduces several new challenges as cattle management must be tailored to the environment, cattle type and feedlot objectives.

Factors Affecting Beef Cattle Performance

The World Organization for Animal Health (WOAH, 2023) outlines specific criteria for assessing animal welfare in beef cattle production systems, including behavior, morbidity and mortality rates, and changes in weight and body condition (WOAH, 2023). Ensuring high standards of animal welfare not only improves the quality of life for cattle but also enhances productivity and profitability for producers. Research has shown that feeder cattle performance is influenced by multiple factors such as age, breed, management, environment, feed intake, and nutrition (Basarab et al., 2003, Hammack, 2022, Maciel et al., 2021, Tenn, 1967, USDA, 1995, Vanek et al., 2008). All factors are important to consider when discussing both challenges and opportunities that can impact beef cattle performance.

Breed

The beef industry makes use of different animal genotypes in a wide range of environments throughout North America. In the United States, beef production currently takes place in all 50 states, with over 80 breeds and crosses thereof (Drouillard, 2018, World Population Review, 2023). Although breed diversity is extensive within the U.S., certain breeds contain the desired genetics that exhibit ideal qualities for feedlot production. Both Bos Taurus and Bos Indicus breeds are found in the U.S., however in 2012 it was reported that only 8% of the total U.S. cowherd is Bos Indicus influenced (Cundiff et al., 2012). Bos Indicus cattle are well-adapted to hot climates due to their genetic makeup, which includes several unique characteristics that enhance their ability to withstand high temperatures (Davis, 2022). Bos Indicus cattle have loose skin appendages, large ears, and a cervico-thoracic hump, all of which increase their surface area per unit body weight, aiding in heat dissipation (Allen, 1962, Allen et al., 1963). Additionally, Bos Indicus cattle possess a higher density of larger and more superficially located sweat glands, which allows them to produce more sweat and effectively dissipate heat (Pan, 1963). Their lighter skin color, thinner skin, shorter hair, and sleek, shiny coat further reduce heat absorption compared to the darker, denser hide of Bos Taurus cattle (Dowling, 1955, Ney & Heyman, 1956). These adaptations contribute to their greater longevity and robust nature, making them well-suited for warmer environments (Davis, 2022). For example, Bos indicus breeds, such as the Boran cattle, are more adapted to high temperatures and can maintain homeostasis more effectively in hot conditions compared to Bos taurus breeds (Bayssa et al, 2021). This breed-specific thermoregulation is crucial for their health and productivity, as it impacts their ability to cope with heat stress and maintain performance (Santos et al., 2021). Understanding these breed-specific differences is essential for optimizing cattle management practices across various geographies and climates.

However, Bos Indicus's reproductive performance is generally inferior to Bos Taurus breeds because the cattle tend to be more excitable, may be more challenging to handle, and their beef is generally leaner and tougher than Bos Taurus breeds (Cooke et al., 2017, Rodrigues et al., 2017, Sartori et al., 2009). In contrast, Bos Taurus cattle are known for their superior carcass traits, early sexual maturation, and docile temperament (Feuz et al., 2022), making them the predominant breed in the U.S. cattle industry. Bos Taurus breeds of British and Continental descent have exceptional characteristics that are appealing to the industry. For example, the British breeds Hereford and Angus cattle are popular in the feedlot due to their ability to deposit fat, reach puberty at an early age, and have good longevity (Cottle et al., 2014). Continental breeds such as Charolais and Simmental are also popular in the feedlot due to their high degrees of muscling and a lean body composition (Cottle et al., 2014). Bos Taurus cattle's ability to efficiently gain weight, produce quality meat with exceptional marbling, and yield a desirable amount of meat has significantly influenced the feedlot industry and overall beef production.

Studies have further assessed the characteristics of Bos Taurus cattle, resulting in quantifying several differences between Bos Taurus breed types. Laborde & colleagues (2021) measured breed effects on growth performance and carcass characteristics in Red Angus and Simmental finishing steers, reporting that average daily gain (ADG) between the breeds were similar, however Simmental steers needed additional days on feed to achieve the same level of backfat thickness as the Red Angus steers. Cross & colleagues (1984) conducted a study using four different breeds (Charolais, Simmental, Hereford, and Angus) to assess the influence of breed, sex, age, and electrical stimulation on carcass and palatability traits. It was reported that Simmental and Charolais cattle produced heavier carcasses with less subcutaneous fat, while Hereford and Angus cattle contained more intramuscular fat and consequently had higher USDA marbling quality grades. While breed had little impact on the palatability effect, the authors suggested that the use of Continental breeds of cattle could be used to produce heavier and leaner carcasses of acceptable quality (Cross et al., 1984). These findings are echoed in recent research, as Engle & colleagues (2025) recently quantified differences in breed-specific heterosis for growth and carcass traits in 18 U.S. beef breeds. They found that Continental breeds, such as Charolais and Simmental, produced leaner and heavier carcasses, while British breeds, like Hereford and Angus, had higher marbling scores (Engle et al., 2025).

While several breeds of Bos Taurus cattle have independently performed well, the practice of crossbreeding has paved the way for greater achievements. Crossbreeding is used in beef cattle production to improve performance, enhance carcass quality, meet market requirements and make use of varying genetics with desirable traits (Cross et al., 1984, Gregory et al., 1980, Gregory et al., 1994). Crossbreeding leads to hybrid vigor or heterosis, where the offspring exhibit improved performance and health compared to their purebred parents (Nwosu et al., 2019). Adding genetic diversity and enhancing performance through crossbreeding systems has increased beef production by improving feed efficiency, increasing profitability and optimizing traits that determine carcass value (Cottle & Kahn, 2014, Cundiff et al., 2024, Gregory et al., 1980)

One of the most sought out traits for feedlot cattle is carcass quality, where intramuscular fat and fatty acid composition of marbling is a determinant of beef flavor, quality and shelf life (Dinh et al., 2010). Breed has a substantial effect on meat quality, with the Black Angus breed consistently producing flavorful beef while maintaining efficiency (Ellis et al., 2022, Harper et al., 2017, Roberts et al., 2017). This has resulted in 60% or more cattle intended for slaughter in the U.S. having some degree of Angus influence (Droulliard, 2018). Chambaz & colleagues (2003) reported that there were clear differences in meat quality between Angus, Simmental, Charolais and Limousin steers, with Angus carcasses reporting at the lowest weight but the highest fatness score. Dinh & colleagues (2010) compared the composition of intramuscular fat from the longissimus muscle in Angus, Brahman and Romosinuano cattle. The study reported significant differences between muscle fatness and intramuscular fat between the breeds, with Angus having a greater amount of intramuscular fat and fatty acid composition. Several other studies have shown that the Black Angus breed has proven to be efficient while yielding well-marbled and flavorful beef (Albertí et al., 2008, Arthur et al., 2001, McClure et al., 2010)

In addition to their high performance, Black Angus popularity could be due in part to Certified Beef Programs (CBP's). Certified Beef Programs are an agricultural marketing service in the United States that has requirements of cattle characteristics and qualities at the time of slaughter (USDA, 2023). Certified Beef Programs such as the Premium Black Angus Beef and Certified Angus Beef brand, require that Angus-influenced cattle exhibit a predominantly black hide to meet their carcass merit standards (USDA, 2017). If the animal meets the criteria as stated by the American Angus Association's (AAA) live animal requirements for a CBP, the producer will receive a premium for the carcass, thus, increasing profitability and creating producer incentives to utilize CBP's. In 2021, Angus-influenced cattle evaluated for the Certified Angus Beef brand received significant grid premiums, totaling $182 million in a year, demonstrating the added value and profitability for producers who meet the CBP criteria (Certified Angus Beef, 2022). This could be a contributor to the increased popularity of black hided cattle, and therefore, is part of the reason as to why we see black hided cattle raised in more regions of the world than any other breed.

As a result of CBP premiums we have seen an upward trend of Black Angus cattle globally (Scasta, 2021) with thousands of feedlot cattle being crossbred with Angus genetics and nearly 75% of U.S. cattle having black hides (Greenwood, 2021, Zimmerman, 2012). While this crossbreeding provides numerous opportunities for success and growth, it potentially presents thermal challenges regarding how different environments impact various breed types and their performance.

Feed Intake

The ability to efficiently convert feed to muscle combined with desired fat deposition is one of the goals feedlot cattle managers. For a feedlot to be sustainable and profitable, cattle must be able to produce desirable outputs with minimal inputs. For instance, a 5% improvement in feed efficiency can generate four times the economic return of a 5% improvement in average daily gain (Gibb et al., 1999). However, feed intake and feed efficiency are multifactorial traits that are difficult to measure as they are influenced by management practices, genetic determinants and environmental factors (Kenny et al., 2018). Feed intake must first be predicted before the diet can be formulated to meet requirements for growth (NASEM, 1987), however it is dependent on several physiological factors, environmental effects and dietary factors including body size, sex, age, breed type, ambient temperature, weather events, photoperiod, time of feeding, forage availability, diet water content, degree of fermentation, feed processing, and dietary protein content (NASEM, 1987).

Similarly to feed intake, feed efficiency in beef cattle is affected by many physiological processes, which contribute to the variation in feed efficiency such as feed digestion, metabolism, diet, physical activity, and thermoregulation (Herd et al., 2009). One significant variable affecting feed efficiency and cattle intake behavior is genetic predisposition (Kenny et al., 2018). Our understanding of genotype affecting cattle feed efficiency has significantly advanced in recent years. Zhang & colleagues (2023) investigated liver data from Angus and Charolais cattle, reporting that specific gene modules were positively correlated with feed efficiency in Angus cattle, but negatively correlated in Charolais cattle. In addition, the study identified five key genes associated with lipid metabolism that may explain differences in feed efficiency between the breeds. Smith & colleagues (2022) investigated the genetic basis of growth traits in Red Angus cattle and identified key genomic regions that provide valuable targets for improving feed efficiency and growth traits.

Although genotype significantly influences cattle efficiency, environmental conditions can substantially impact feed intake and overall efficiency. According to the National Academies of Sciences, Engineering, and Medicine (NASEM) (NASEM, 1981), environmental conditions affect the level of voluntary feed intake and the utilization of metabolizable energy. Studies have shown that both high and low temperatures can significantly impact feed intake and nutrient utilization of animals (Ames, 1980, Baumgard & Rhoads, 2012, Young, 1983). Milligan & Christison (1974) investigated the effects of severe winter conditions on 1,970 steers from the University of Saskatchewan over 7 years, reporting that during the months of December, January and February, average daily gain fell to 70% of the average record over the remainder of the year. Severe winter conditions resulted in a significant increase in feed intake among feedlot steers due to the higher energy demands required to maintain body temperature. Despite this increased feed intake, growth performance was negatively impacted by the harsh winter conditions when compared to steers in more moderate conditions. In addition, efficiency of feed conversion was reduced during severe winter conditions as steers required more feed to achieve the same weight gain as those in milder conditions.

Heat stress greatly impacts feed intake as well. Studies have shown a significant negative correlation between temperature-humidity index (THI) and dry matter intake (DMI) in cattle, reporting that for every unit increase in THI, DMI decreases by 0.45 kg/day (Chang et al., 2021). Reduction of DMI is a direct effort to lower metabolic heat production, which in turn, results in poor production and performance (Farooq et al., 2010). Ruminants experience reduced gut motility and changes in the fermentation pattern under heat stress, which ultimately impairs digestibility and nutrient utilization (Baile & Forbes, 1974, Baumgard & Rhoads, 2012, Yadav et al., 2013). The main losses of reduced intake due to heat stress are decreased growth performance and immunocompetence (Gouvêa et al., 2019). These changes in intake may lead to more severe metabolic disorders such as ruminal acidosis (Marchesini et. al, 2018).

Environment

Environmental extremes in both hot and cold environments affect cattle in many ways. Homeostasis, the process by which cattle maintain a constant internal environment despite external changes, is crucial for their health and productivity (Romero et al., 2017). While responses to thermal changes are extremely varied, it is well documented that environmental conditions influence the health, welfare, and productivity of cattle (Ames, 1980). Cold temperatures cause cattle energy expenditures to increase to maintain a stable internal body temperature (Webster, 1971), which therefore inhibits both the gain and performance of steers wintering at feedlots (Milligan & Christison, 2011). In warm temperatures, cattle respond to heat stress using a variety of mitigation strategies and physiological changes that may have a negative effect on gain and carcass quality (Neinaber, 2007). These strategies include increased respiration rate, sweating, and seeking shade, all aimed at dissipating excess body heat to maintain homeostasis (Hoppe et al., 2021). However, prolonged heat stress can overwhelm these mechanisms, leading to reduced feed intake, lower weight gain, and poorer carcass quality (Cooke, 2017).

Variables such as wind speed, air temperature, relative humidity and solar radiation have a great impact on cattle (Abdelnour et al., 2018). Exceedingly hot and cold environments adversely affect beef cattle productivity and welfare. Therefore, thermal challenges in livestock production systems can cause serious economic loss if not properly managed (Milligan et al., 1974, Nienaber et al., 2007, St. Pierre, 2003). In addition, breed type largely influences the ability of an animal to thermoregulate themselves in certain environments, as Bos Indicus cattle have much higher tolerances to heat when compared to Bos Taurus cattle (Pereira et al., 2014). Different breeds have been developed to tackle specific environmental challenges, often combining multiple purebred lines to capitalize on their most advantageous traits, known as a composite breed. For example, the Beefmaster breed was developed in the early 1930s by Tom Lasater in South Texas to thrive in hot conditions and produce an adequate carcass (Lasater, 1981). Beefmaster cattle are a composite breed, combining Hereford, Shorthorn, and Brahman genetics, which makes them well-suited for harsh environments due to their hardiness, fertility, and milking ability (Ochsner et al., 2017). This breed's development highlights the importance of selecting cattle that can perform well under specific environmental conditions.

When cattle do not have to expend energy to maintain their normal body temperature, they are considered to be in their thermoneutral zone and the metabolic rate is minimal (Ames, 1980, Godyn et al., 2019). In this condition, there is no need to dissipate heat into the environment or generate endogenous heat, allowing for the allocation of available energy to maximize performance while maintaining thermal equilibrium (Medeiros dos Santos et al., 2021). However, animals may enter zones of critical temperature in times of extreme heat or extreme cold. As defined by Ames (1980), when the effective ambient temperature (EAT) requires an animal to increase its rate of heat production to maintain constant body temperature, the critical temperature is at the lower limit of the thermoneutral zone, known as the lower critical temperature (LCT). When an animal approaches the upper limit of the thermoneutral zone, known as the upper critical temperature (UCT), it must increase evaporative heat loss to maintain thermal balance. At this point, performance will decline as the effective ambient temperature continues to rise (Ames, 1980). Cattle exposed to the environment often experience lower critical temperatures and upper critical temperatures, resulting in effects on intake and maintenance requirements.

As global climate change is expected to alter temperatures, create variable precipitation patterns, increase atmospheric carbon dioxide levels, and affect water availability (Cheng et al., 2022, Seijang et al., 2015), a significant challenge is posed to the cattle industry. Climate changes alter the thermal environment of animals that could increase thermal stress and therefore affect animal health, production and efficiency (Seijang et al., 2105, St Pierre, 2003). Given that the feedlot industry utilizes a diverse range of nutritional inputs such as different feed types and supplements, as well as animal genetic makeup and observable characteristics across various geographies and climates (Drouillard, 2018), it is crucial to understand how feeder cattle interact with these environments to enhance the economic viability of livestock production systems.

Heat Stress

Heat stress occurs when an animal's body generates more heat than it can dissipate to its surroundings. When the ambient temperature increases and the UCT has reached its limit, cattle respond to heat stress through various physiological, behavioral, and biological mechanisms, which are influenced by multiple factors (Medeiros dos Santos et al., 2021). Periods of hot weather are known to be associated with reduced animal health, reduced reproductive efficiency and decreased feed conversion efficiency (St. Pierre et al., 2003). Heat stress in cattle impairs production due to reductions in immunity and changes in blood constituents and biological pathways (Abdelnour et al., 2018). As cattle experience heat stress, changes in energy and nutrient metabolism are occurring that affect their heat tolerance and production parameters such a lean tissue accretion (Madhusoodan et al., 2019). When body temperature rises, the hypothalamus-pituitary axis is activated, leading to increased water consumption, decreased dry matter intake, and subsequent weight loss (Kamal et al., 2018).

Heat stress can be divided into acute heat stress and chronic heat stress. Acute heat stress is when there is a rapid increase in ambient temperature, and the heat load associated with ambient air temperature, solar radiation and humidity exceeds the ability of the animal to dissipate excess heat from work and metabolism (Abdelnour et al., 2018, Hall et al., 2012). The result is an elevated core body temperature, elevated basal metabolism, and initiation of physiological acclimation responses that disrupt homeostasis and reduces production (Hall et al., 2012). In addition to several physiological responses, short term behavioral responses such as reduced feed intake and decreased milk production are likely (Potts, 2017).

Chronic heat stress is when the ambient temperature increases for a long period of time, which allows for environmental acclimation (Abdelnour et al., 2018). Chronic heat stress can impair growth rates, reduce fertility rates, cause irregular estrous cycles, increase embryonic loss, compromise the immune system and therefore increase susceptibility to disease, and lead to long-term reductions in productivity that affects both meat and milk production (Kelley et al., 1982, Moriel et al., 2024, Pinto et al., 2020, Rincker & Meeter, 2023). Regardless, both types of heat stress trigger thermoregulatory mechanisms and stimulate the depression of immune and endocrine functions, changes in blood amino acids, reductions in cellular energy bioavailability, and several other physiochemical responses that negatively impact animal welfare and productivity (Abdelnour et al., 2018, Medeiros dos Santos et al., 2019).

Mitigation strategies against heat stress include drinking more water, increasing respiration, increasing sweating, and seeking shade (Lees et al., 2019). Shade reduces radiant heat gain, body heat storage, and evaporative cooling through panting and sweating (Brown-Brandl et al., 2005, Sullivan et al., 2011). Some studies have reported that providing shelter for animals may reduce their radiant heat load by 30% (Bond et al., 1967), reduce respiration rate at the peak of the day, and help maintain feed intake (Brown-Brandl et al., 2005). Feedlot cattle are especially vulnerable to heat wave events, which are periods of abnormally hot weather lasting more than two days (Lees et al., 2019). These events can significantly increase the risk of heat stress due to the varying designs of feedlot facilities and the inconsistent provision of shade. During heat waves, the effectiveness of mitigation strategies becomes even more critical to prevent severe health impacts and maintain productivity (Lees et al., 2019, Brown-Brandl et al., 2005).

A 2017 survey of feedlots in the High Plains region of the United States (TX, OK, NM, CO, KS, NE) reported only 17% of feedlots provide shade in feeding pens (Simroth et al., 2017).

It is widely recognized that providing shade has beneficial effects on cattle welfare and productivity. However, some studies have provided inconsistent results of providing shade in hot weather, with reduction in direct and indirect losses in some areas of the United States but not in others (Brown-Brandl et al., 2005). These inconsistencies may be attributed to geographical differences, such as variations in climate and humidity levels between the southern and northern regions. In the southern regions, higher humidity levels can exacerbate heat stress, making shade more beneficial, whereas in the northern regions, cooler temperatures and lower humidity may reduce the necessity for shade (Guo et al., 2024, Narayanan et al., 2025). Additionally, differences in feedlot design, construction materials, and the availability of natural versus artificial shade structures can also impact the effectiveness of shade provision (Edwards-Callaway et al., 2021).

This leads to uncertainty on the economic return of shade implementation. Some studies have found that through the reduction of heat stress that shade provides, feedlot profitability increases (Blaine & Nsahlai, 2011). Others have reported that while cattle showed a slight improvement in performance, the differences in weight gain and feed intake were not statistically significant (Hayes et al., 2017). A 2023 study (Maia et al., 2023) proposed a novel shade design to optimize shade coverage within feedlot pens that aims to motivate cattle to seek shade, protect them from solar radiation, and withstand adverse weather conditions. The study reported that cattle in shaded pens experienced a reduction in heat stress and improved performance. Additionally, the shade structure proved to be economically viable with the expected payback period to be within four finishing cycles (~110 days per cycle) (Maia et al., 2023).

In addition to the lack of shade, feedlot cattle are particularly more susceptible to heat stress as they are fed high-concentrate diets that lead to a significant heat increment in their bodies (Idris, 2021). Metabolic heat produced during microbial fermentation accounts for 3 to 8% of the total heat production (Beatty et al., 2008). Moreover, a substantial portion of cattle are subjected to extreme heat. In 2023, 80% of cattle worldwide experienced conditions that surpassed the median threshold temperature-humidity index (THI) of 68.8 (95% CI: 67.3 – 70.7) for a minimum of 30 days annually (North et al., 2023). Combinations of high direct and indirect solar radiation, high ambient temperatures, humidity, and wind speed beyond the ability of animals to thermoregulate all contribute to heat stress in domesticated livestock (Silanikove, 2000). Understanding the impact of hot environmental conditions is increasingly critical due to the changing global environment, particularly because climate change has the potential to alter the thermal environment. These changing climatic conditions ultimately impact the welfare and productivity of cattle (Lees et al., 2019).

Heat stress significantly impacts the morbidity and mortality of beef cattle (Chauhan et al., 2023). When exposed to high temperatures, cattle experience physiological stress that can lead to severe health issues, including heat exhaustion and heat stroke. These conditions can increase the risk of mortality, particularly during prolonged heat waves (Santos et al., 2021). Studies have shown that heat stress can lead to increased mortality rates in beef cattle, with a 1°C increase above the hot threshold associated with a 5% increase in mortality risk (Morignat et al., 2015). Additionally, heat stress compromises the immune system, making cattle more susceptible to diseases, which further contributes to morbidity and mortality (Chauhan et al., 2023). Furthermore, decreased cattle productivity leads to lower profitability and diminished sustainability. St. Pierre & colleagues (2003) estimated an economic burden of between $1.69 and $2.36 billion (USD) on U.S. animal agricultural industries due to heat stress, with $370 million of that economic burden estimated for the beef industry.

While cattle are responding to heat stress using a variety of mitigation strategies and physiological responses, a negative effect on gain and carcass quality is likely (Neinaber, 2007). In growing and finishing beef cattle, heat stress reduces weight gain, fat gain and carcass yield, ultimately affecting other meat attributes such as quality and tenderness (Wankar et al., 2024). Bunning & Wall (2022) investigated how minimum and maximum temperatures affected carcass traits and growth rates in beef cattle, where data from over 1.6 million slaughter records across the UK were analyzed. The authors reported a higher daily maximum temperature was associated with slower calf growth rates and subsequently smaller carcasses, and the frequency of extreme weather events (i.e. heatwaves, cold waves, dry and wet days) had significant effects on almost all traits considered. Poor growth rates, average daily carcass gain, carcass weight and 200-day weight gain were reported in heat stress beef calves, while the age at slaughter and production costs increased significantly (Bunning & Wall, 2022).

Despite differing management techniques or cattle mitigation strategies to manage heat stress, cattle often succumb to heat load during prolonged heat wave events where there is limited nighttime relief (Mader, 2003). There are several reports of thousands of cattle succumbing to heat waves across the globe over the last 30 years due to large metabolic and environmental heat loads, high relative humidity, limited air movement, and high overnight ambient temperatures (Lees et al., 2019). In 2017, upwards of 6,000 dairy cows died in three counties in California, USA, during a heat wave (Lees et al., 2019), and in 2022 an estimated

10,000 feedlot cattle died in Kansas, USA, due to the lack of nighttime cooling (DTN, 2022). Heat stress remains a significant challenge in our current livestock production systems, highlighting the ongoing vulnerability of cattle to extreme weather conditions.

Cold Stress

Historically, livestock in North America have been raised in regions where average winter temperatures fall below 0°C (Young, 1981). Even today, millions of livestock are still raised in these environments (USDA, 2017). However, as cattle are exposed to cold weather their energy expenditures increase to maintain a stable internal body temperature (Webster, 1971). During cold stress events, cattle rely on reserves of food energy to maintain homeothermy, in lieu of synthesis of meat or milk (Webster, 1971) making the impacts of cold environments on beef cattle welfare and productivity essential to understand. Cold temperatures, particularly at northern latitudes, cause stress to cattle, inhibiting both the gain and performance of steers wintering at feedlots (Milligan & Christison, 2011).

Cattle respond to cold stress through various adaptive changes that alter their physiological, behavioral, and biological mechanisms. The combination of metabolic heat production and behavioral and physiological adaptations, such as seeking wind shelter and growing a thicker coat, enables cattle to maintain their core body temperature with minimal impact on nutrient requirements (Wagner, 1988). However, when the lower critical temperature (LCT) is reached as the ambient temperature decreases, the animal's thermoregulatory system is activated to retain body heat and/or produce endogenous heat (Medeiros dos Santos et al., 2021). The production of endogenous heat is achieved by increasing feed intake to generate metabolic heat through the breakdown of nutrients in the digestive system (Medeiros dos Santos et al., 2021). Due to the substantial amount of dietary energy that is diverted from productive functions to the generation of body heat (Young, 1983), a direct impact is seen in decreased body weight and gain, leading to significant impacts on metabolic processes, reduced digestive efficiency and cattle growth (Wang et al., 2023).

Extreme weather swings, such as a sudden decrease in temperature, pose significant challenges to cattle welfare and productivity. A sudden drop in temperatures can cause severe stress to cattle, especially if they are not acclimated to the cold (Rusche & Walker, 2021). During extreme cold fronts, cattle experience increased metabolic rates as they expend more energy to maintain their body temperature. This heightened energy demand can lead to weight loss and decreased body condition if not adequately managed (Penn State Extension, 2023). With prolonged exposure, physiological adaptations occur such as alterations in digestive functions, increasing thermal insulation, increasing appetite and increasing basal metabolic intensity (Young, 1983).

Research has shown that effects of winter cold are compounded in regions with drastic and unpredictable seasonal temperature variation—such as intermountain grassland regions and semi-arid deserts—as cattle undergo hormonal and adaptive behaviors that lead to an increased energy requirement and reduced digestive efficiency (Young, 1981). In Northern Montana, where daily and seasonal temperature swings are common, these effects are particularly pronounced. The USDA defines temperature variation in this context as fluctuations that push cattle outside their thermoneutral zone, requiring them to expend additional energy to maintain core body temperature (USDA NRCS, 1997). Hormonal responses, including increased secretion of thyroid hormones (T3 and T4), can begin within 24 to 48 hours of exposure to cold stress, initiating a rise in metabolic rate and energy demand (Bhimte et al., 2018). Full physiological adaptation—such as changes in coat thickness, feed intake, and behavior—typically develops over several weeks, depending on the severity and duration of the cold exposure (Gaughan et al., 2019).

A 2023 study (Wang et al., 2023) investigated the effects of long-term cold stress in Simmental crossbred bulls. The study reported that long-term cold stress increased dry matter intake, yet a reduction was seen in body weight and average daily gain. In addition, cold stress altered physiological behaviors such as increased lying time and effects on various blood biochemical parameters and hormone levels, indicating significant impacts on cattle growth and metabolic processes (Wang et al., 2023).

Cold stress poses significant challenges to the welfare of beef cattle. Cold stress can cause frostbite, particularly affecting extremities such as ears, tails, and feet (Kim et al., 2023). Prolonged exposure to extreme cold can lead to significant health issues, including respiratory problems and weakened immune systems, making cattle more vulnerable to diseases (UNL Beef, 2024). Cold stress in cattle can significantly impact both mortality and morbidity rates, as the energy diversion to maintain core body temperature can weaken their immune systems, making them more susceptible to diseases and infections (Kim et al., 2023). Consequently, morbidity rates increase as cattle experience higher incidences of respiratory illnesses, frostbite, and other cold-related health issues. In severe cases, prolonged exposure to cold stress without adequate shelter, nutrition, and care can result in increased mortality rates (Debnath et al., 2024).

Kim and colleagues (2023) investigated the impacts of cold stress on beef cattle at various stages of growth. Steers and calves reported to have increased heart rate and rectal temperature under extreme cold stress, elevated cortisol with decreased glucose levels in calves, and altered feeding behaviors. Animals will increase their metabolic scale to increase heat production as a direct effort to maintain their core body temperature (Tarr, 2013), thus increasing their energy demand for dietary energy. Diet digestibility in ruminants decreases by 0.2% for every degree below 20°C (Kennedy et al., 1986). For every 1°C decline below the lower critical temperature there is roughly a 2% rise in energy requirement (Tarr, 2013). It is recommended that an increase in energy and protein content in the feed is beneficial during the cold climatic conditions (Manzoor et al., 2019). As feed already accounts for 70% of costs for producers, and the consequences of metabolic cold adaptation can result in a 30 to 70% feed requirement increase (Scasta, 2021), understanding the relationship between beef cattle gain and the weather patterns of the environment is paramount. In addition, recent droughts in the Northwestern regions of the United States have resulted in a substantial decrease in hay production and an increase in commodity prices further impacting the bottom line (Milligan & Christison, 2011).

The economic impact of increased feed requirements due to cold stress can significantly strain producers, necessitating additional resources to maintain cattle health during extreme weather conditions (Penn State Extension, 2023). Furthermore, managing cold stress effectively can mitigate the environmental footprint of beef production by reducing resource use, such as water and energy, to keep cattle warm (SDSU Extension, 2021). Effective management practices, including providing adequate shelter, windbreaks, and nutritional support, are essential to ensure the well-being of the herd and minimize the adverse effects of cold stress (Kim et al., 2023).

Solar Radiation in Relation to Coat Color

As defined by the National Academies of Sciences, Engineering, and Medicine (NASEM) , thermal radiation may be received by an animal from two primary sources; solar radiation and terrestrial or long-wave radiation. Solar radiation is either direct or reflected from clouds and surrounding surfaces and has been reported to have a direct influence on ambient temperature (Brosch et al., 1998) and strongly contributes to the thermal balance of cattle exposed to cold temperatures and high winds (Keren & Olson, 2006). Direct solar radiation is also an important heat source for cattle, and when in sunlight may have a net gain of heat by thermal radiation, resulting in an EAT of 3 to 5 degrees Celsius (NASEM, 1981). In sun-exposed animals, heat from solar radiation substitutes for heat produced in metabolism in the makeup of total heat loss (Webster, 1971). When animals are exposed to solar radiation in excess, there will be an effect on the rate of heat exchange and indirectly affect the critical temperatures (NASEM, 1981). It has been reported that cattle will alter their behavior in times of extreme cold weather and spend more time standing to maximize heat gain from solar radiation instead of lying down (Olson & Wallander, 2002).

Surface temperature of cattle is affected by solar radiation and is a good indicator of thermal stress response. As body surface temperature increases, peripheral vasodilation occurs, which facilitates heat dissipation to the environment (Medeiros dos Santos et al., 2019). Brown-Brandl & colleagues (2010) reported that animals exposed to direct solar radiation had a higher surface temperature than those in the shade whose lower surface temperature ultimately led to lower daily stress. This relationship between surface temperature and solar radiation is closely linked to the concept of albedo.

Albedo is defined as the tendency of a surface to reflect sunlight based on its color, with darker surfaces having a greater tendency to absorb more heat from solar radiation than light-colored surfaces (Coakley, 2003). McManus & colleagues (2011) investigated the use of multivariate analyses for determining heat tolerance in Brazilian cattle, and reported that traits such as coat reflectance, hair length, and the number of hairs per unit area were found to be crucial in explaining physiological responses to heat stress. The highest correlations were generally found with coat reflectance, showing that coat color is the first important means of defense against radiation. This is evident as dark-coated animals acquire more heat load from solar radiation and are therefore generally considered less suitable for tropical environments than light-coated animals. Research has shown that solar radiation directly affects the surface that an animal has contact with and the temperature of the animal in dark hided cattle (Mader et al., 2006). Brown-Brandl & colleagues (2010) reported a significant variation in dorsal surface temperature between black, dark red, tan and white hided cattle, in which animals with a darker coat had higher dorsal surface temperature when exposed to the sun and absorbed more radiation. A more recent study by Lima & colleagues (2020) found a similar pattern, where the animals with a darker coat color exhibited lower solar radiation reflectance and higher dorsal surface temperatures among cattle whose coat color ranged from light to dark red. A study done on coat characteristics in different colored sheep reported that coat color presented a direct influence on the hair structure and the activation mechanisms related to thermoregulation (Leite et al., 2020).

A recent study was conducted in Wyoming to measure variation of albedo and how it is related to hide color on high-elevation rangeland cows. Scasta (2021) took several photos of 2nd trimester rangeland cows and used pixel analysis to calculate the brightness of specific cow hide colors. Individual cattle's surface temperature was measured using an infrared high temperature thermometer and a handheld weather meter, over the course of the winter months. The temperatures were taken at multiple times throughout the day to capture variations in thermal stress experienced by the cows. The results suggested that black cattle may suffer more thermal stress in the summer while white cattle may suffer more thermal stress in the winter due to their significant variation in abilities to absorb and reflect solar radiation. This work may also suggest that such contrasting traits may have implications for selecting black cattle for colder high–altitude and high-latitude environments and white cattle for warmer, more tropical environments. Scasta concluded that understanding solar radiation and hide color interactions has implications for optimizing cattle selection and may enhance the performance of growing cattle such as yearling steers or heifers (Scasta, 2021). This study shows how cows hide color influences the amount of solar radiation, and that black and red cows experience higher surface temperatures compared to white hided cows.

Da Silva & colleagues (2003) investigated how different radiative properties of the skin and haircoat affect heat regulation in various animals, including various types of cattle breeds. They reported that white hairs have a higher reflectance compared to other coat colors, with approximately 60-67% of solar radiation being reflected back into the environment. They also noted that the reflectance of the light-colored hairs is influenced by the absorptance of the underlying skin, with non-pigmented skins present lower reflectance values compared to light gray skins (Da Silva et al., 2003). Other studies have assessed this in different livestock species and have reported similar results. McManus & colleagues (2008) investigated the effect of climate on physiological and blood parameters in sheep with brown, black, and white coats. The study involved thirty Santa Ines adult, non-lactating, non-pregnant ewes, with ten sheep each having brown, black, and white coats. The researchers measured various parameters, including sweating rate, heart rate, breathing rate, rectal and skin temperatures, and complete hemogram. The measurements were taken at two different times of the day, 0600 and 1400, over six days. The results indicated that light-colored coats help reflect 50 to 60% of direct solar radiation compared to dark-colored animals. White-coated sheep showed lower heart rates, breathing rates, and rectal temperatures, particularly in the afternoon when solar radiation is more intense. These findings suggest that coat color significantly influences the thermal stress experienced by sheep, with light-colored coats providing better adaptation to hot climates by reflecting more solar radiation.

Coat color and albedo are critical in livestock production systems due to their impact on heat stress and associated mortality rates. In 1995, 13 counties in Iowa experienced high temperatures, high humidity and no wind that resulted in a loss of 3,750 feedlot cattle. A survey of 36 producers was conducted, where reports were made of a disproportionately higher death loss in dark-hided cattle. Out of 36 producers, 30 reported a higher death loss in black cattle. The remaining six producers, did not have black cattle on feed, indicated a higher death loss in red cattle. Additionally, one producer noted that although only 20% of their cattle were black, these black cattle accounted for 80% of the death loss (Busby & Loy, 1996).

Coat length, thickness and hair density also greatly affect an animal's adaptive ability to thermoregulate and are particularly important in times of thermal stress (Da Silva 2003, Gebremedhin et al., 2008, Madhusoodan et al., 2019). Thicker coats and increased subcutaneous fat deposition insulate the body core temperature, which ultimately increases heat stress in the summer season but may be helpful in the colder seasons. The effect of wind on heat loss depends on the external insulation provided by the haircoat (Webster, 1971). Short hair, thin skin and fewer hair follicles per unit area are directly linked to the higher adaptive capacity to hotter climates (Madhusoodan et al., 2019). These characteristics, as mentioned earlier, are adaptations of the Bos indicus breeds that make them more well-suited for heat tolerance.

Hair coat type is a multifactorial trait that varies between breed type and environmental conditions and greatly impacts cattle's ability to thermoregulate themselves in various types of weather. A newly discovered genetic mutation, known as the slick coat gene (SLICK), enables cattle to better tolerate heat by producing short, smooth hair coats that significantly improve heat tolerance (Porto-Neto et al., 2018). This gene could have significant impacts on livestock production systems as producers may be able to use this to better match cattle to their production systems. Specifically, the SLICK gene could allow producers to use cattle that are not traditionally adapted to hot environments, such as dark-hided cattle, in regions with higher temperatures. Although much is known about the SLICK gene, ongoing research is needed to determine the thermotolerance benefits, long term effects, impact on cold tolerance, gene interaction and any other unintended or indirect risks related to animal welfare (Pozzebon et al., 2024).

In addition to this genomic discovery, the American Angus Association (AAA) introduced an expected progeny difference (EPD) for hair shedding in 2020 (AAA, 2020). Since hair shedding is a moderately heritable trait (Durbin et al., 2020), the purpose of this EPD to help identify cattle that shed their winter coat earlier in the spring, which may be an indicator of better heat tolerance and adaptability to hot environments. This would allow for cattle to allocate more energy towards growth and milk production, rather than thermoregulation (AAA, 2020). This EPD is relatively new, and ongoing research is still needed to refine the accuracy of the EPD, its implications in different environmental conditions, genetic correlations between hair shedding and other economically important traits, and long-term implications of selecting for hair shedding on overall herd health and productivity.

Potential Implications on Beef Cattle Selection with the Consideration of Coat Color

Historically, coat color has been used to identify genetic merit due to its ease of observation. Coat color significantly influences market preferences and perceptions, driven by breed reputation and consumer demand. However, an emphasis on selection of coat color can reduce genetic diversity if other important traits are overlooked. The genetic mechanisms underlying coat color variations and their associated traits require further exploration. More studies are necessary to quantify the economic impact of coat color on market value, feed efficiency, and overall profitability. Consumer preferences, particularly those of beef consumers and cattle buyers, for coat color must also be considered, as they influence cattle selection and breeding programs.

Coat color plays a significant role in the activation of thermoregulatory mechanisms as darker coats absorb more sunlight and lighter coats reflect more sunlight (Finch et. al, 1984). Understanding this relationship between solar radiation and coat coloration may have implications for optimizing cattle selection and may enhance the performance of growing cattle such as yearling steers or heifers (Scasta, 2021). For instance, a black hided animal may be a better selection for a colder high-altitude environment than a white hided animal due to its ability to better absorb heat from the sun. However, further research is needed on how these environmental interactions will affect overall cattle performance.

The incorporation of genetic tools, such as the SLICK gene and Hair Shedding EPD, may provide producers with the opportunity to improve their herds tolerance to extreme weather events, leading to better productivity and animal welfare. This is particularly beneficial as cattle from around the world are shipped to finishing locations in states like Iowa, Kansas, Texas, Oklahoma, and Colorado, where they undergo final stages of growth and preparation for market (USDA, 2025). As U.S. cattle production continues to be affected by climatic changes, incorporating Bos Indicus genetics into the U.S. beef herd presents a potential solution for mitigating heat stress (Okamoto et al., 2024). However, it is important to note that breed-specific effects may still influence carcass quality. Fuez & colleagues (2022) suggested that feedlots within relatively hotter climates may see benefits of using Bos Indicus influenced cattle as they have been shown to be more heat tolerant as compared to Bos Taurus cattle.

While considerable strides have been made in understanding the role of coat color in cattle production systems, there is a prominent need for further comprehension of hide color influence on cattle performance, which in turn impacts cattle selection for specific environments and production systems. Additionally, investigations into the impacts of important genes are crucial as we move towards more marker-assisted selection and the identification of specific genotypes of cattle. This approach can enhance the precision of breeding programs, leading to improved productivity and adaptability in various production systems.

Future Research Needs

To further understand the relationship between hide color and thermoregulation in cattle, several areas warrant additional investigation. While considerable advancements have been made in understanding beef cattle genetics, thermoregulation, feed efficiency, behavior, economic factors, and the application of advanced technologies, hide color remains a largely overlooked aspect in this research.

While some work has been done on the impact of hide color and heat tolerance, which can indirectly impact feed intake, further research is required to better understand the mechanisms responsible for variations in cattle feed efficiency and feed intake behavior. Yusuf & colleagues (2022) investigated how solar radiation and ambient temperature affect DMI in beef steers. They reported that with increasing temperature and reduction in solar radiation, DMI intake increased, which may be attributed to the interaction and influences between temperature and solar radiation. This may suggest a DMI decrease on sunny days with high temperatures, but a DMI increase on sunny days with extremely low temperatures. This would make sense as the energy requirements for maintenance of homeostasis in cattle increases in extreme cold weather. However, there is a scarcity of information on the effect of solar radiation in extremely cold weather conditions and DMI, thus further research is needed.

Due to the significant impact of heat stress on cattle productivity and welfare, especially in the context of climate variability, heat stress in feedlot cattle of Continental or heat tolerant breeds has been more extensively studied than cold stress. There is a definite need for more extensive research on cold stress in feedlot cattle, particularly those at northern latitudes and of Bos Taurus descent. While radiation heat transfer in animals has been extensively studied, further work is still needed to detect the effects of high environmental temperature on animal productivity in relation to hide color. Further research is necessary to evaluate how various hide colors influence cattle's thermoregulation and how hide and coat characteristics impact their heat tolerance. Ensuring cattle remain within their thermoneutral zone is crucial for maintaining their well-being and productivity.

Conclusion

The overall status of feeder cattle research is robust and continually evolving. Significant advancements have been made in areas such as feed efficiency, animal welfare, genetic selection, health management, and sustainability. Research has led to improvements in growth rates, feed conversion ratios, and carcass quality. However, hide color is infrequently considered when measuring all these factors in research. Historically, hide color has played a significant role in market perceptions and pricing, which has the potential to overshadow more critical performance traits. Some studies have emphasized the need to shift away from superficial traits like hide color and move to more objective genetic measures that better predict cattle performance and value (Garrick & Taylor, 2014, Saatchi et al., 2014, Van Eenennaam et al., 2012).

Nonetheless, there is a significant impact of environmental factors on beef cattle that can vary with hide color. Due to differences in heat absorption and thermoregulation, there is an importance to integrate genetic selection for traits such as hide color to enhance resilience and adaptability in different climates. Understanding these dynamics are essential for developing effective strategies to manage cattle in varying environmental conditions. There is a need for more comprehensive data encompassing various environmental and management conditions to better understand how hide color may indirectly affect feeder cattle performance and well-being.

CHAPTER TWO

HIDE COLOR INFLUENCE ON FEEDLOT STEER GROWTH, PERFORMANCE, AND CARCASS TRAITS

Introduction

The ability of cattle to maintain a stable internal environment despite external changes is essential for maintaining homeostasis, which is crucial for their health and productivity (Romero et al., 2017). Environmental conditions, such intense heat and cold, can greatly affect cattle by increasing energy demands to maintain thermal balance, leading to reduced performance. (Ames, 1980). Prolonged heat stress reduces feed intake, weight gain, and carcass quality (Cooke, 2017; Wankar et al., 2024), and extreme cold may cause increased metabolic rates, leading to weight loss and decreased body condition (Penn State Extension, 2023). These extreme environmental conditions additionally impact mortality and morbidity rates by weakening immune systems (Kim et al., 2023).

Solar radiation, whether direct or reflected, influences ambient temperature (Brosch et al., 1998) and plays a significant role in the thermal balance of cattle, especially under cold and windy conditions (Keren & Olson, 2006). It serves as a major heat source, potentially raising the effective ambient temperature (EAT) by 3 to 5°C in sun-exposed animals (NASEM, 1981). In such cases, solar heat can substitute for metabolic heat in total heat loss (Webster, 1971), but excessive exposure may disrupt heat exchange and alter critical temperature thresholds (NASEM, 1981).

Albedo, the reflectivity of a surface, plays a crucial role in how cattle absorb solar radiation, with darker coats absorbing more heat than lighter ones (Coakley, 2003). As a result black and red hided cattle exhibit higher surface temperatures than white hided cattle, which reflect more solar radiation (Leite et al., 2020; Da Silva et al., 2003). This difference is largely influenced by coat characteristics such as reflectance, hair length, and density, which are critical factors in heat tolerance and make coat color a primary defense against solar radiation (McManus et al., 2011). Because dark-coated cattle tend to accumulate more heat and are generally less suited to hot climates (Mader et al., 2006; Brown-Brandl et al., 2010; Lima et al., 2020), this raises concern in the U.S., where black hided Angus cattle represent nearly 75% of the national herd.

Despite the link between hide color and heat stress, information on cattle hide color and environmental response across temperature conditions is limited. This research aims to evaluate feeder cattle intake behavior, carcass characteristics, and surface temperature changes in response to environmental conditions and hide color. We hypothesize that dark-hided cattle are more susceptible to heat stress in warm conditions, while light-hided cattle are more vulnerable to cold stress in colder environments. Additionally, we propose that periods of thermal stress may negatively impact overall cattle performance.

Materials and Methods

Experimental design and procedures were approved by the Agriculture Animal Care and Use Committee of Montana State University (#2022-267-AA). Research was conducted at the Northern Agricultural Research Center in Havre, Montana, USA (48.5500°N, 109.6841°W) over the course of 2 years: 2023 (Study 1) and 2024 (Study 2), each lasting 140 days from February to July. The 140 days were divided into five 28-day periods for analysis: Period 1 (day 0 to day 28), Period 2 (day 29 to day 56), Period 3 (day 57 to day 84), Period 4 (day 85 to day 112), and Period 5 (day 113 to day 140). All procedures were consistent across both study durations. Unless otherwise specified, the Materials and Methods described apply uniformly to both studies.

To test the role that hide color and environment play on cattle performance and carcass characteristics, cattle of varying hide colors were used in a 140-day feedlot trial conducted over two years. Steers were chosen for the experiment based on uniformity in weight, age, and hide color. Treatments were Red hided, Red Angus steers (REDANG), Black hided, Angus steers (BLKANG), White Hided steers (Charolais sires bred to Angus cows; CHARANG), and Black hided steers (Simmental sires bred to Angus cows; SIMANG). Animals utilized in this study were sourced from the Northern Agricultural Research Center and the Red Angus cattle from a collaborator’s herd located in Northern Montana near NARC. The Black Angus White Charolais crossbred cattle featured entirely white coats. Black hided Angus steers were included as a control group. The inclusion of the Angus crosses helped reduce the genetic variability between different breed types while exhibiting the desired hide color for this study.

Steers chosen for this study were comparable in weight (409.28±8.33 kg in Study 1; 404.95±12.73 kg in Study 2) and were approximately of one year of age. Cattle were weaned each year in early fall and background by grazing forages until entry into the feed yard. Cattle were adapted to high concentrate diets in the feedyard and were on full feed starting on Day 1 for both studies. Prior to the study, steers were implanted with a Synovex One Feedlot Implant (Zoetis, Parsippany-Troy Hills, NJ, USA).

Study 1

Forty Angus-based yearling steers (409.28±8.33 kg) were stratified by weight and hide color (*n*=10 REDANG, *n*=10 BLKANG, and *n*=10 SIMANG, *n*=10 CHARANG) and randomly assigned to ten pens, following a randomized design. Each pen measured 47.6 square meters and contained four steers: one of each treatment.

Steers were fitted with electronic identification ear tags and were adapted to the Vytelle system (Vytelle, Lenexa, KS, USA) for 14 days prior to the start of the study. Each pen had two electronic feed bunks equipped with antennas to detect animal presence, neck bars that allowed only one animal to eat at a time, load cells to measure feed disappearance, and wireless transfer to a data-acquisition computer. Twenty Vytelle electronic feed bunks (one per two steers) were used.

Steers were fed daily at approximately 0900 hours. Feed bunks were inspected daily before feeding and the amount of feed was adjusted daily using a slick bunk management system. The order in which the pens were fed was alternated to ensure that no pen was consistently fed first or last. When clean bunks were present for two consecutive days, feed was increased by 0.23 kg per head. Feed was not increased two days in a row. Any large amounts of feed refused were weighed and removed from the bunk. Any spoiled or wet feed was weighed, sampled, and removed from the bunk. All animals had ad libitum water access for the entirety of the trial.

Steers received a finishing diet consisting of 69% corn, 21% corn silage, 10% wheat straw on a dry matter (DM) basis, and 0.45 kg per head per day of a medicated pellet with a fortified mineral and vitamin package (Table 2.1). The diets were formulated to meet the expected 1.36 to 1.81 kg of average daily gain (ADG) based on the recommendation of the National Academies of Sciences, Engineering, and Medicine (NASEM, 2016). Diet samples were collected weekly for the entirety of the study for nutrient analysis. The wet weight of each sample was recorded immediately after the sample was taken and then dried in a Thermo Fisher Scientific Heratherm™ oven (model 51028112) at 55°C for 48 hours. After drying, the samples were allowed to cool to room temperature, and the dry weight was recorded. The samples were then returned to the oven at 55°C for an additional hour. A second dry weight was recorded to ensure consistency. If a significant difference was observed between the first and second dry weights, the drying process was repeated until consistent weights were obtained. The dried samples were subsequently sent to Dairy One for basic nutrient analysis.

Table 2.1. Nutrient composition of finishing diet in Study 1, conducted at [1]NARC in 2023

Chemical Composition	-
Moisture, %	8.82
Dry Matter, %	91.18
Crude Protein, %	8.50
Adjusted Crude Protein, %	8.50
Acid detergent fiber, %	11.02
Neutral detergent fiber,%	18.94
Total digestible nutrients, %	75.00
Net energy maintenance, Mcal/kg	1.71
Net energy gain, Mcal/kg	1.20

[1] NARC: Northern Agricultural Research Center, Havre, Montana, USA.
All nutrient values are presented on a dry matter basis to ensure consistency in comparison.

Initial and final unshrunk steer weights were obtained on two consecutive days and averaged. Every 28 days during the experiment, steers were weighed prior to feeding. Average daily gain (ADG), average daily intake per kg of body weight per day, and a feed efficiency ratio (kg weight gain: kg feed intake; G:F) were calculated for each steer.

A technician used the Syntek 200mm digital caliper to measure hair coat depth. Measurements were taken at five random locations on the left ribs, lumbar, and thoracic vertebrae at the time of weighing cattle every 28 days. The average coat depth was then calculated and recorded. Additionally, tag scores based on predefined criteria according to Iowa State University’s mud and manure scoring were taken at the time of weighing, on a scale of 1 to 5, with 1 being no tag and a clean hide and 5 being lumps of manure on hide continuously on the underbelly and side of the animal from front to rear (Doran, 2016). Animal surface temperature was recorded on the same day of each week for the entire 20 weeks of the trial using a FLIR

E5xt thermal imaging camera weekly at 0730 (pre-feeding) and 1330 (6 hours post-feeding). Measurements were taken from the center of the left shoulder while steers were in their pens to limit variation (Scasta, 2021). The thermal imaging camera was calibrated by FLIR systems prior to the study.

Steers were ultrasound scanned for longissimus muscle area and 12th rib back fat by a certified technician (Ultrasound Guidelines Council, Pleasantville, IA) on day 0 and day 84 of the study. Steers were scanned using an ExaGo (IMV imaging North America, Rochester, MN) with a 17 cm ultrasound probe.

After the 140-day study period, steers were transported to the Cargill slaughter plant in Fort Morgan, Colorado, USA, for harvesting and carcass measurements. After a 48-h chill at 4C, the following data were collected by a USDA grader: hot carcass weight (HCW), marbling score (MS), back fat thickness (BFT), kidney, pelvic, and heart fat (KPH), ribeye area (REA), USDA yield grade (USYG), and quality grade (QG). Percent yield grade (PYG) was calculated from these carcass measurements.

For the entire trial, an Onset HOBO U30-NRC Weather Station (Bourne, MA, USA) was installed near the feedlot and configured to record air temperature, wind speed, and wind chill every 10 minutes throughout the finishing period (Table 2.2). For each variable recorded by the weather station, the minimum, maximum, mean, and standard deviation were calculated and reported over the course of five 28-day periods. An official NOAH weather station at the Northern Agricultural Research Center collected data on precipitation events. Precipitation accumulation totals were reported for each period.

Table 2.2. Weather conditions recorded during Study 1, conducted at [1]NARC in 2023.

	28d Period				
	1	2	3	4	5
Temperature (°C)	-	-	-	-	-
Min.	-27.42	-17.15	-4.98	2.44	3.45
Max.	23.26	24.74	31.29	32.31	36.39
Mean	-7.93	0.67	11.51	18.41	19.57
[2]Sd	8.69	8.51	7.54	5.27	6.72
Wind speed (ms)	-	-	-	-	-
Min.	0.00	0.00	0.00	0.00	0.00
Max.	9.60	9.10	9.10	8.60	7.00
Mean	2.15	1.61	2.05	1.24	1.69
Sd	1.96	1.45	1.82	1.16	1.29
Wind Chill (°C)	-	-	-	-	-
Min.	-35.07	-21.97	-9.51	1.56	1.11
Max.	27.58	24.38	32.56	33.20	37.70
Mean	-9.41	0.43	11.39	19.47	19.53
Sd	12.32	9.98	8.23	5.42	7.13
[3]Precipitation (mm)	340.11	39.88	71.63	82.30	13.46

[1] NARC: Northern Agricultural Research Center, Havre, Montana, USA.

[2] Sd: Standard deviation.

[3] Total precipitation recorded for each period for the 140-d trial.

Minimum, maximum, and mean temperatures (°C), wind speed (ms), and wind chill (°C) recorded during each period.

Study 2

Forty-seven Angus-based yearling steers (404.95±12.73 kg) were stratified by weight and hide color, then randomly assigned within strata to one of the four treatment groups: (*n*=11 REDANG; *n*=12 BLKANG; *n*=12 SIMANG; *n*=12 CHARANG). These steers were distributed among twelve pens, following a randomized design. Each pen measured 47.6 square meters, with each pen containing four steers of a single treatment (either REDANG, BLKANG, SIMANG, OR CHARANG), with the exception if one pen only containing three REDANG steers due to one Red hided, Red Angus steer being removed from the study early on due to injury. Study 2's design was altered to reduce the impacts of perceived breed dynamics and social dominances observed in Study 1's design.

All animal handling, feeding protocols, and data collection procedures—including adaptation to the Vytelle system, diet formulation, feed intake monitoring, performance metrics (ADG, G:F), ultrasound scanning, coat depth and tag scoring, thermal imaging, and carcass evaluation—were conducted as described in Study 1. A total of 24 Vytelle feed bunks (1 per 2 steers) were used.

Steers received the same finishing diet as in Study 1, with minor differences in nutrient composition (Table 2.3). Weekly diet sampling and analysis followed identical procedures. Feeding behavior data were extracted from the Vytelle system, including daily dry matter intake (DMI), eating rate (g/min), time spent eating (min/day), and intake variation (CV%).

Table 2.3. Nutrient composition of finishing diet in Study 2, conducted at [1]NARC in 2024.

Chemical Composition	-
Moisture, %	7.02
Dry matter, %	93.00
Crude protein, %	9.28
Adjusted crude protein, %	9.28
Acid detergent fiber, %	11.12
Neutral detergent fiber, %	19.48
Total digestible nutrients, %	80.40
Net energy maintenance, Mcal/kg	1.99
Net energy gain, Mcal/kg	1.34

[1]NARC: Northern Agricultural Research Center, Havre, Montana, USA.
All nutrient values are presented on a dry matter basis to ensure consistency in comparison.

Environmental conditions were monitored using the same Onset HOBO U30-NRC Weather Station as in Study 1. Weather data, including temperature, wind speed, wind chill, and precipitation, were recorded throughout the trial (Table 2.4).

Table 2.4. Weather conditions recorded during Study 2, conducted at [1]NARC in 2024.

	28d Period				
	1	2	3	4	5
Temperature (°C)	-	-	-	-	-
Min	-23.09	-12.51	-8.65	1.11	4.35
Max	17.34	22.81	24.85	30.38	35.53
Mean	-4.00	2.32	8.69	13.37	16.87
[2]Sd	8.79	6.89	6.78	5.81	6.23
Wind speed (ms)	-	-	-	-	-
Min	0.00	0.00	0.00	0.00	0.00
max	9.10	7.00	9.60	10.60	9.60
Mean	0.60	1.67	2.09	1.84	2.01
Sd	1.28	1.61	1.78	1.68	1.77
Wind Chill (°C)	-	-	-	-	-
Min	-28.02	-16.43	-11.01	-4.35	1.32
Max	23.90	26.19	28.35	32.00	36.28
Mean	5.70	2.91	7.66	12.84	16.84
Sd	11.07	10.51	8.55	7.23	6.71
[3]Precipitation (mm)	13.46	58.93	9.65	105.41	63.75

[1] NARC: Northern Agricultural Research Center, Havre, Montana, USA.
[2] Sd: Standard deviation.
[3] Total precipitation recorded for each period for the 140-d trial.
Minimum, maximum, and mean temperatures (°C), wind speed (ms), and wind chill (°C) recorded during each period.

After 140 days, steers were harvested at the same commercial facility as in Study 1. Carcass data were collected by a USDA grader following identical protocols.

Statistical Analysis

For both studies, to evaluate the effects of hide color on performance metrics, we used generalized linear mixed models including steer hide color, period of the trial, and their interaction as fixed effects and steer and pen as random intercepts. Individual steer was used as a random intercept to account for autocorrelation of multiple measurements for each individual. Carcass characteristics were also analyzed using generalized linear mixed models including steer hide color as fixed effect and pen as random intercept. Individual steer was considered the experimental unit. An $\alpha \leq 0.05$ was considered significant, with a tendency considered at $\alpha > 0.05$ and ≤ 0.10. The Tukey Method was used to separate means when α was less than 0.05. All statistical procedures were conducted in R (R Core Team, 2017).

Results

Study 1

There was a difference in initial body weight (*P*<0.01), however this was limited to REDANG being on average 35.66 kg lighter than BLKANG (*P*<0.01). There was no effect of treatment on overall ADG (*P*=0.57), which averaged 1.34 kg per day. However, Period 5 had significantly lower ADG compared to all other periods (*P*<0.01). Period 5 also exhibited lower G:F compared to all other periods (*P*<0.01). While treatment effects on G:F showed a tendency (*P*=0.08), post hoc analysis revealed no significant differences across treatments (*P*≥0.94) (Table 2.5).

Table 2.5. Performance metrics of steers in Study 1, conducted at [1]NARC in 2023

	[2]**Treatment**					***p*-Value**		
	BLKANG	SIMANG	REDANG	CHARANG	[3]SE	Treatment	Period	[4]Tx by Period
Initial wt, kg	428.24^{a}	410.84^{ab}	392.58^{b}	407.10^{ab}	8.33	<0.01	-	-
Final wt, kg	612.82	586.29	596.02	591.60	15.19	0.55	-	-
[5]ADG, kg	-	-	-	-	0.17	0.57	<0.01	0.83
Period 1	1.26	1.55	1.51	1.50	-	-	-	-
Period 2	1.50	1.33	1.41	1.33	-	-	-	-
Period 3	1.44	1.16	1.66	1.42	-	-	-	-
Period 4	1.69	1.59	1.63	1.50	-	-	-	-
Period 5	0.78	0.83	0.84	0.79	-	-	-	-
[6]G:F	-	-	-	-	0.02	0.08	<0.01	0.60
Period 1	0.10	0.15	0.14	0.15	-	-	-	-
Period 2	0.14	0.12	0.13	0.12	-	-	-	-
Period 3	0.13	0.11	0.14	0.13	-	-	-	-
Period 4	0.15	0.14	0.14	0.13	-	-	-	-
Period 5	0.07	0.08	0.07	0.07	-	-	-	-

[1] NARC: Northern Agricultural Research Center, Havre, Montana, USA

[2] Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus; CHARANG: White hided, Charolais Angus.

[3] SE: Pooled standard error across all treatments.

[4] Tx by Period: Treatment by Period Interaction.

[5] ADG: Average Daily Gain, kg.

[6] G:F: Gain to Feed.

Superscripts (a, b, c) within rows indicate significant differences ($P < 0.05$) among treatments; values that lack a common superscript in a row are significantly different.

No treatment effect was observed on tag scores. However, a significant period effect was noted, with tag scores being highest in Period 1 ($P<0.01$) compared to all other periods, and lowest in Period 5 ($P<0.01$). Tag scores in all other periods did not differ significantly ($P\geq0.15$) (Table 2.6). There was no difference in hair depth between CHARANG and other treatments

($P \geq 0.26$), however, there was a significant Period effect ($P<0.01$) with the initial and Period 1 coat depths were the greatest (Table 2.7).

Table 2.6. [1]Tag scores across different treatment periods in Study 1, conducted at [2]NARC in 2023

	[3]Treatment					***p*-Value**		
	BLKANG	SIMANG	REDANG	CHARANG	[4]SE	Treatment	Period	[5]Tx by Period
	-	-	-	-	0.21	0.19	<0.01	0.37
Initial	2.75	2.61	2.35	2.50	-	-	-	-
Period 1	3.30	3.11	2.80	3.35	-	-	-	-
Period 2	2.47	2.48	2.30	3.10	-	-	-	-
Period 3	2.92	2.16	2.10	2.85	-	-	-	-
Period 4	2.47	2.25	1.80	2.50	-	-	-	-
Period 5	1.14	1.07	1.20	1.60	-	-	-	-

[1] Tag scores range from 1 to 5 based on mud and manure coverage, where 1 indicates minimal mud and manure and 5 indicates extensive coverage

[2] NARC: Northern Agricultural Research Center, Havre, Montana, USA.

[3] Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus; CHARANG: White hided, Charolais Angus.

[4] SE: Pooled standard errors across all treatments.

[5] Tx by Period: Treatment by Period Interaction.

Table 2.7. Coat depth measurements (mm) across different treatment periods in Study 1, conducted at [1]NARC in 2023

	[2]**Treatment**					***p*-Value**		
	BLKANG	SIMANG	REDANG	CHARANG	[3]SE	Treatment	Period	[4]Tx by Period
	-	-	-	-	1.93	0.11	<0.01	0.37
Initial	55.72	62.07	59.00	55.80	-	-	-	-
Period 1	50.86	54.60	48.83	53.80	-	-	-	-
Period 2	30.51	29.77	29.46	30.48	-	-	-	-
Period 3	25.13	28.67	26.40	26.02	-	-	-	-
Period 4	23.85	25.76	26.72	21.76	-	-	-	-
Period 5	22.05	23.76	22.04	24.86	-	-	-	-

[1]NARC: Northern Agricultural Research Center, Havre, Montana, USA.
[2]Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus; CHARANG: White hided, Charolais Angus.
[3]SE: Pooled standard errors across all treatments.
[4]Tx by Period: Treatment by Period Interaction.

There was a treatment effect (*P*=0.01) of hide color on cattle surface temperature, with BLKANG, SIMANG, and REDANG averaging 2.85°C higher than CHARANG. CHARANG were cooler than other treatments (*P*<0.01), with BLKANG, REDANG, and SIMANG all showing similar temperatures (*P*≥0.1). On average, CHARANG were 3.62°C cooler than steers of other colors. All periods differed significantly from each other (P<0.01), except for Periods 4 and 5 (*P*=0.43) (Table 2.8).

Table 2.8. Steer Surface Temperature (°C) across different treatment periods in Study 1, conducted at [1]NARC in 2023

	[2]Treatment					***p*-Value**		
	BLKANG	SIMANG	REDANG	CHARANG	[3]SE	Treatment	Period	[4]Tx by Period
	-	-	-	-	-	-	-	-
AM	-	-	-	-	1.08	0.32	<0.01	0.44
Period 1	2.35	2.95	4.13	1.38	-	-	-	-
Period 2	10.62	11.85	12.24	9.58	-	-	-	-
Period 3	18.83	18.32	17.97	16.67	-	-	-	-
Period 4	28.10	27.45	26.55	25.96	-	-	-	-
Period 5	32.26	33.40	29.55	28.11	-	-	-	-
PM	-	-	-	-	1.13	<0.01	<0.01	0.38
Period 1	17.02	17.19	16.28	10.85	-	-	-	-
Period 2	23.79	19.53	21.08	17.86	-	-	-	-
Period 3	28.30	27.60	27.98	25.42	-	-	-	-
Period 4	34.27	33.70	32.68	30.53	-	-	-	-
Period 5	36.11	35.78	32.76	31.93	-	-	-	-

[1]NARC: Northern Agricultural Research Center, Havre, Montana, USA.
[2]Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus; CHARANG: White hided, Charolais Angus.
[3]SE: Pooled standard errors across all treatments.
[4]Tx by Period: Treatment by Period Interaction.

Period effects on ribeye area (REA) were significant (*P*<0.01), with REA being lowest at the start of the trial compared to the midpoint and harvest (*P*<0.01), and showing a tendency for REA to be greater at harvest compared to the midpoint (*P*=0.08) (Table 2.9 and 2.10). Period effects on back fat thickness were also significant (*P*<0.01), with less thickness at the start compared to the midpoint and harvest (*P*<0.01), and no difference between the midpoint and harvest (*P*=0.96). There was a tendency for treatment effects on back fat thickness (*P*=0.07), with CHARANG having less back fat thickness than BLKANG and SIMANG (*P*≤0.05), and REDANG having less back fat thickness than BLKANG (*P*<0.01) (Table 2.9).

Table 2.9. Ribeye area and 12th rib fat among treatments in Study 1, conducted at [1]NARC in 2023

	[2]**Treatment**					***p*-Value**		
	BLKANG	SIMANG	REDANG	CHARANG	[3]SE	Treatment	Period	[4]Tx by Period
Ribeye area, cm²	-	-	-	-	1.88	0.18	<0.01	0.27
Start (Day 0)	74.69	71.77	71.15	68.71	-	-	-	-
Midpoint (Day 84)	83.12	83.43	82.11	81.20	-	-	-	-
Harvest (Day 140)	84.77	83.34	84.84	85.55	-	-	-	-
12th rib fat, cm	-	-	-	-	0.08	0.07	<0.01	0.18
Start (Day 0)	1.10	0.99	0.91	0.81	-	-	-	-
Midpoint (Day 84)	1.41	1.29	1.07	1.04	-	-	-	-
Harvest (Day 140)	1.51	1.25	1.06	0.94	-	-	-	-

[1] NARC: Northern Agricultural Research Center, Havre, Montana, USA.
[2] Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus; CHARANG: White hided, Charolais Angus.
[3] SE: Pooled standard errors across all treatments.
[4] Tx by Period: Treatment by Period Interaction.

There was no treatment effect on hot carcass weight (HCW) (*P*=0.42) or REA (*P*=0.83). BLKANG and SIMANG had greater marbling than CHARANG (*P*<0.01). BLKANG and SIMANG also tended to have greater marbling than REDANG (*P*≤0.08), while marbling did not differ between REDANG and CHARANG (*P*=0.80). BLKANG steers had greater 12th rib fat than CHARANG and REDANG (*P*≤0.01), but did not differ from SIMANG (*P*=0.02). SIMANG did not differ from CHARANG or REDANG (*P*≥0.11). BLKANG steers had greater yield grades than CHARANG (*P*=0.02) but did not differ from SIMANG (*P*=0.48). BLKANG tended to have greater yield grades than REDANG (*P*=0.07). Yield grades did not differ among SIMANG, REDANG, and CHARANG (*P*≥0.24) (Table 2.10).

Table 2.10. Carcass characteristics of steers at harvest in Study 1, conducted at [1]NARC in 2023.

	[2]Treatment					***p*-Value**
	BLKANG	SIMANG	REDANG	CHARANG	[3]SE	Treatment
Hot carcass weight, kg	371.61	349.75	349.04	350.99	11.08	0.42
Marbling	712.5^{a}	699.09^{a}	591.0^{ab}	551.0^{b}	31.72	< 0.01
12th rib fat, cm	1.53^{a}	1.25^{ab}	1.06^{b}	0.94^{b}	0.10	<0.01
Harvest ribeye area, cm²	85.08	83.34	84.84	85.55	1.85	0.83
Yield Grade	3.28^{a}	2.94^{ab}	2.66^{ab}	2.52^{b}	0.16	<0.01

[1] NARC: Northern Agricultural Center, Havre, Montana, USA.

[2] Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus; CHARANG: White hided, Charolais Angus.

[3] SE: Pooled standard errors across all treatments.

Based on USDA quality grade/marbling scores : 200-299 = traces; 300-399 = slight; 400-499 = small; 500-599 = modest; 600-699 = moderate. Calculated yield grade = 2.5 + (2.5 x adjusted fat thickness, 12th rib, inches) + (0.0038 x hot carcass weight, pounds) + (0.2 x percentage kidney, pelvic and heart fat) – (0.32 x ribeye area, square inches).

Superscripts (a, b, c) within rows indicate significant differences (*P* < 0.05) among treatments; values that lack a common superscript in a row are significantly different.

Study 2

There was no treatment effect on initial body weight (*P*=0.14). There was a treatment effect on ADG (P=0.02); however, post hoc means separation showed no significant differences in ADG (*P*≥0.24). ADG exhibited both treatment and period effects (*P*≤0.02), but no significant differences were found (*P*≥0.24). A period effect on ADG was observed (*P*<0.01), with Period 2 having the highest ADG (1.97 kg/day) compared to all other periods (*P*<0.01), and Period 3 having the lowest ADG (0.82 kg/day) compared to all other periods (*P*<0.01) (Table). An interaction between treatment and period was observed for G:F (*P*=0.02), where in Period 1, REDANG had greater G:F compared to BLKANG and SIMANG steers (*P*≤0.02), and CHARANG tended to have higher G:F than BLKANG (*P*=0.06). No treatment differences were noted in other periods (*P*≥0.20) (Table 2.11).

Table 2.11. Performance metrics of steers by treatment group in Study 2, conducted at [1]NARC in 2024

	[2]Treatment					***p*-Value**		
	BLKANG	SIMANG	REDANG	CHARANG	[3]SE$_{pooled}$	Treatment	Period	[4]Tx by Period
Initial weight, kg	427.20	407.54	386.30	398.75	12.73	0.14	-	-
Final weight, kg	632.77	612.41	611.46	600.76	14.82	0.48	-	-
[5]ADG, kg	-	-	-	-	0.12	0.02	<0.01	0.09
Period 1	1.42^{ab}	1.35^{a}	1.84^{b}	1.44^{ab}	-	-	-	-
Period 2	2.03^{a}	1.87^{a}	2.20^{a}	1.78^{a}	-	-	-	-
Period 3	0.95^{a}	0.72^{a}	0.82^{a}	0.79^{a}	-	-	-	-
Period 4	1.45^{a}	1.62^{a}	1.67^{a}	1.49^{a}	-	-	-	-
Period 5	1.47^{a}	1.68^{a}	1.50^{a}	1.75^{a}	-	-	-	-
[6]G:F	-	-	-	-	0.01	<0.01	<0.01	0.02
Period 1	0.12^{a}	0.13^{a}	0.17^{b}	0.15^{ab}	-	-	-	-
Period 2	0.16^{a}	0.16^{a}	0.19^{a}	0.17^{a}	-	-	-	-
Period 3	0.07^{a}	0.06^{a}	0.06^{a}	0.07^{a}	-	-	-	-
Period 4	0.11^{a}	0.14^{a}	0.12^{a}	0.13^{a}	-	-	-	-
Period 5	0.11^{a}	0.13^{a}	0.11^{a}	0.13^{a}	-	-	-	-

[1] NARC: Northern Agricultural Research Center, Havre, Montana, USA.

[2] Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus; CHARANG: White hided, Charolais Angus.

[3] SE$_{pooled}$: Pooled standard errors across all treatments.

[4] Tx by Period: Treatment by Period Interaction.

[5] ADG: Average Daily Gain.

[6] G:F: Gain to Feed.

Superscripts (a, b, c) within rows indicate significant differences ($P < 0.05$) among treatments; values that lack a common superscript in a row are significantly different.

A treatment by period interaction was observed for tag scores ($P \leq 0.01$). In Period 2, BLKANG steers had higher tag scores than SIMANG and REDANG ($P \leq 0.01$), but scores were similar to CHARANG ($P = 0.44$). No other treatment differences were observed across periods ($P \geq 0.21$) (Table 2.12).

Table 2.12. [1]Tag scores across different treatment periods in Study 2, conducted at [2]NARC in 2024

	[3]**Treatment**					**P value**		
	BLKANG	SIMANG	REDANG	CHARANG	[4]SE	Treatment	Period	[5]Tx by Period
	-	-	-	-	0.19	0.16	<0.01	<0.01
Initial	2.71^{a}	2.92^{a}	2.16^{a}	2.42^{a}	-	-	-	-
Period 1	2.08^{a}	1.67^{a}	1.53^{a}	1.96^{a}	-	-	-	-
Period 2	3.50^{a}	2.54^{b}	2.34^{b}	3.08^{ab}	-	-	-	-
Period 3	1.54^{a}	1.08^{a}	1.30^{a}	1.21^{a}	-	-	-	-
Period 4	1.67^{a}	1.54^{a}	1.43^{a}	1.92^{a}	-	-	-	-
Period 5	1.79^{a}	1.29^{a}	1.30^{a}	1.71^{a}	-	-	-	-

[1] Tag scores range from 1 to 5 based on mud and manure coverage, where 1 indicates minimal mud and manure and 5 indicates extensive coverage.

[2] NARC: Northern Agricultural Research Center, Havre, Montana, USA.

[3] Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus; CHARANG: White hided, Charolais Angus.

[4] SE_{pooled}: Pooled standard errors across all treatments.

[5] Tx by Period: Treatment by Period Interaction.

Superscripts (a, b, c) within rows indicate significant differences ($P < 0.05$) among treatments; values that lack a common superscript in a row are significantly different.

There was a treatment by period interaction in hair depth (*P*≤0.01), with REDANG having the longest hair length at 28 days (*P*≤0.02) with no differences recorded for other treatments (Table 2.13).

Table 2.13. Coat depth measurements (mm) across different treatment periods in Study 2, conducted at [1]NARC in 2024

	[2]Treatment					**P value**		
	BLKANG	SIMANG	REDANG	CHARANG	[3]SE	Treatment	Period	[4]Tx by Period
	-	-	-	-	2.38	<0.01	<0.01	<0.01
Initial	55.88^{a}	53.53^{a}	56.75^{a}	56.72^{a}	-	-	-	-
Period 1	48.90^{a}	47.32^{a}	59.15b^{b}	44.17^{a}	-	-	-	-
Period 2	30.16^{a}	33.12^{a}	34.61^{a}	33.86^{a}	-	-	-	-
Period 3	34.09^{a}	34.19^{a}	33.13^{a}	33.63^{a}	-	-	-	-
Period 4	33.97^{a}	32.92^{a}	32.18^{a}	33.28^{a}	-	-	-	-
Period 5	23.68^{a}	24.52^{a}	20.44^{a}	26.06^{a}	-	-	-	-

[1] NARC: Northern Agricultural Research Center, Havre, Montana, USA.

[2] Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus; CHARANG: White hided, Charolais Angus.

[3] SE$_{pooled}$: Pooled standard errors across all treatments.

[4] Tx by Period: Treatment by Period Interaction.

Superscripts (a, b, c) within rows indicate significant differences ($P < 0.05$) among treatments; values that lack a common superscript in a row are significantly different.

Hide color did not impact morning surface temperatures, but a significant period effect was observed (*P*≤0.01). BLKANG and SIMANG steers consistently had higher surface temperatures than CHARANG across all periods (*P*≤0.02). A treatment by period interaction was noted (*P*≤0.01), where REDANG had higher temperatures than CHARANG during the first three periods (*P*≤0.01). In Periods 4 and 5, REDANG and had similar temperatures (*P*≥0.43). BLKANG and SIMANG consistently exhibited warmer surface temperatures than CHARANG (*P*≤0.02) (Table 2.14).

Table 2.14. Steer Surface Temperature (°C) across different treatment periods in Study 2, conducted at [1]NARC in 2024

	[2]Treatment					***p*-Value**		
	BLK-ANG	SIM-ANG	RED-ANG	CHAR-ANG	[3]SE	Treatment	Period	[4]Tx by Period
	-	-	-	-	-	-	-	-
AM	-	-	-	-	1.03	0.15	<0.01	<0.01
Period 1	9.35^{a}	8.68^{a}	9.23^{a}	6.43^{a}	-	-	-	-
Period 2	15.83^{a}	15.44^{a}	16.35^{a}	12.72^{a}	-	-	-	-
Period 3	24.46^{a}	21.96^{a}	24.01^{a}	17.64^{b}	-	-	-	-
Period 4	25.11^{a}	25.20^{a}	26.03^{a}	22.88^{a}	-	-	-	-
Period 5	37.24^{a}	38.40^{a}	34.64^{a}	29.13^{b}	-	-	-	-
PM	-	-	-	-	0.96	<0.01	<0.01	<0.01
Period 1	30.13^{a}	32.59^{a}	24.76^{b}	18.94^{c}	-	-	-	-
Period 2	30.69^{a}	30.30^{a}	27.80^{a}	22.66^{b}	-	-	-	-
Period 3	29.58^{a}	28.24^{a}	27.11^{a}	22.86^{b}	-	-	-	-
Period 4	31.72^{a}	31.54^{a}	29.44^{ab}	27.64^{b}	-	-	-	-
Period 5	36.58^{a}	36.41^{a}	32.51^{b}	30.43^{b}	-	-	-	-

[1] NARC: Northern Agricultural Research Center, Havre, Montana, USA.

[2] Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus; CHARANG: White hided, Charolais Angus.

[3] SE_{pooled}: Pooled standard errors across all treatments.

[4] Tx by Period: Treatment by Period Interaction.

Superscripts (a, b, c) within rows indicate significant differences (*P* < 0.05) among treatments; values that lack a common superscript in a row are significantly different.

A treatment by period interaction on REA was observed (*P*<0.01). Post hoc analysis showed no differences between treatments at the start and midpoint of the trial (*P*≥0.13), with a tendency for SIMANG to have greater REA than BLKANG and REDANG at harvest (*P*≤0.07). A treatment by period interaction on back fat thickness was also noted (*P*<0.01). At the midpoint of the trial, BLKANG had greater back fat thickness than REDANG (*P*=0.02), with a tendency to have greater back fat thickness than CHARANG (*P*=0.06). At harvest, BLKANG had greater back fat thickness than all other treatments (*P*<0.01) (Table 2.15).

Table 2.15. Ribeye area and 12th rib fat among treatments in Study 2, conducted at [1]NARC in 2024

	[2]**Treatment**					***p*-Value**		
	BLK-ANG	SIM-ANG	RED-ANG	CHAR-ANG	[3]SE	Treatment	Period	[4]Tx by Period
Ribeye area, cm²	-	-	-	-	1.97	0.21	<0.01	<0.01
Start (Day 0)	69.82	69.44	65.74	65.25	-	-	-	-
Midpoint (Day 84)	84.80	85.18	80.72	78.70	-	-	-	-
Harvest (Day 140)	84.52	91.94	84.25	90.38	-	-	-	-
12th rib fat, cm	-	-	-	-	0.08	0.05	<0.01	<0.01
Start (Day 0)	10.20	9.30	7.00	8.20	-	-	-	-
Midpoint (Day 84)	13.20	11.30	9.00	9.70	-	-	-	-
Harvest (Day 140)	16.80	11.90	10.00	10.00	-	-	-	-

[1]NARC: Northern Agricultural Research Center, Havre, Montana, USA.
[2]Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus; CHARANG: White hided, Charolais Angus.
[3]SE_{pooled}: Pooled standard errors across all treatments.
[4]Tx by Period: Treatment by Period Interaction.

There was no treatment effect on HCW (*P*=0.3). BLKANG and SIMANG had greater marbling than REDANG and CHARANG (*P*≤0.03), while marbling did not differ between REDANG and CHARANG (*P*=0.59). BLKANG had greater 12th rib fat than REDANG and CHARANG (*P*=0.02) and tended to have more than SIMANG (*P*=0.08). SIMANG did not differ from REDANG or CHARANG (*P*≥0.70). Post hoc analysis showed no differences between treatments (*P*≥0.14). BLKANG had greater yield grades than all other treatments (*P*≤0.02), with no differences in yield grade between SIMANG, REDANG, and CHARANG (*P*≥0.69) (Table 2.16).

Table 2.16. Carcass characteristics of steers at harvest in Study 2, conducted at [1]NARC in 2024

	[2]Treatment					***p*-Value**
	BLK-ANG	SIM-ANG	RED-ANG	CHAR-ANG	[3]SE	Treatment
Hot Carcass Weight, kg	374.14	365.90	346.33	355.65	10.87	0.30
Marbling	784.17^{a}	708.33^{a}	535.45^{b}	581.67^{b}	24.93	<0.01
12th rib fat, cm	1.68^{a}	1.19^{ab}	1.00^{b}	1.00^{b}	0.12	<0.01
Harvest ribeye area, cm^2	84.52	91.94	84.25	90.38	2.20	0.02
Yield Grade	3.49^{a}	2.58^{b}	2.63^{b}	2.38^{b}	0.15	<0.01

[1]NARC: Northern Agricultural Research Center, Havre, Montana, USA.
[2]Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus; CHARANG: White hided, Charolais Angus.
[3]SE_{pooled}: Pooled standard errors across all treatments.
Based on USDA quality grade/marbling scores: 200-299 = traces; 300-399 = slight; 400-499 = small; 500-599 = modest; 600-699 = moderate. Calculated yield grade = 2.5 + (2.5 x adjusted fat thickness, 12th rib, inches) + (0.0038 x hot carcass weight, pounds) + (0.2 x percentage kidney, pelvic and heart fat) – (0.32 x ribeye area, square inches).
Superscripts (a, b, c) within rows indicate significant differences ($P < 0.05$) among treatments; values that lack a common superscript in a row are significantly different.

Discussion

Average daily gain & Gain to Feed

Cattle performance is influenced by a complex interplay of environmental, physiological, and genetic factors, necessitating tailored management strategies to optimize outcomes (Finney, 1974; Wyffels et al., 2022). One key physiological consideration is that as steers approach harvest weight, the proportion of gain that is fat increases. Since fat contains approximately 2.25 times more energy than protein, this shift results in reduced average daily gain (ADG) and gain-to-feed ratio (G:F), as energy is increasingly partitioned toward fat deposition rather than lean tissue accretion (Baile & Forbes, 1974).

In both studies, hide color did not significantly affect ADG or G:F, suggesting that under the conditions tested, coat color alone may not be a reliable predictor of performance. However, significant period effects were observed, highlighting the importance of temporal and environmental influences on growth efficiency.

In Study 1, ADG and G:F were lowest during Period 5, which spanned late June to July. This decline likely reflects the impact of rising ambient temperatures during this time, which can induce heat stress in cattle. Heat stress is well-documented to reduce feed intake, alter metabolic efficiency, and impair growth performance (Baumgard & Rhoads, 2012; Gouvêa et al., 2019; Yadav et al., 2013). The observed reduction in performance during this period may also be compounded by the natural deceleration in growth as cattle near the finishing phase, where energy is increasingly directed toward fat deposition rather than muscle growth (Finney, 1974;

Romao et al., 2014). This dual effect—environmental stress and physiological transition—likely contributed to the observed performance decline.

In Study 2, period effects were even more pronounced. ADG peaked in Period 2 and dropped significantly in Period 3, suggesting that cattle were initially able to capitalize on favorable conditions before experiencing a setback, possibly due to extreme temperature fluctuations or other environmental stressors. These fluctuations can disrupt feed intake patterns and metabolic stability, leading to inconsistent growth rates.

A notable finding in Study 2 was the significant interaction between treatment and period for G:F. Specifically, REDANG steers exhibited superior feed efficiency in Period 1, outperforming other treatment groups. This suggests that under certain environmental conditions, specific genetic or phenotypic traits—potentially linked to hide color or associated physiological characteristics—may confer a performance advantage. However, the lack of consistency across periods indicates that these advantages are context-dependent and may not be sustained under varying environmental pressures.

These findings highlight the importance of flexible and responsive management strategies that consider not only genetic or physical traits like hide color but also the influence of changing environmental conditions throughout the production cycle. Future research should aim to better understand the reasons behind these interactions by examining how cattle respond to different environmental pressures—such as heat, feed availability, and seasonal changes—in terms of their growth patterns, feeding behavior, and ability to regulate body temperature. Gaining a clearer picture of these responses could support the development of more targeted and effective management practices. By aligning feeding programs, housing, and other care strategies with both the animal’s characteristics and the surrounding conditions, producers can improve efficiency and overall cattle performance.

Hair Depth

Hair depth measurements revealed no significant differences among treatment groups in Study 1, suggesting that hide color alone did not influence coat characteristics under those specific environmental conditions. In Study 2, a treatment by period interaction was observed, with REDANG steers exhibiting the longest hair length at the 28-day mark. However, no other statistically significant differences were detected across treatments or periods.

The absence of consistent treatment effects may be due to the limited genetic variability among the animals, as most originated from the same maternal herd. This shared lineage likely contributed to similar coat characteristics across groups. It’s possible that the Angus influence was more strongly expressed than the Simmental genetics in some of the crossbred steers, further reducing observable differences in traits like hair depth. Additionally, environmental uniformity—such as shared housing, feeding, and management—may have minimized external influences on coat development.

Despite the lack of statistical significance, visual and seasonal trends in hair depth were evident. A clear seasonal pattern emerged, with longer hair observed during colder months and a gradual reduction in coat length as temperatures increased into the summer. This aligns with well-established biological responses in cattle, where coat shedding and regrowth are part of the animal’s natural thermoregulatory adaptation to ambient temperature changes (Gebremedhin et al., 2023; Da Silva et al., (2003).

Although these trends did not reach statistical thresholds, they may still carry biological relevance. Coat characteristics such as length, density, and thickness play a critical role in heat dissipation and insulation, directly affecting an animal’s ability to maintain thermal balance (Da Silva, 2003; Gebremedhin et al., 2008; Madhusoodan et al., 2019). For instance, a thicker coat may offer protection during cold stress but could hinder heat loss during warmer periods, potentially impacting feed intake, energy expenditure, and overall performance.

These observations suggest that monitoring coat characteristics over time—even in the absence of significant treatment effects—can provide valuable insights into how cattle respond to seasonal shifts. Future studies might benefit from incorporating more frequent measurements, larger sample sizes, or additional variables such as humidity, wind speed, and solar radiation to better capture the environmental context influencing hair growth. Understanding these dynamics could contribute to more refined management practices, particularly in regions with wide seasonal variability.

Tag Scores

In Study 1, tag scores were highest in Period 1 and lowest in Period 5, reflecting changes in steer hide condition over time as the season transitioned from winter to summer. This decline in tag score in Period 5 likely corresponds with increased temperatures and reduced precipitation, which would have led to drier pen conditions and, consequently, lower mud and manure accumulation on the animals. These findings suggest that environmental or management factors during specific periods may have had a greater influence on tag scores than the treatments themselves.

In Study 2, a treatment by period interaction was observed, with BLKANG steers exhibiting higher tag scores in Period 2 compared to other treatments. However, no other significant differences in tag scores were detected, indicating that mud and manure coverage was generally consistent across treatments throughout the study.

Interestingly, coat depth appeared to follow a seasonal pattern, with longer hair observed during the winter months and shorter coats as the study progressed into summer. This aligns with expected physiological adaptations to seasonal changes. Due to this pattern, the longer, denser coats in colder months may have contributed to increased mud and manure accumulation, potentially elevating tag scores. It is important to note that high tag scores may elevate maintenance energy requirements, significantly reduce daily gains and daily intakes, resulting in overall decreased performance (Boyles, 2001; Morrison et. al, 1970; NASEM, 1981).

While these factors are well-documented in the literature as important considerations for animal welfare and productivity, it is important to note that this study did not detect a clear or consistent effect of tag score on steer performance or behavior within the 28-day observation periods. Nonetheless, the observed seasonal trends in coat characteristics and tag scores highlight the need to consider environmental and physiological factors when evaluating animal condition, even if their short-term impacts on performance are not statistically evident.

Cattle Surface Temperature

Surface temperature measurements revealed significant effects of hide color on cattle surface temperature. In Study 1, CHARANG surface temperature averaged 3.62°C lower than all other treatments across all periods. Similarly, in Study 2, BLKANG and SIMANG steers consistently had higher surface temperatures than CHARANG steers across all periods. These findings support the hypothesis that darker hide colors absorb more solar radiation, resulting in elevated surface temperatures compared to lighter-colored animals. This observation aligns with previous research, which has consistently reported higher surface temperatures in dark-hided cattle due to increased solar heat absorption (Brown-Brandl et al., 2010; Lima et al., 2020; Mader et al., 2006).

The implications of these findings are particularly relevant in the context of thermoregulation. Elevated surface temperatures can increase the thermal load on animals, potentially leading to heat stress, especially under high ambient temperatures. It is well documented that ambient temperature influences the metabolic rate of cattle, as animals must expend additional energy to maintain homeostasis, which can negatively impact feed efficiency, growth, and overall productivity (NASEM, 2016). Although this study did not detect a clear relationship between surface temperature and performance or behavior within the 28-day observation periods, the consistent differences in surface temperature by hide color suggest that coat pigmentation may play a role in thermoregulatory efficiency.

These findings demonstrate the importance of considering hide color as a potential factor in cattle management, particularly in regions prone to heat stress. While short-term performance metrics did not show significant variation, the physiological burden associated with elevated surface temperatures in dark-hided cattle may manifest over longer periods or under more extreme environmental conditions. Further research incorporating physiological indicators such as respiration rate, core body temperature, and heat stress biomarkers would provide deeper insight into the mechanisms by which hide color influences thermoregulation and animal welfare.

Carcass Characteristics

The results from both studies indicate that while there was no significant treatment effect on HCW, there were notable differences in marbling, 12^{th} rib fat, and yield grades among the different treatments - particularly favoring BLKANG steers. In both years, BLKANG and SIMANG steers exhibited greater marbling scores compared to other treatments, with BLKANG also demonstrating higher 12th rib fat and more favorable yield grades. These findings are consistent with previous research showing that Angus cattle tend to deposit more intramuscular fat, resulting in higher USDA marbling scores and improved carcass quality (Cross et al., 1984; Ellis et al., 2022; Engle et al., 2025; Harper et al., 2017; Roberts et al., 2017).

The more desirable carcass traits observed in BLKANG steers can likely be attributed to breed-specific genetic predispositions that favor intramuscular fat deposition. Angus cattle, particularly those selected for carcass merit, are known for their ability to produce highly marbled beef, which enhances both meat quality and market value. This genetic advantage likely contributed to the improved carcass performance of BLKANG steers compared to other treatments.

Interestingly, despite the higher surface temperatures observed in the dark-hided cattle throughout the study, there were no significant differences in ADG among the treatments. This suggests that while darker hide colors may increase heat absorption and surface temperature, these cattle were still able to maintain growth performance. The ability of dark-hided cattle to perform well under potentially greater thermal load may reflect effective thermoregulatory mechanisms or adaptive behaviors that mitigate the physiological impacts of heat stress.

However, the performance of REDANG steers did not match that of BLKANG steers, despite both having darker hides than the CHARANG steers. This discrepancy could be due to differences in genetic lines within the Angus breed, where in our study, the Black hided Angus cattle were more intensively selected for carcass traits such as marbling and fat deposition, whereas the Red Angus cattle may have originated from lines with different selection priorities. This highlights the importance of considering not only breed but also genetic line and selection history when evaluating performance outcomes.

While dark-hided cattle may face challenges related to increased heat absorption, their genetic advantages in carcass quality can be leveraged to optimize production outcomes. These findings emphasize the complex relationship between environmental stressors and genetic potential. Further research incorporating physiological measurements and genomic data could provide deeper insight into how hide color and genetic background influence thermoregulation and carcass performance under varying environmental conditions.

Conclusion

This research draws attention to the multifaceted relationship among period, treatment, and hide color in shaping cattle performance and carcass traits. While ADG and G:F were not significantly affected by hide color, clear period effects emerged – particularly in response to seasonal temperature fluctuations. Surface temperature measurements confirmed that darker hide colors absorb more solar radiation, resulting in consistently higher surface temperatures. Despite this, dark-hided cattle maintained comparable growth rates, suggesting the presence of effective thermoregulatory mechanisms or adaptive behaviors that mitigate heat stress.

The carcass traits observed in BLKANG steers, including greater marbling, 12th rib fat, and improved yield grades—are likely due to breed-specific genetic predispositions favoring intramuscular fat deposition. These findings align with previous research on Angus cattle and emphasize the value of targeted genetic selection for carcass quality (Chambaz et el., 2003; McClure et al., 2010; Roberts et al., 2017). Interestingly, REDANG steers did not perform as well as their black-hided counterparts, despite similar hide pigmentation. This discrepancy may reflect differences in genetic lines or selection priorities within the Angus breed, highlighting the importance of considering both breed and lineage when evaluating performance outcomes.

Overall, while hide color clearly influences surface temperature, its impact on short-term growth metrics such as ADG and G:F appears limited. Period effects, particularly those tied to environmental conditions, had a more pronounced influence on performance and carcass traits. The consistent surface temperature differences observed between treatments suggest that hide color may play a role in thermoregulation, though no direct effects on behavior or performance were evident within the 28-day evaluation windows.

These findings emphasize the importance of integrating environmental, physiological, and genetic factors when assessing cattle performance. Future research should incorporate physiological indicators—such as core body temperature, respiration rate, and heat stress biomarkers—alongside genomic data to better understand how hide color and breed characteristics influence thermoregulation and carcass development. Such insights could inform more effective breeding and management strategies tailored to diverse environmental conditions.

CHAPTER THREE

THE INFLUENCE OF HIDE COLOR AND NORTHERN LATTITUDE CLIMATES ON FEED INTAKE BEHAVIOR OF BEEF STEERS

Introduction

Efficient feed conversion is a cornerstone of profitability and sustainability in beef production. Cattle that can convert feed into muscle while maintaining desirable fat deposition offer significant economic advantages to feedlot operations. A 5% improvement in feed efficiency can yield four times the economic return of a 5% improvement in average daily gain (Gibb et al., 1999). However, feed efficiency and intake are complex traits influenced by a combination of genetic, physiological, and environmental factors (Kenny et al., 2018).

Environmental stressors such as heat and cold are known to significantly affect voluntary feed intake and the efficiency of metabolizable energy use (Ames, 1980; Baumgard & Rhoads, 2012; Young, 1983). For example, dry matter intake (DMI) decreases by approximately 0.45 kg/day for every unit increase in the temperature-humidity index (THI), as animals reduce intake to lower metabolic heat production (Chang et al., 2021). Conversely, cold stress increases energy demands for thermoregulation, often leading to increased intake but reduced feed conversion efficiIt is important to note that microbial fermentation in the rumen alone contributes approximately 3–8% of total heat production in cattle (Beatty et al., 2008). Feedlot cattle are especially vulnerable to heat stress due to the high metabolic heat produced from digesting energy-dense, high-concentrate diets (Idris, 2021). In 2023, it was estimated that 80% of cattle worldwide experienced conditions exceeding the median THI threshold of 68.8 for at least 30 days annually (North et al., 2023). These environmental pressures, combined with genetic variation in feed efficiency, point out the need to better understand how external factors like hide color may influence performance outcomes.

This study investigates how hide color—specifically its albedo, or reflectivity—interacts with environmental conditions to influence feed intake behavior and feed efficiency in beef cattle. Albedo refers to the proportion of solar radiation reflected by a surface. In the context of livestock, animals with darker hides absorb more solar radiation, potentially increasing surface temperature and altering thermoregulatory demands. These changes may influence feed intake, nutrient utilization, and ultimately, growth performance. However, the potential interaction between environmental heat load—modulated by hide color—and feed efficiency remains underexplored.

The objective of this study is to evaluate whether hide color, through its effect on surface temperature (albedo), influences feed intake behavior and feed efficiency in beef cattle under varying environmental conditions. Understanding this relationship could inform breed selection and management strategies aimed at improving performance and resilience in feedlot systems.

Materials and Methods

All animal procedures were approved by the Montana State University Agriculture Animal Care and Use Committee (#2022-267-AA). This behavioral study was conducted at the Northern Agricultural Research Center in Havre, Montana, USA (48.5500°N, 109.6841°W) over two consecutive years: 2023 (Study 1) and 2024 (Study 2). Each trial spanned 140 days from February to July and was divided into five 28-day periods for temporal analysis of behavioral patterns. The 140 days were divided into five 28-day periods for analysis: Period 1 (day 0 to day 28), Period 2 (day 29 to day 56), Period 3 (day 57 to day 84), Period 4 (day 85 to day 112), and Period 5 (day 113 to day 140). Procedures were consistent across both study durations. Unless otherwise specified, the Materials and Methods described apply uniformly to both studies.

The objective of this study was to evaluate the influence of hide color and environmental conditions on feedlot cattle behavior. Angus-influenced yearling steers were selected based on uniformity in age, weight, and hide color. Four treatment groups were established: Red Angus (REDANG), Black Angus (BLKANG), Charolais × Angus crossbreds (CHARANG; white hide), and Simmental × Angus crossbreds (SIMANG; black hide). Animals were sourced from the Northern Agricultural Research Center and a collaborating Red Angus herd. The Charolais × Angus crossbred steers, despite their Angus lineage, exhibited completely white coats due to the influence of the Charolais sire. Black-hided purebred Angus steers served as the control group. The use of Angus-based crossbreds allowed for consistent hide color variation while minimizing genetic differences across treatment groups.

Steers chosen for this study were comparable in weight (409.28±8.33 kg in Study 1; 404.95±12.73 kg in Study 2), were approximately of one year of age, and had been backgrounded on forage prior to feedlot entry. All steers were adapted to a high-concentrate finishing diet and implanted with Synovex One Feedlot (Zoetis, Parsippany-Troy Hills, NJ, USA) prior to the study. Diet composition and feeding protocols were consistent across both years.

Study 1

Forty Angus-based yearling steers (409.28±8.33 kg) were grouped by weight and hide coloration into four categories (*n*=10 REDANG, *n*=10 BLKANG, and *n*=10 SIMANG, *n*=10 CHARANG). Animals were randomly allocated to ten pens using a randomized design, with each pen housing one steer from each treatment group (four steers per pen). Each pen provided 47.6 m^2 of space.

All steers were equipped with electronic identification ear tags and underwent a 14-day acclimation period to the Vytelle system (Vytelle, Lenexa, KS, USA) prior to data collection. Each pen was outfitted with two Vytelle electronic feed bunks (20 total across the study), which included animal presence sensors, single-access neck bars, load cells for feed disappearance measurement, and wireless data transmission to a central computer. Feeding behavior parameters derived from this system included average daily intake (ADI, dry matter basis), daily eating duration (minutes), and eating rate (grams per minute). Intake variability was expressed as the coefficient of variation (CV, %) based on individual daily intake. ADI normalized to body weight (g/kg BW) was calculated post-harvest.

Steers were fed once daily at 0900 h. To avoid bias, the feeding sequence of pens was rotated daily. Feed bunks were checked each morning before feeding, and rations were adjusted to meet targeted average daily gains. If bunks were empty for two consecutive days, feed was increased by 0.23 kg per animal, but not on back-to-back days. Any uneaten feed was weighed and removed, and spoiled or wet feed was sampled, weighed, and discarded. Water was available ad libitum throughout the trial.

In cases where feed disappearance data could not account for at least 95% of the feed offered the Vytelle system flagged the 24-hour period as invalid. Previous validation studies have shown that missing up to 30% of data does not compromise the accuracy of dry matter intake (DMI) estimates (Wang et al., 2006). In this study, 9.17% of DMI data points were excluded due to such failures.

The finishing diet consisted of 69% corn, 21% corn silage, 10% wheat straw, and 0.45 kg per head per day of a medicated pellet containing a fortified vitamin and mineral mix. Weekly diet samples were collected for nutrient analysis. Each sample’s wet weight was recorded before drying in a Thermo Fisher Scientific Heratherm™ oven (model 51028112) at 55°C for 48 hours. After cooling to room temperature, dry weights were recorded. Samples were then returned to the oven for an additional hour at the same temperature, and a second dry weight was taken. If discrepancies were observed between the two dry weights, the drying process was repeated until consistent values were achieved. Final dried samples were submitted to Dairy One for nutrient composition analysis (Table 2.1).

Throughout the finishing period, environmental conditions were monitored using an Onset HOBO U30-NRC Weather Station (Onset Computer Corporation, Bourne, MA, USA), which was positioned near the feedlot. The station was programmed to log air temperature, wind speed, and wind chill at 10-minute intervals for the duration of the trial (Table 2.2).

<u>Study 2</u>

A total of 47 Angus-influenced yearling steers (404.95 ± 12.73 kg) were categorized by body weight and hide color, then randomly allocated within those strata to one of four treatment groups: REDANG (*n* = 11), BLKANG (*n* = 12), SIMANG (*n* = 12), and CHARANG (*n* = 12). Animals were housed in twelve pens, each measuring 47.6 m^2, with pens assigned to a single treatment group to minimize inter-breed interactions. Each pen contained four steers of the same treatment. This penning strategy was implemented to mitigate the breed-related social dynamics and dominance behaviors observed in the previous study.

All steers were tagged with electronic identification devices and underwent a 14-day acclimation period to the Vytelle system (Vytelle, Lenexa, KS, USA) before data collection commenced. Each pen was equipped with two Vytelle electronic feed bunks (24 total), which included animal detection antennas, single-access neck bars, load cells for measuring feed disappearance, and wireless data transmission to a central computer. Behavioral feeding metrics derived from the system included average daily intake (ADI, dry matter basis), time spent eating (minutes/day) and eating rate (grams/minute). Intake variability was expressed as the coefficient of variation (CV, %) based on individual daily intake. ADI per unit of body weight (g/kg BW) was calculated after harvest.

Feeding occurred once daily at 0900 h, with the order of pen feeding rotated daily to avoid systematic bias. Feed bunks were evaluated each morning, and rations were adjusted to meet targeted growth rates. If bunks were empty for two consecutive days, feed was increased by 0.23 kg per steer, but not on consecutive days. Refusals were weighed and removed, and any spoiled or wet feed was sampled, weighed, and discarded. Water was available ad libitum throughout the trial.

If feed disappearance could not be accounted for at a rate of 95% or greater, the Vytelle system flagged the 24-hour period as invalid. Previous validation studies have shown that missing up to 30% of data does not compromise the accuracy of dry matter intake estimates. In Study 2, 13.79% of DMI data points were excluded, with an average failure rate of 11.48% across both years.

The finishing ration consisted of 69% corn, 21% corn silage, 10% wheat straw, and 0.45 kg per head per day of a medicated pellet containing a fortified vitamin and mineral premix. Weekly diet samples were collected for nutrient analysis and dried following the same protocol as described in Chapter two. Final dried samples were submitted to Dairy One for nutrient composition analysis (Table 2.3).

To maintain continuity in environmental data collection, the same Onset HOBO U30-NRC Weather Station from Study 1 was utilized in Study 2, with identical configuration and placement near the feedlot. It recorded air temperature, wind speed, and wind chill at 10-minute intervals for the same duration as in Study 1 (Table 2.4).

Statistical Analysis

In both studies, to evaluate the effects of hide color on intake behavior metrics, we used generalized linear mixed models including steer hide color, period of the trial, and their interaction as fixed effects and steer and pen as random intercepts. Individual steer was used as a random intercept to account for autocorrelation of multiple measurements for each individual. Individual steer was considered the experimental unit. An $\alpha \leq 0.05$ was considered significant, with a tendency considered at $\alpha > 0.05$ and ≤ 0.10. The Tukey Method was used to separate means when α was less than 0.05. All statistical procedures were conducted in R (R Core Team, 2017).

Results

Study 1

In Study 1, ADI displayed a treatment by period interaction ($P<0.01$). There were no treatment differences in Periods 1 or 2 ($P\geq0.41$). In Period 3, REDANG had greater intakes than SIMANG ($P<0.01$) and tended to have greater intakes than CHARANG ($P=0.05$). In Period 4, REDANG steers had greater intakes than SIMANG ($P=0.04$). In period 5, REDANG steers had greater intakes than both SIMANG and CHARANG ($P\leq0.03$) (Table 3.1).

Looking at ADI on g/kg of BW basis, a treatment by period interaction was observed ($P<0.01$), where in Period 1, REDANG tended to consume more than CHARANG ($P=0.06$), with no other treatment effects observed ($P\geq0.26$). In Period 2, REDANG had greater intakes (g/kg/d) than BLKANG steers ($P=0.02$) and tended to have greater intakes than SIMANG ($P=0.09$). In Period 3, REDANG had greater intakes than all other treatments ($P<0.01$). In Period 4, REDANG tended to have greater intakes than SIMANG ($P=0.06$), with no other treatment effects observed ($P\geq0.25$). In Period 5, REDANG had greater intakes than SIMANG ($P=0.01$) and tended to have greater intakes than CHARANG ($P=0.06$). There was no effect of treatment or period on CV of intake ($P\geq0.15$) in Study 1 (Table 3.1).

A treatment by period effect was observed for time spent eating ($P<0.01$) where REDANG spent more time eating than all other treatments in Periods 1 and 2 ($P<0.01$). In Period 3, SIMANG spent less time at the bunk than BLKANG and REDANG ($P\leq0.04$), and REDANG spent more time at the bunk than all other treatments ($P<0.01$). In Period 4, REDANG spent more time at the bunk than SIMANG ($P<0.01$) and tended to spend more time at the bunk than

CHARANG and BLKANG (*P*≤0.08). In Period 5, REDANG ate more than SIMANG (P<0.01), with no other treatment effects (*P*≥0.12) (Table 3.1).

There was a treatment by period interaction for eating rate (*P*<0.01), where in Period 2 REDANG had a lower eating rate than SIMANG (*P*=0.04) and in Period 5 CHARANG had lower eating rates than BLKANG and SIMANG (*P*≤0.03). No other treatment effects were observed across other periods (*P*≥0.12) (Table 3.1).

Table 3.1. Effects of Coat Color on Intake Behavior Across Periods in Study 1, conducted at [1]NARC in 2023

	[2]Treatment					P value		
	BLK-ANG	SIM-ANG	RED-ANG	CHAR-ANG	[3]SE	Treatment	Period	[4]Tx by Period
Time spent eating, min/day	-	-	-	-	4.61	<0.01	<0.01	<0.01
Period 1	118.02^{a}	115.68^{a}	140.50^{b}	118.35a	-	-	-	-
Period 2	118.43^{a}	108.72^{a}	139.14^{b}	118.99^{a}	-	-	-	-
Period 3	115.95^{a}	98.80^{b}	136.79^{c}	112.63^{ab}	-	-	-	-
Period 4	107.69^{ab}	94.35^{a}	123.69^{b}	108.36^{ab}	-	-	-	-
Period 5	89.06^{ab}	77.64^{a}	100.06^{b}	91.77ab	-	-	-	-
Eating rate, g/min	-	-	-	-	5.34	0.07	<0.01	<0.01
Period 1	93.43^{a}	94.57^{a}	76.65^{a}	86.65^{a}	-	-	-	-
Period 2	92.20^{ab}	101.36^{a}	81.48^{b}	90.44^{ab}	-	-	-	-
Period 3	102.68^{a}	107.44^{a}	90.70^{a}	99.69^{a}	-	-	-	-
Period 4	110.47^{a}	115.96^{a}	98.15^{a}	104.38^{a}	-	-	-	-
Period 5	141.11^{a}	141.01^{a}	126.70^{ab}	119.90^{b}	-	-	-	-
[5]CV of intake, %	16.28	14.52	15.52	16.84	1.14	0.31	0.15	0.75
[6]ADI	-	-	-	-	0.39	0.39	<0.01	<0.01
Period 1	10.75^{a}	10.68^{a}	10.58^{a}	10.01^{a}	-	-	-	-
Period 2	10.59^{a}	10.66^{a}	11.11^{a}	10.56^{a}	-	-	-	-
Period 3	11.47^{ab}	10.34^{a}	12.21^{b}	10.96^{ab}	-	-	-	-
Period 4	11.36^{ab}	10.54^{a}	11.84^{b}	11.03^{ab}	-	-	-	-
Period 5	11.3^{ab}	10.25^{a}	11.90^{b}	10.58^{a}	-	-	-	-
[7]ADI, g/kg of BW	-	-	-	-	0.71	0.07	<0.01	<0.01
Period 1	25.35^{a}	26.02^{a}	26.94^{a}	24.72^{a}	-	-	-	-
Period 2	22.94^{a}	23.46^{ab}	25.53^{b}	23.49^{ab}	-	-	-	-
Period 3	22.78^{a}	21.04^{a}	25.79^{b}	22.59^{a}	-	-	-	-
Period 4	20.98^{a}	20.28^{a}	22.51^{a}	20.88^{a}	-	-	-	-
Period 5	19.15^{ab}	18.18^{a}	20.84b	18.56^{ab}	-	-	-	-

[1] NARC: Northern Agricultural Research Center, Havre, Montana, USA.

[2] Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus;
CHARANG: White hided, Charolais Angus.

[3] SE: Pooled standard errors across all treatments.

[4] Tx by Period: Treatment by Period Interaction.

---

[5] CV = Coefficient of variation

[6] ADI = Average daily intake

[7] ADI = Average daily intake grams per kilogram of body weight

Superscripts (a, b, c) within rows indicate significant differences (*P* < 0.05) among treatments; values that lack a common superscript
in a row are significantly different.

Study 2

In Study 2, ADI displayed a treatment by period interaction (*P*<0.01). In Period 1, BLKANG had greater average daily intakes than SIMANG and CHARANG (*P*<0.01), and REDANG had greater intakes than CHARANG (*P*<0.01). In Period 2, CHARANG had lower ADI than all other treatments (*P*≤0.04). In Period 3, BLKANG had greater intakes than SIMANG and CHARANG (*P*≤0.03), and REDANG had greater intakes than CHARANG (*P*=0.03). In Period 4, BLKANG and REDANG had greater intakes than SIMANG and CHARANG (*P*≤0.02). In Period 5, there were no differences in ADI among treatments (*P*≥0.01) (Table 3.2).

A treatment by period interaction was observed for ADI on a g/kg/BW basis (P<0.01). In Period 1, CHARANG had lower intakes compared to all other treatments (P≤0.03), and SIMANG had lower intakes than REDANG and BLKANG (P≤0.03). In Period 2, CHARANG had lower intakes than all other treatments (P≤0.03). In Period 3, REDANG had greater intakes than SIMANG (P=0.02) and tended to have greater intakes than CHARANG (P=0.06). In Period 4, REDANG had greater intakes than all other treatments (P≤0.03). In Period 5, there was a tendency for REDANG to have greater intakes than BLKANG (P=0.07), with no other differences among treatments (P≥0.20) (Table 3.2).

There was a tendency for period by treatment interaction on CV of intake (*P*=0.06), however was limited to SIMANG having greater CV in Period 4 (*P*≤0.04) compared to BLKANG and REDANG. No other differences across periods (*P*≥0.15) (Table 3.2).

A treatment by period effect was observed for time spent at the bunk (P<0.01). In Period 1, REDANG tended to spend more time at the bunk than SIMANG (P=0.06), with no other treatment effects observed ($P \geq 0.28$). In Period 2, REDANG steers spent more time at the bunk than BLKANG ($P=0.03$) and SIMANG ($P=0.05$). In Period 3, REDANG tended to spend more time at the bunk than BLKANG ($P=0.09$), and CHARANG tended to spend more time at the bunk than BLKANG ($P=0.07$). In Period 4, REDANG spent more time at the bunk than BLKANG ($P=0.04$) and SIMANG ($P=0.02$). In Period 5, there were no differences among treatments ($P \geq 0.17$) (Table 3.2).

A treatment by period interaction for eating rate was observed ($P<0.01$), where in Periods 2 and 3, CHARANG had lower eating rates than BLKANG ($P \leq 0.03$) and in Period 5, CHARANG had lower eating rates than BLKANG and REDANG ($P \leq 0.03$). No other treatment differences observed in Periods 1 and 4 ($P \geq 0.13$) (Table 3.2).

Table 3.2. Effects of Coat Color on Intake Behavior Across Periods in Study 2, conducted at [1]NARC in 2024

	[2]Treatment					**P value**		
	BLK-ANG	SIM-ANG	RED-ANG	CHAR-ANG	[3]SE	Treatment	Period	[4]Tx by Period
Time spent eating (min/day)	-	-	-	-	6.60	0.08	<0.1	<0.1
Period 1	138.29^{a}	124.22^{a}	147.43^{a}	130.70^{a}	-	-	-	-
Period 2	123.51^{a}	125.50^{a}	149.91^{b}	137.55^{ab}	-	-	-	-
Period 3	116.85^{a}	123.81^{a}	138.80^{a}	139.65^{a}	-	-	-	-
Period 4	117.38^{a}	114.69^{a}	142.25^{b}	129.08^{ab}	-	-	-	-
Period 5	105.53^{a}	108.23^{a}	116.24^{a}	124.45^{a}	-	-	-	-
Eating rate (g/min)	-	-	-	-	7.12	0.40	<0.1	<0.1
Period 1	87.29^{a}	87.76^{a}	78.42^{a}	73.39^{a}	-	-	-	-
Period 2	105.20^{a}	97.93^{ab}	83.44^{ab}	77.43^{b}	-	-	-	-
Period 3	111.28^{a}	97.69^{ab}	93.41^{ab}	82.39^{b}	-	-	-	-
Period 4	116.38^{a}	107.88^{a}	101.52^{a}	94.25^{a}	-	-	-	-
Period 5	135.32^{a}	125.53^{ab}	142.19^{a}	108.05^{b}	-	-	-	-
[5]CV of intake	15.88	16.28	16.40	16.63	0.59	0.56	0.46	0.06
[6]ADI	-	-	-	-	0.30	<0.01	<0.01	<0.01
Period 1	11.82^{a}	10.49^{bc}	10.72^{ab}	9.42^{c}	-	-	-	-
Period 2	12.56^{a}	11.58^{a}	12.00^{a}	10.47^{b}	-	-	-	-
Period 3	12.69^{a}	11.53^{bc}	12.54^{ab}	11.36^{c}	-	-	-	-
Period 4	13.05^{a}	11.81^{b}	13.48^{a}	11.79^{b}	-	-	-	-
Period 5	13.45^{a}	13.05^{a}	14.00^{a}	13.01^{a}	-	-	-	-
[7]ADI g/kg BW	-	-	-	-	5.23	<0.01	<0.01	<0.01
Period 1	27.66^{a}	25.65^{b}	27.67^{a}	23.65^{c}	-	-	-	-
Period 2	26.82^{a}	25.84^{a}	27.38^{a}	23.86^{b}	-	-	-	-
Period 3	24.13^{ab}	23.01^{a}	25.17^{b}	23.24^{ab}	-	-	-	-
Period 4	23.65^{a}	22.74^{a}	25.78^{b}	23.05^{a}	-	-	-	-
Period 5	22.61^{a}	22.98^{a}	24.45^{a}	23.52^{a}	-	-	-	-

---

[1] NARC: Northern Agricultural Research Center, Havre, Montana, USA.
[2] Treatment: BLKANG: Black hided, Angus; SIMANG: Black hided, Simmental Angus; REDANG: Red hided, Red Angus; CHARANG: White hided, Charolais Angus.
[3] SE: Pooled standard errors across all treatments.
[4] Tx by Period: Treatment by Period Interaction.
[5] CV = Coefficient of variation
[6] ADI = Average daily intake
[7] ADI = Average daily intake grams per kilogram of body weight
Superscripts (a, b, c) within rows indicate significant differences ($P < 0.05$) among treatments; values that lack a common superscript in a row are significantly different.

Discussion

Average Daily Intake

Both studies observed a significant treatment by period interaction for ADI, showing the dynamic nature of feed intake behavior across different breeds and time points. However, the patterns observed across the two studies present a complex and nuanced picture that warrants further investigation.

In both studies, REDANG steers consistently demonstrated higher feed intakes during the later periods, suggesting a potential breed-specific adaptation or delayed growth response. In Study 1, REDANG steers had significantly greater intakes than SIMANG and tended to exceed CHARANG in Period 3, with this trend continuing into Periods 4 and 5. Similarly, in Study 2, REDANG steers consumed more feed than CHARANG in Period 1 and surpassed both CHARANG and SIMANG in Periods 3 and 4. Despite this consistent increase in ADI, REDANG steers did not exhibit corresponding improvements in intramuscular fat deposition, average daily gain (ADG), or feed efficiency. This disconnect suggests that higher intake alone may not translate into superior performance outcomes, highlighting the importance of evaluating feed utilization efficiency rather than intake volume alone (Arthur et al., 2001; Nkrumah et al., 2007).

In contrast, CHARANG steers consistently exhibited lower feed intakes during the early periods. While no treatment differences were observed in Periods 1 and 2 of Study 1, CHARANG steers in Study 2 consumed less feed than all other treatments during the same periods. This pattern may reflect breed-specific differences in early-stage metabolism, appetite regulation, or stress responsiveness (Basarab et al., 2003; Kelly et al., 2010). Supporting this, surface temperature data from Chapter 2 revealed that CHARANG steers had lower surface temperatures compared to their dark-hided counterparts. According to thermoregulatory literature, animals exposed to colder conditions typically increase feed intake to generate metabolic heat (Ames, 1980; Young, 1983; NASEM, 1981). However, CHARANG steers did not exhibit this compensatory behavior, suggesting a possible inefficiency in their thermoregulatory or metabolic response (Baumgard & Rhoads, 2012; Scasta, 2021).

On the other hand, BLKANG steers consistently exhibited higher surface temperatures across all periods in both studies. Literature suggests that as ambient or body temperature rises, animals reduce feed intake to minimize metabolic heat production (Baile & Forbes, 1974; Gouvêa et al., 2019; Yadav et al., 2013). Interestingly, in Study 1, BLKANG steers did not consume more feed than other treatments, yet they demonstrated greater fat deposition, as discussed in Chapter 2. This suggests a potential advantage in feed efficiency, where BLKANG steers may require fewer inputs to achieve desirable carcass traits. Their ability to deposit more fat with relatively lower intake could indicate superior nutrient partitioning or metabolic efficiency.

In Study 2, however, BLKANG steers showed higher feed intakes across multiple periods while still maintaining elevated surface temperatures. Despite this increased intake, they continued to exhibit greater fat deposition, consistent with Study 1 findings. This suggests that BLKANG steers may possess inherently desirable carcass characteristics, even if their feed efficiency appears less pronounced in Study 2. These findings raise important questions about the interplay between thermoregulation, intake behavior, and carcass outcomes.

While these results offer valuable insights into breed-specific intake behavior and performance, they also reveal inconsistencies that merit further exploration. The contrasting intake patterns of BLKANG steers between the two studies highlight the complexity of feed efficiency and thermoregulatory responses. Although higher surface temperatures are generally associated with reduced intake, the observed data challenge this assumption. This stresses the need for a more holistic understanding of the physiological mechanisms governing feed intake, including metabolic rate, hormonal regulation, and genetic predispositions. Future research should aim to integrate these factors to better predict and enhance feed efficiency across diverse cattle breeds and environmental conditions.

Average Daily Intake g/kg BW

Similarly, a significant treatment by period interaction was observed for average daily intake (ADI) when expressed on a grams per kilogram of body weight (g/kg BW) basis. This interaction highlights how feed intake patterns varied not only by breed but also across different time periods. In both studies, REDANG steers consistently exhibited higher feed intakes during the later periods, suggesting a potential adaptive or compensatory intake behavior as they matured or acclimated to the feeding environment. In contrast, CHARANG steers consistently demonstrated lower intake levels during the early periods across both studies, which may reflect breed-specific differences in early growth stage metabolism, appetite regulation, or stress responsiveness (Basarab et al., 2003; Nkrumah et al., 2007).

Interestingly, BLKANG steers did not show elevated intake levels compared to other treatments in Study 1 on a g/kg BW basis. However, in Study 2, they exhibited higher intake levels during the early periods, indicating a possible environmental or management influence that may have interacted with genetic predispositions. These variations reinforce the complexity of feed intake behavior and suggest that breed-specific physiological and genetic mechanisms—such as differences in metabolic rate, digestive efficiency, or hormonal regulation—may be driving these patterns.

To better understand and leverage these differences for improved feed efficiency, further research is warranted. Investigating the underlying physiological and genetic factors contributing to these breed-specific intake patterns could provide deeper insights into improving feed efficiency (Arthur et al., 2001; Basarab et al., 2003; Nkrumah et al., 2007). Long-term studies should investigate how these intake trends influence overall growth performance, carcass quality, health outcomes, and lifetime productivity. Additionally, incorporating factors such as thermoregulation and environmental adaptability could provide a more holistic understanding of breed-specific efficiency under varying production conditions. Such insights could ultimately inform more targeted breeding and management strategies in beef cattle production systems.

Coefficient of variation of intake

There was no significant effect of treatment or period on the coefficient of variation (CV) of intake in Study 1, indicating that feed intake remained relatively consistent across all treatments and time points. This stability suggests that, under the conditions of Study 1, cattle maintained uniform feeding behavior regardless of breed or period, which is advantageous for predicting growth performance and implementing consistent feeding strategies.

In contrast, Study 2 revealed a tendency for a treatment by period interaction in CV of intake. This interaction was primarily driven by SIMANG steers, which exhibited a notably higher CV in Period 4 compared to BLKANG and REDANG steers. Although no other significant differences in CV were observed across periods, this spike in variability suggests that SIMANG steers may have experienced greater fluctuations in feed intake during this specific period. Such variability could be influenced by a range of factors, including sensitivity to environmental changes, social dynamics within pens, or individual differences in appetite regulation and digestive efficiency.

Interestingly, despite expectations based on thermoregulation, BLKANG steers did not exhibit increased variability in intake. Literature suggests that animals experiencing heat stress often reduce feed intake to minimize metabolic heat production, which can lead to inconsistent feeding patterns (Baumgard & Rhoads, 2012; Gouvêa et al., 2019). However, the relatively stable CVs observed in BLKANG steers across both studies may indicate a degree of physiological resilience or behavioral adaptation to thermal stress. This consistency in intake, even under potentially stressful conditions, could be a valuable trait for maintaining performance in variable climates.

The overall lack of significant differences in CV across most treatments and periods suggests that, under controlled conditions, breed-related variability in intake behavior may be minimal. However, the isolated increase in SIMANG steers highlights the importance of monitoring breed-specific responses to environmental or management changes. Understanding the factors that contribute to intake variability—such as metabolic rate, hormonal regulation, and stress responsiveness—can help refine selection criteria for feed efficiency and support the development of precision feeding strategies tailored to specific genetic lines.

Time Spent Eating

In both studies, REDANG steers consistently spent more time at the feed bunk compared to other treatments across multiple periods. This observation aligns with their consistently higher average daily intake (ADI), as discussed previously, and suggests a strong correlation between time spent eating and total feed consumption. Both studies also revealed significant treatment by period interactions, indicating that the duration of feeding behavior varied not only by breed but also across different stages of the feeding trial.

In Study 1, REDANG steers spent significantly more time eating than all other treatments during Periods 1 and 2, suggesting an early and sustained engagement with feed. This trend continued in Periods 4 and 5, where REDANG steers again spent more time at the bunk than SIMANG steers. These findings suggest that REDANG cattle may have a more persistent or motivated feeding behavior, potentially driven by metabolic demands or breed-specific appetite regulation.

In contrast, Study 2 showed a more muted pattern. REDANG steers only tended to spend more time at the bunk than SIMANG in Period 1, with no significant treatment differences observed in later periods. By Period 5, time spent eating appeared to level off across all breeds, indicating a convergence in feeding behavior as the trial progressed. This shift may reflect physiological adaptation, changes in feed composition or palatability, or behavioral acclimation to the feeding environment.

The differences in feeding behavior between the two studies may be partially explained by changes in study design. In Study 1, pens were composed of one steer from each treatment group, allowing for inter-breed social interactions. This setup may have introduced competitive dynamics or social hierarchies that influenced feeding time. For example, dominant breeds may have monopolized bunk access, while more submissive breeds may have altered their feeding patterns to avoid conflict. In contrast, Study 2 grouped steers by treatment, with four animals of the same breed per pen. This design potentially reduced inter-breed competition and may have contributed to the more uniform feeding times observed across treatments.

These findings suggest that social dynamics and pen composition may influence feeding behavior. Breed-specific traits such as size, temperament, and social dominance may affect how long animals spend at the bunk, especially in mixed-treatment settings (Hubbard et al., 2021). For instance, smaller or more submissive breeds may be displaced more frequently in competitive environments, leading to shorter or more fragmented feeding bouts. Conversely, dominant breeds may exhibit longer, uninterrupted feeding sessions (Hubbard et al., 2021; Reyes et al., 2024; Valente et al., 2023).

Understanding these behavioral nuances is critical for optimizing feed access and intake efficiency. If certain breeds are more susceptible to social stress or bunk competition, management strategies such as individualized feeding systems or breed-specific grouping may help ensure equitable access to feed and improve overall performance. Further research is needed to explore the role of social hierarchy, temperament, and behavioral adaptability in shaping feeding behavior across different cattle breeds and production systems.

Eating Rate

Both studies observed a significant treatment by period interaction for eating rate, indicating that the speed at which cattle consumed feed varied across different periods and breeds. Notably, CHARANG steers consistently exhibited lower eating rates compared to other treatments in several periods. In Study 1, CHARANG had significantly lower eating rates than BLKANG in Period 5, while in Study 2, this trend was observed in Periods 2, 3, and 5. These findings suggest a breed-specific feeding behavior that may influence overall feed intake efficiency.

Although it is commonly expected that dark-hided cattle, such as BLKANG, would reduce their eating rate in response to elevated surface temperatures due to thermoregulatory stress (Baumgard & Rhoads, 2012), the results from both studies did not consistently support this hypothesis. Instead, the lower eating rates observed in CHARANG steers—despite their lighter hides and lower surface temperatures—point toward intrinsic behavioral or physiological traits rather than environmental stress responses. This could include genetic predispositions toward slower eating habits, differences in rumination patterns, or variations in appetite regulation mechanisms (Bouissou et al., 2001).

In addition to breed-specific physiological traits, body size and behavioral adaptation likely play a role in shaping eating rate. Steers may have a greater capacity for feed intake due to their larger rumen volume as they grow throughout the trial period. This physical advantage can enable them to consume more feed in a shorter period, potentially contributing to faster eating rates. Moreover, these breeds may have become behaviorally adapted to feedlot environments, exhibiting more assertive or efficient feeding strategies that allow them to maximize intake during limited bunk access times (Bouissou et al., 2001; Kondo & Hurnik, 1990). Such adaptations could include reduced sensitivity to social stress, greater feeding motivation, or learned behaviors that enhance bunk attendance efficiency. These traits may give more dominant breeds a competitive edge in group-feeding scenarios, allowing them to maintain or even increase eating rates despite environmental or social pressures.

The inconsistencies observed between Study 1 and Study 2 may also reflect the influence of pen composition and social dynamics. As discussed previously, Study 1 involved mixed-treatment pens, potentially introducing competitive pressures that could alter feeding behavior. In contrast, Study 2 grouped animals by treatment, possibly reducing social stress and allowing more natural feeding patterns to emerge. These contextual factors underscore the complexity of interpreting eating rate data and the need for controlled studies that isolate behavioral, genetic, and environmental influences.

Further research is needed to clarify the mechanisms driving breed-specific eating rates and to determine how these behaviors interact with feed efficiency, carcass traits, and overall production. Integrating behavioral monitoring with physiological and genomic data could provide a more comprehensive understanding of how eating rate contributes to overall production efficiency.

Conclusion

The findings from both studies demonstrate the complexity of feeding behavior in beef cattle and highlight the significant influence of breed-specific traits, environmental conditions, and social dynamics. While REDANG steers consistently demonstrated higher feed intake and longer time spent at the bunk, these behaviors did not always translate into improved feed efficiency or carcass traits, suggesting that intake volume alone is not a sufficient predictor of performance. Conversely, CHARANG steers exhibited lower intake levels and eating rates across multiple periods, which may reflect inherent physiological or behavioral characteristics rather than responses to thermoregulatory stress.

The role of social structure and pen composition emerged as a critical factor influencing feeding behavior. The contrast between mixed-treatment pens in Study 1 and uniform-treatment pens in Study 2 revealed how social interactions, including dominance and displacement, may affect access to feed and feeding consistency. Notably, BLKANG steers, despite higher surface temperatures, maintained stable intake patterns and demonstrated favorable carcass characteristics, possibly due to their physiological capacity or behavioral adaptation to feedlot environments.

Variability in eating rate and intake behavior across breeds and periods points to the need for a more nuanced understanding of how genetic, physiological, and behavioral factors interact. Metrics such as the coefficient of variation of intake and time spent eating provide valuable insights into feeding consistency, which is essential for optimizing growth performance and feed management strategies.

Future research should aim to disentangle the effects of breed, environment, and social hierarchy on feeding behavior. Integrating behavioral observations with physiological measurements and genomic data will be key to developing precision feeding systems that enhance feed efficiency, support sustainable production, and improve overall system performance.

CHAPTER FOUR

CONCLUSIONS AND MANAGEMENT CONSIDERATIONS

As global climate change is anticipated to alter temperatures, create variable precipitation patterns, increase atmospheric carbon dioxide levels, and affect water availability (Seijang et al., 2015; Cheng et al., 2022), the cattle industry faces significant challenges. Climate changes modify the thermal environment of animals, potentially increasing thermal stress and thereby impacting animal health, production, and efficiency (Seijang et al., 2015; St Pierre, 2003). Given that the feedlot industry utilizes a diverse range of nutritional inputs, including different feed types and supplements, as well as animal genetic makeup and observable characteristics across various geographies and climates (Drouillard, 2018), it is crucial to understand how feedlot cattle interact with these environments to enhance the economic viability of livestock production systems.

Coat color significantly influences the activation of thermoregulatory mechanisms, with darker coats absorbing more sunlight and lighter coats reflecting more sunlight (Finch et al., 1984). Understanding the relationship between solar radiation and coat coloration can have important implications for optimizing cattle selection and enhancing the performance of growing cattle, such as yearling steers or heifers (Scasta, 2021). The data presented in this study exhibit that light-hided cattle consistently had colder surface temperatures than the dark-hided cattle, across all seasons in both studies. According to existing literature, we would expect the light-hided cattle in this study to increase their feed intake to compensate for the colder temperatures observed (Ames, 1980, Baumgard & Rhoads, 2012, NASEM, 1981, Scasta, 2021, Young, 1983). In contrast, as temperatures increased, we would have expected the dark-hided cattle to reduce their feed intake as a higher surface temperature was recorded, as a direct result for their need to expel more heat to regulate their body temperature (Baile & Forbes, 1974, Baumgard & Rhoads, 2012, Gouvêa et al., 2019, Yadav et al., 2013). However, we observed significant variation and inconsistency in the eating behavior across all treatments, which did not align with the expectations set by existing literature. This warrants further research on variability in intake behavior and changing environmental conditions.

Despite the inconsistencies in feed intake behavior and feed efficiency, the Black hided Angus steers had greater fat deposition in both studies. Breed-specific findings indicated that Black hided Angus steers typically exhibited high levels, rib fat, and yield grades, suggesting that breed characteristics can greatly influence carcass quality. This suggests that the Black hided Angus steers may possess desirable carcass characteristics, even if their feed efficiency is variable, as seen in this study.

The results of this study suggest that hide color has an impact on albedo due to the consistent differences in surface temperature between black and white hided steers, which could have an ability on an animal's ability to thermoregulate. In addition, the consistent findings in the difference of surface temperatures suggests a black-hided animal may be better suited for colder, high-altitude environments due to its ability to absorb more heat from the sun compared to a white-hided animal. The data present in this study suggest that light hided cattle may have an advantage in times of heat stress as they reflected more heat from the sun, and in contrast, dark hided cattle may have an advantage in times of cold weather due to their ability to absorb more heat from the sun. However, there were no clear effects on performance and behavior at the scale presented in this study. More comprehensive data is needed to provide better physiological insight on the relationship between coat color albedo and individual thermoregulatory mechanisms.

Overall, our studies have shown that while hide color affects certain performance indicators, its impact on growth metrics like ADG and G:F is less consistent. These findings highlight the significant influence of period effects on cattle performance and carcass traits, with notable treatment interactions, particularly for Black hided Angus steers. Additionally, the results emphasize the complexity of factors affecting cattle performance, the intricate relationship between time and breed on cattle performance, and the necessity for tailored management.

In conclusion, our studies evaluated several aspects of beef cattle performance and the impact of environmental changes on albedo, coat depth changes, intake behavior, and carcass characteristics. Steers of darker hides exhibited increased surface temperatures, however there we no clear effects of surface temperature on cattle performance and behavior. Presumably, these differences were due to breed-specific differences. However, these studies used advanced precision agricultural technology to address beef cattle management concerns, particularly for those of young growing beef cattle at Northern latitudes. Utilizing detailed data analysis to understand the complex interactions between period, treatment, and breed can inform better management decisions. The use of these unique tools provided valuable insight on beef cattle production and gave us the opportunity to address questions in new ways.

REFERENCES CITED

Abdelnour, S. A., Abd El-Hack, M. E., Khafaga, A. F., Arif, M., Taha, A. E., & Noreldin, A. E. (2018). Stress biomarkers and proteomics alteration to thermal stress in ruminants: A review. *Journal of Thermal Biology, 79,* 120-134.

Albertí, P., Panea, B., Sañudo, C., Olleta, J. L., Ripoll, G., Ertbjerg, P., Christensen, M., Gigli, S., Failla, S., Concetti, S., Hocquette, J. F., Jailler, R., Rudel, S., Renand, G., Nute, G. R., Richardson, R. I., & Williams, J. L. (2008). Live weight, body size and carcass characteristics of young bulls of fifteen European breeds. *Livestock Science, 114*(1), 19-30.

Allen, T. E. (1962). Sweating rate and the electrolyte content of skin secretions of Bos taurus and Bos indicus cross-bred cows. *The Journal of Agricultural Science, 75*(3), 397-402.

Allen, T. E., Wang, J., Duangjinda, M., Vajrabukka, C., & Katawatin, S. (1963). Differences of skin morphology in Bos indicus, Bos taurus, and their crossbreds. *International Journal of Biometeorology, 58,* 1087-1094.

American Angus Association (AAA). (2020). *Research Hair Shedding EPD Launched by Angus Genetics Inc.*

Ames, D. (1980). Thermal environment affects production efficiency of livestock. *BioScience, 30*(7), 457–460.

Arthur, P. F., Archer, J. A., Johnston, D. J., Herd, R. M., Richardson, E. C., & Parnell, P. F. (2001). Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other postweaning traits in Angus cattle. *Journal of Animal Science, 79*(11), 2805-2811.

Baile, C. A., & Forbes, J. M. (1974). Control of feed intake and regulation of energy balance in ruminants. *Physiological Reviews, 54*(1), 160–214.

Baumgard, L. H., & Rhoads, R. P. (2012). Ruminant nutrition symposium: Ruminant production and metabolic responses to heat stress. *Journal of Animal Science, 90*(6), 1855-1865.

Basarab, J. A., Price, M. A., Aalhus, J. L., Okine, E. K., Snelling, W. M., & Lyle, K. L. (2003). Residual feed intake and body composition in young growing cattle. *Canadian Journal of Animal Science, 83*(2), 189–204.

Bayssa, M., Yigrem, S., Betsha, S., & Tolera, A. (2021). Production, reproduction and some adaptation characteristics of Boran cattle breed under changing climate: A systematic review and meta-analysis. *PLOS One*.

Beatty, D. T., Barnes, A., Taylor, E., & Maloney, S. K. (2008). Do changes in feed intake or ambient temperature cause changes in cattle rumen temperature relative to core temperature? *Journal of Thermal Biology, 33*(1), 12–19.

Bertipaglia, E. C. A., Da Silva, G., Cardoso, V., & Fries, L. A. (2007). Hair-coat characteristics and sweating rate of Bradford cows in Brazil. *Livestock Science, 112*(1–2), 99–108.

Bhimte, A., Thakur, N., Lakhani, N., Yadav, V., Khare, A., & Lakhani, P. (2018). Endocrine changes in livestock during heat and cold stress. *Journal of Pharmacognosy and Phytochemistry, 7*(4), 127–132.

Blaine, K. L., & Nsahlai, I. V. (2011). The effects of shade on performance, carcass classes and behaviour of heat-stressed feedlot cattle at the finisher phase. *Tropical Animal Health and Production, 43*(3), 609-615.

Bond, T. E., Kelly, C. F., & Morrison, S. R. (1967). Solar, atmospheric, and terrestrial radiation received by shaded and unshaded animals. *Transactions of the ASAE, 10*(5), 622-625.

Boyles, S. (2001). Feedlot mud management. Ohio State University Extension.

Brosh, A., Aharoni, Y., Degen, A. A., Wright, D., & Young, B. A. (1998). Effects of solar radiation, dietary energy, and time of feeding on thermoregulatory responses and energy balance in cattle in a hot environment. *Journal of Animal Science, 76*(10), 2671-2677.

Brown-Brandl, T. M., Eigenberg, R. A., & Nienaber, J. A. (2010). Water spray cooling during handling of feedlot cattle. *International Journal of Biometeorology, 54*(9), 609–616.

Brown-Brandl, T. M., Eigenberg, R. A., Nienaber, J. A., & Hahn, G. L. (2005). Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, Part 1: Analyses of indicators. *Biosystems Engineering, 90*(4), 451-462.

Bunning, H. B., & Wall, E. (2022). The effects of weather on beef carcass and growth traits. *Animal, 16*(11), Article 100657.

Busby, D., & Loy, D. (1996). Heat stress in feedlot cattle: Producer survey results. In *Iowa State University Beef Research Report* (AS-632, pp. 108-110). Iowa State University.

Cernicchiaro, N., White, B. J., Renter, D. G., & Babcock, A. H. (2012). Associations between weather conditions during the first 45 days following feedlot arrival and daily respiratory disease risks in autumn-placed U.S. feeder cattle. *Journal of Animal Science, 90*(4), 1328-1337.

Certified Angus Beef. (2022). CAB Premiums Reach Record $182 Million. Retrieved from CAB Cattle.

Chambaz, A., Scheeder, M. R., Kreuzer, M., & Dufey, P. A. (2003). Meat quality of Angus, Simmental, Charolais and Limousin steers compared at the same intramuscular fat content. *Meat Science, 63*(4), 491-500.

Chang-Fung-Martel, J., Harrison, M. T., Brown, J. N., & Smith, R. (2021). Negative relationship between dry matter intake and the temperature-humidity index with increasing heat stress in cattle: A global meta-analysis. *International Journal of Biometeorology, 65,* 2099–2109.

Chauhan, S. S., Zhang, M., Osei-Amponsah, R., Clarke, I., Sejian, V., Warner, R., & Dunshea, F. R. (2023). Impact of heat stress on ruminant livestock production and meat quality, and strategies for amelioration. *Animal Frontiers*, 13(5), 60-68.

Cheng, M., McCarl, B., & Fei, C. (2022). Climate change and livestock production: A literature review. *Atmosphere*, *13*(1), 140.

Coakley, J. (2003). Reflectance and albedo, surface. In *Encyclopedia of Atmospheric Sciences*.

Cooke, R. F. (2017). Nutritional and management considerations to minimize stress and optimize production efficiency in cow-calf systems. *Department of Animal Science, Texas A&M University*.

Cooke, R. F., Schubach, K. M., Marques, R. S., Peres, R. F. G., Silva, L. G. T., Carvalho, R. S., Cipriano, R. S., Bohnert, D. W., Pires, A. V., & Vasconcelos, J. L. M. (2017). Effects of temperament on physiological, productive, and reproductive responses in Bos indicus beef cows. *Journal of Animal Science, 95*(1), 1–8.

Cundiff, L. V., Thallman, R., & Kuehn, L. (2012). Impact of Bos Indicus genetics on the global beef industry. In *Proceedings of the Beef Improvement Federation 44th Annual Research Symposium and Annual Meeting* (p. 31). Houston, TX.

Da Silva, R. G., La Scala, N., Jr., & Tonhati, H. (2003). Radiative properties of the skin and hair coat of cattle and other animals. *American Society of Agricultural and Biological Engineers*, *46*(3), 913–918.

Davis, M. J. (2022). Zebu (Bos indicus) cattle: Characteristics and management. *Mississippi State University Extension Service.*

Debnath, A., Elangbam, S., Pandey, A., Madhuri, P., & Michui, D. (2024). The hidden dangers of winter: A brief review how cold stress affects cattle production. *International Journal of Veterinary Sciences and Animal Husbandry, 9*(6), 152-156.

Dinh, T. T. N., Blanton, J. R., Riley, D. G., Chase, C. C., Coleman, S. W., Phillips, W. A., Brooks, J. C., Miller, M. F., & Thompson, L. D. (2010). Intramuscular fat and fatty acid composition of longissimus muscle from divergent pure breeds of cattle. *Journal of Animal Science, 88*(2), 756-766.

Dowling, D. F. (1955). Differences of skin morphology in Bos indicus, Bos taurus, and their crossbreds. *International Journal of Biometeorology, 58*, 1087-10942.

Drouillard, J. S. (2018). Current situation and future trends for beef production in the United States of America - A review. *Asian-Australasian Journal of Animal Sciences, 31*(7), 1007-1016.

DTN/Progressive Farmer. (2022). *Heat stress kills estimated 10,000 cattle in Kansas*.

Durbin, H. J., Lu, D., Yampara-Iquise, H., Miller, S. P., & Decker, J. E. (2020). Development of a genetic evaluation for hair shedding in American Angus cattle to improve thermotolerance. *Genetics Selection Evolution, 52*, 63.

Edwards-Callaway, L. N., Cramer, M. C., Cadaret, C. N., Bigler, E. J., Engle, T. E., Wagner, J. J., & Clark, D. L. (2021). Impacts of shade on cattle well-being in the beef supply chain. *Journal of Animal Science*, 99(2), 1-21.

Ellis, R. J., Martinez, P. S., & Jones, L. K. (2022). Genetic and environmental determinants of beef quality: A review. *Frontiers in Veterinary Science, 9*, Article 819605.

Engle, B. N., Thallman, R. M., Snelling, W. M., Wheeler, T. L., Shackelford, S. D., King, D. A., & Kuehn, L. A. (2025). Breed-specific heterosis for growth and carcass traits in 18 U.S. cattle breeds. *Journal of Animal Science*.

Farooq, U., Qayyum, A., Abdus Samad, H., & Chaudhry, H. (2010). Physiological responses of cattle to heat stress. *World Applied Sciences Journal, 8*, 38-43.

Feuz, R., Reichhardt, C. C., Larsen, R., Thornton, K. J., & Garcia, M. D. (2022). Comparing net returns in the feedlot: Bos Taurus vs. Bos Indicus influenced steers with varying anabolic implant intensity. *Translational Animal Science, 6*(3), txac111.

Finch, V. A., Bennett, I. L., & Holmes, C. R. (1984). Coat colour in cattle: Effect on thermal balance, behaviour and growth, and relationship with coat type. *The Journal of Agricultural Science, 102*(1), 141-147.

Finney, D. J. (1974). Growth curves: Their nature, uses, and estimation. In *Patterns of Growth and Development in Cattle* (pp. 658–672). Springer.

Garrick, D. J., & Taylor, J. F. (2014). The role of genomics in beef cattle breeding. *Animal Frontiers, 4*(1), 37-41.

Gaughan, J. B., Sejian, V., Mader, T. L., & Dunshea, F. R. (2019). Adaptation strategies: Ruminants. *Animal Frontiers*, *9*(1), 47–53.

Gebremedhin, K. G., Fonseca, V. D. F. C., & Maia, A. S. C. (2023). Methods, thermodynamic applications, and habitat implications of physical and spectral properties of hair and haircoats in cattle. *Animals*, *13*(19), 3087.

Gebremedhin, K. G., Porter, W. P., & Warner, R. G. (1984). Heat flow through pelage of calves—A sensitivity analysis. *American Society of Agricultural Engineers*, *27*, 1140–1143.

Gebremedhin, K. G., Hillman, P. E., Lee, C. N., Collier, R. J., Willard, S. T., Arthington, J. D., & Brown-Brandl, T. M. (2008). Sweating rates of dairy cows and beef heifers in hot conditions. *Transactions of the ASABE*, *51*, 2167–2178.

Gilbert, R. P., & Bailey, D. R. C. (1991). Hair coat characteristics and postweaning growth of Hereford and Angus cattle. *Journal of Animal Science*, *69*, 498–506.

Godyń, D., Herbut, P., & Angrecka, S. (2018). Measurements of peripheral and deep body temperature in cattle – A review. *Journal of Thermal Biology*, 79, 42-49. doi:10.1016/j.jtherbio.2018.11.019.

Gouvêa, V. N., Cooke, R. F., Marques, R. S., Fernandes, H. J., & Vasconcelos, J. L. M. (2019). Impacts of stress-induced inflammation on feed intake of beef cattle. *Animal Feed Science and Technology, 251*, 12-21.

Guo, Q., Mistry, M. N., Zhou, X., Zhao, G., Kino, K., Wen, B., Yoshimura, K., Satoh, Y., Cvijanovic, I., & Kim, Y. (2024). Regional variation in the role of humidity on city-level heat-related mortality. *PNAS Nexus*, 3(8), 290.

Hahn, G. L. (1999). Dynamic responses of cattle to thermal heat loads. *Journal of Animal Science*, *77*(suppl_2), 10-20.

Harper, T. M., Nguyen, H. T., & Kim, S. Y. (2017). Network analysis reveals putative genes affecting meat quality in Angus cattle. *Frontiers in Genetics*, *8*, Article 171.

Hall, L. W., Garcia, S., & Collier, R. J. (2012). Climatology: The effects of heat stress on beef cattle production. In *Climatology: New Developments* (pp. 43-62). Nova Science Publishers, Inc.

Hayes, M. D., Brown-Brandl, T. M., Eigenberg, R. A., Kuehn, L. A., & Thallman, R. M. (2017). Evaluating a new shade for feedlot cattle performance and heat stress. *Transactions of the ASABE, 60*, 1301–1311.

Herd, R. M., & Arthur, P. F. (2009). Physiological basis for residual feed intake. *Journal of Animal Science*, *87*(14), E64–E71.

Hoppe, K., Stokka, G., & Carlson, Z. (2021). Dealing with heat stress in beef cattle operations. *NDSU Agriculture*.

Hubbard, A. J., Foster, M. J., & Daigle, C. L. (2021). Social dominance in beef cattle — A scoping review. *Applied Animal Behaviour Science*, *241*, 105390.

Idris, M., Uddin, J., Sullivan, M., McNeill, D. M., & Phillips, C. J. C. (2021). Non-invasive physiological indicators of heat stress in cattle. *Animals*, *11*(1), 71.

Kamal, R., Dutt, T., Patel, M., & Singh, G. (2018). Heat stress and effect of shade materials on hormonal and behavior response of dairy cattle: A review. *Tropical Animal Health and Production*, *50*, 701–706.

Kelley, D. W., Osborne, C. A., Evermann, J. F., Parish, S. M., & Gaskins, C. T. (1982). Effects of chronic heat and cold stressors on plasma immunoglobulin and mitogen-induced blastogenesis in calves. *Journal of dairy science*, *65*(8), 1514–1528.

Kenny, D. A., Fitzsimons, C., Waters, S. M., & McGee, M. (2018). Invited review: Improving feed efficiency of beef cattle – The current state of the art and future challenges. *Animal, 12*(9), 1815-1826.

Kennedy, P. M., Christopherson, R. J., & Milligan, L. P. (1986). Digestive responses to cold. In L. P. Milligan, W. L. Grovum, & A. Dobson (Eds.), *Control of Digestion and Metabolism in Ruminants* (pp. 285-303). Englewood Cliffs, NJ: Reston Books.

Keren, E. N., & Olson, B. E. (2006). Thermal balance of cattle grazing winter range: Model application. *Journal of Animal Science*, *84*(5), 1238-1247.

Kim, W. S., Nejad, J. G., Park, K. K., & Lee, H. G. (2023). Heat stress effects on physiological and blood parameters, and behavior in early fattening stage of beef steers. *Animals, 13*(7), 1130.

Kim, W. S., Ghassemi Nejad, J., & Lee, H. G. (2023). Impact of cold stress on physiological, endocrinological, immunological, metabolic, and behavioral changes of beef cattle at different stages of growth. *Animals, 13*, 1073.

Lasater, T. M. (1981). *The Lasater Philosophy of Cattle Raising*. University of Texas Press.

Lees, A. M., Sejian, V., Wallage, A. L., Steel, C. C., Mader, T. L., Lees, J. C., & Gaughan, J. B. (2019). The impact of heat load on cattle. *Animals, 9*, 322.

Lima, S. B. G. P. N. P., Stafuzza, N. B., Pires, B. V., et al. (2020). Effect of high temperature on physiological parameters of Nelore (Bos taurus indicus) and Caracu (Bos taurus taurus) cattle breeds. *Tropical Animal Health and Production, 52*, 2233–2241.

Leite, J. H. G. M., Da Silva, R. G., Asensio, L. A. B., & Pereira, M. M. (2020). Coat color and morphological hair traits influence on the mechanisms related to the heat tolerance in hair sheep. *International Journal of Biometeorology, 64*(12), 2185–2194.

Maia, A. S. C., Moura, G. A. B., Fonsêca, V. F. C., Gebremedhin, K. G., Milan, H. M., Chiquitelli Neto, M., Simão, B. R., Campanelli, V. P. C., & Pacheco, R. D. L. (2023). Economically sustainable shade design for feedlot cattle. *Frontiers in Veterinary Science, 10*, 1110671.

Mader, T. L. (2003). Environmental stress in confined beef cattle. *Journal of Animal Science, 81*(14), E110-E119.

Mader, T. L., Davis, M. S., & Brown-Brandl, T. (2006). Environmental factors influencing heat stress in feedlot cattle. *Journal of Animal Science*, *84*(3), 712-719.

Mader, T. L., Gaughan, J. B., Johnson, L. J., & Hahn, G. L. (2010). Tympanic temperature in confined beef cattle exposed to excessive heat load. *International Journal of Biometeorology, 54*, 629–635.

Madhusoodan, A. P., Seijian, V., Rashamol, V. P., Savitha, S. T., Bagath, M., Krishnan, G., & Bhatta, R. (2019). Resilient capacity of cattle to environmental challenges – An updated review. *Journal of Animal Behaviour and Biometeorology, 7*, 104–118.

Manzoor, A., Maqbool, I., Ganaie, Z. A., Afzal, I., Khan, H. M., & Zaffe, B. (2019). Mitigating winter vagaries in dairy animals: A review. *International Journal of Veterinary Sciences and Animal Husbandry, 4*(1), 1-5.

Marchesini, G., Cortese, M., Mottaran, D., Ricci, R., Serva, L., Contiero, B., Segato, S., & Andrighetto, I. (2018). Effects of axial and ceiling fans on environmental conditions, performance and rumination in beef cattle during the early fattening period. *Livestock Science, 214*, 225–230.

McClure, M. C., Morsci, N. S., Schnabel, R. D., Kim, J. W., Yao, P., Rolf, M. M., McKay, S. D., Gregg, S. J., Chapple, R. H., Northcutt, S. L., & Taylor, J. F. (2010). A genome scan for quantitative trait loci influencing carcass, post-natal growth and reproductive traits in commercial Angus cattle. *Animal Genetics, 41*(6), 597-607.

McManus, C., Paludo, G. R., Louvandini, H., Gugel, R., Sasaki, L. C., & Paiva, S. R. (2009). Heat tolerance in Brazilian sheep: Physiological and blood parameters. *Tropical Animal Health and Production, 41*(1), 95-101.

McManus, C., Castanheira, M., Paiva, S. R., Louvandini, H., Fioravanti, M. C. S., Paludo, G. R., Bianchini, E., & Corrêa, P. S. (2011). Use of multivariate analyses for determining heat tolerance in Brazilian cattle. *Tropical Animal Health and Production*, *43*, 623-630.

Medeiros dos Santos, M., de Souza-Junior, J. B. F., dos Santos, V. J. S., Castelo, T. de S., de Queiroz, J. P. A. F., & de Costa, L. L. M. (2019). Differences between times of day for the basic physiological traits of Nellore bulls exposed to solar radiation. *Biological Rhythm Research*, *52*(3), 342–346.

Milligan, J. D., & Christison, G. I. (1974). Effects of severe winter conditions on performance of feedlot steers. *Canadian Journal of Animal Science*, *54*(4), 605-610.

Moriel, P., Izquierdo, V. S., & Vendramini, J. M. B. (2024). Short- and long-term effects of heat stress in cow-calf pairs adapted to tropical and subtropical regions. *Journal of Animal Science, 102*(Supplement_3), 17–18.

Morrison, S., Givens, R., Garrett, W., & Bond, T. (1970). Effects of mud, wind, and rain on beef cattle performance in feed lot. *California Agriculture,* 24(8).

Morignat, E., Perrin, J. B., Gay, E., Vinard, J. L., Calavas, D., & Hendrikx, P. (2015). Assessment of the impact of the 2003 and 2006 heat waves on cattle mortality in France. *Environmental Research,* 142, 67-72.

Muzzo, B. I., Ramsey, R. D., & Villalba, J. J. (2025). Changes in climate and their implications for cattle nutrition and management. *Climate*, *13*(1), 1.

Narayanan, A., Rezaali, M., Bunting, E., & Keellings, D. (2025). It’s getting hot in here: Spatial impact of humidity on heat wave severity in the United States. *Science of the Total Environment*, 963, 178397.

National Agricultural Statistics Service (NASS). (2024). Cattle on feed. U.S. Department of Agriculture. ISSN: 1948-9080.

National Academies of Sciences, Engineering, and Medicine (NASEM) (1987). Predicting feed intake of food-producing animals. In *Predicting feed intake of food-producing animals* (pp. 51-62). Washington, DC: The National Academies Press.

National Academies of Sciences, Engineering, and Medicine (NASEM) . (1981). *Effect of environment on nutrient requirements of domestic animals*. Washington, DC: The National Academies Press.

Ney, J. D., & Heyman, H. (1956). Differences of skin morphology in Bos indicus, Bos taurus, and their crossbreds. *International Journal of Biometeorology, 58,* 1087-10942.

Nienaber, J. A., & Hahn, G. L. (2007). Livestock production system management responses to thermal challenges. *International Journal of Biometeorology, 52*(2), 149-157.

Nkrumah, J. D., Basarab, J. A., Wang, Z., Li, C., Price, M. A., Okine, E. K., Crews, D. H., & Moore, S. S. (2007). Genetic and phenotypic relationships of feed intake and measures of efficiency with growth and carcass merit of beef cattle. *Journal of Animal Science, 85*(10), 2711–2720.

North, M. A., Franke, J. A., Ouweneel, B., & Trisos, C. H. (2023). Global risk of heat stress to cattle from climate change. *Environmental Research Letters, 18*(9), 094027. IOP Publishing Ltd.

Nwosu, C. C., & Ogbu, C. C. (2019). Importance of hybrid vigor or heterosis for animal breeding. *Net Journal of Agricultural Science, 7*(1), 1-8.

Ochsner, K. P., MacNeil, M. D., Lewis, R. M., & Spangler, M. L. (2017). Economic selection index development for Beefmaster cattle II: General-purpose breeding objective. *Faculty Papers and Publications in Animal Science*.

Okamoto, L., Stegemiller, M. R., Reichhardt, C. C., Alberto, A. F., Bayles, S. A., Roholt, B. W., Murdoch, B. M., & Thornton-Kurth, K. J. (2024). Examining the effect of genetics between Bos taurus and Bos indicus influenced cattle on production performance, carcass characteristics, and feeding behavior. *Journal of Animal Science*, *102*(Suppl_3), 13–14.

Olson, B. E., & Wallander, R. T. (2002). Influence of winter weather and shelter on activity patterns of beef cows. *Canadian Journal of Animal Science, 82*, 491–501.

O’Quinn, T. G., Legako, J. F., Brooks, J. C., & Miller, M. F. (2018). Evaluation of the contribution of tenderness, juiciness, and flavor to the overall consumer beef eating experience. *Translational Animal Science, 2*(1), 26-36.

Pan, Y. (1963). Sweating rate and the electrolyte content of skin secretions of Bos taurus and Bos indicus cross-bred cows. *The Journal of Agricultural Science, 75*(3), 397-4021.

Penn State Extension. (2023). Cold Stress and Beef Cattle.

Pereira, A. M. F., Titto, E. L., Infante, P., Titto, C. G., Geraldo, A. M., Alves, A., Leme, T. M., Baccari Jr., F., & Almeida, J. A. (2014). Evaporative heat loss in Bos taurus: Do different cattle breeds cope with heat stress in the same way? *Journal of Thermal Biology, 45*, 87-94.

Pinto, A. K., Rosa, G. J. M., Weigel, K. A., Rosa, G., & Cole, J. B. (2020). Reducing heat stress impacts in dairy cattle using on-farm management strategies and genomic selection. *Journal of Animal Science and Biotechnology, 11*, 94.

Porto-Neto, L. R., Bickhart, D. M., Landaeta-Hernandez, A. J., Utsunomiya, Y. T., Pagan, M., Jimenez, E., Hansen, P. J., Dikmen, S., Schroeder, S. G., Kim, E.-S., Sun, J., Crespo, E., Amati, N., Cole, J. B., Null, D. J., Garcia, J. F., Reverter, A., Barendse, W., & Sonstegard, T. S. (2018). Convergent evolution of slick coat in cattle through truncation mutations in the prolactin receptor. *Frontiers in Genetics, 9*, 57.

Potts, S. (2021). Short and long-term effects of heat stress in dairy cattle. *University of Maryland Extension.*

Pozzebon, M., Guldbrandtsen, B., & Sandøe, P. (2024). Gene editing cattle for enhancing heat tolerance: A welfare review of the "PRLR-SLICK cattle" case. *Nanoethics, 18*(6).

Reyes, F. S., White, H. M., Weigel, K. A., & Van Os, J. M. C. (2024). Preference for feed bins shared with cows of the same or different parity and relationships with feeding behavior and feed efficiency. *Journal of Dairy Science*, *107*(6), 3847–3862.

Rincker, G., & Meeter, T. (2023). Managing heat stress in cattle. *University of Illinois Extension.*

Roberts, C. G., Chen, Y. H., & Thompson, M. E. (2017). Deciphering signature of selection affecting beef quality traits in Angus cattle. *Molecular Biology Reports, 44*(12), 1233–1245.

Rodrigues, R. T. d. S., Chizzotti, M. L., Vital, C. E., Baracat-Pereira, M. C., Barros, E., Busato, K. C., & et al. (2017). Differences in beef quality between Angus (*Bos taurus taurus*) and Nellore (*Bos taurus indicus*) cattle through a proteomic and phosphoproteomic approach. *PLoS ONE, 12*(1), e0170294.

Romao, J. M., Jin, W., He, M., McAllister, T., Guan, L. L. (2014). Effect of age on bovine subcutaneous fat proteome: Molecular mechanisms of physiological variations during beef cattle growth. *Journal of Animal Science, 92*(8), 3316–3330.

Romero, J. A., Alves, T. A., Andrade, D. M., Gurjão, T. A., Melo, L. R. B., & Souza, B. B. (2017). Productive and reproductive performance, behavior and physiology of cattle under heat stress conditions. *Journal of Animal Behavior and Bioclimatology,* 5(3), 91-96.

Rusche, W., & Walker, J. (2021). Cold stress impacts on cattle. *SDSU Extension*.

Saatchi, M., Schnabel, R. D., Taylor, J. F., & Garrick, D. J. (2014). Genetic architecture of quantitative traits in beef cattle revealed by genome-wide association studies. *BMC Genomics, 15*, 1-18.

Santos, M. M., Souza-Junior, J. B. F., Dantas, M. R. T., & Costa, L. L. M. (2021). An updated review on cattle thermoregulation: physiological responses, biophysical mechanisms, and heat stress alleviation pathways. *Environmental Science and Pollution Research*, 28, 30471–30485.

Sartori, R., Bastos, M. R., Baruselli, P. S., Gimenes, L. U., Ereno, R. L., & Barros, C. M. (2009). Physiological differences and implications to reproductive management of *Bos taurus* and *Bos indicus* cattle in a tropical environment. *Proceedings of the Eighth International Symposium on Reproduction in Domestic Ruminants*.

Scasta, J. D. (2021). Albedo and thermal ecology of white, red, and black cows (Bos taurus) in a cold rangeland environment. *Animals*, *11*(5), 1186.

SDSU Extension. (2021). *Chapter 8: Cold stress impacts on cattle.*

Sejian, V., Gaughan, J., Baumgard, L., & Prasad, C. (Eds.). (2015). Introduction to concepts of climate change impact on livestock and its adaptation and mitigation. In *Climate change impact on livestock: Adaptation and mitigation* (pp. 1-18). Springer.

Silanikove, N. (2000). Effects of heat stress on the welfare of extensively managed domestic ruminants. *Livestock Production Science, 67*(1-2), 1-18.

Simroth, J. C., Thomson, D. U., Schwandt, E. F., Bartle, S. J., Larson, C. K., & Reinhardt, C. D. (2017). A survey to describe current cattle feedlot facilities in the High Plains region of the United States. *Kansas Agricultural Experiment Station Research Reports, 3*(1).

Smith, J. L., Wilson, M. L., Nilson, S. M., et al. (2022). Genome-wide association and genotype by environment interactions for growth traits in U.S. Red Angus cattle. *BMC Genomics, 23*, 517.

Smith, G. C., and Z. L. Carpenter. (1974). Eating quality of meat animal products and their fat content. National Research Council (US) Board on Agriculture and Renewable Resources. Fat Content and Composition of Animal Products: Proceedings of a Symposium Washington, D.C.

St-Pierre, N. R., Cobanov, B., & Schnitkey, G. (2003). Economic losses from heat stress by US livestock industries. *Journal of Dairy Science, 86*(Suppl), E52-E77.

Sullivan, M. L., Cawdell-Smith, A. J., Mader, T. L., & Gaughan, J. B. (2011). Effect of shade area on performance and welfare of short-fed feedlot cattle. *Journal of Animal Science, 89*(9), 2911-2925.

Tarr, B. (2013). Cold stress in cows. Ministry of Agriculture, Food and Rural Affairs, Factsheet AGDEX 420/51, Ontario.

USDA National Agricultural Statistics Service. (2023). Sector at a glance. National Agricultural Statistics Service (NASS), Agricultural Statistics Board, United States Department of Agriculture.

UNL Beef. (2024). *Winterizing your cowherd: Managing cows through cold stress*.

United States Department of Agriculture **(**USDA). (2017). National Agricultural Statistics Service. Overview of U.S. livestock, poultry, and aquaculture production.

United States Department of Agriculture (USDA). (2025). *Livestock and poultry outlook: 2025 annual report*.

United States Department of Agriculture, Natural Resources Conservation Service. (1997). *National range and pasture handbook* (Rev. ed., Chapter 6: Livestock nutrition, husbandry, and behavior).

Valente, J. de P. S., De-Sousa, K. T., Deniz, M., Bonilha, S. F. M., Mercadante, M. E. Z., & Dias, L. T. (2023). Heritability and genetic association of social organization traits with feeding behavior, feed efficiency and growth in Bos indicus. *Applied Animal Behaviour Science, 265*, 105976.

Van Eenennaam, A. L., & Drake, D. J. (2012). Genomic selection in beef cattle: A review of current applications and future prospects. *Animal Frontiers, 2*(1), 10-19.

Wagner, D. G. (1988). Effects of cold stress on cattle performance and management factors to reduce cold stress and improve performance. *Animal Science Department, Oklahoma State University, Stillwater, Oklahoma*.

Wang, S., Li, Q., Peng, J., & Niu, H. (2023). Effects of long-term cold stress on growth performance, behavior, physiological parameters, and energy metabolism in growing beef cattle. *Animals, 13*(10), 1619.

Wang, Z., Nkrumah, J., Li, C., Basarab, L., Goonewardene, L., Okine, E., Crews, D. H., Jr., & Moore, S. S. (2006). Test duration for growth, feed intake, and feed efficiency in beef cattle using the Growsafe System. *Journal of Animal Science*, 84(9), 2289–2298.

Wankar, A. K., Gajendra, N. B., Sandeep, N. R., Babu, L. K., & Tawheed, A. S. (2024). Heat stress in beef cattle: Climate change and the global scenario – A review. *Annals of Animal Science, 24*(4), 1093-1105.

Webster, A. J. (1971). Prediction of heat losses from cattle exposed to cold outdoor environments. *Journal of Applied Physiology, 30*(5), 684-690.

Webster, A. J. F. (1974). Heat loss from cattle with particular emphasis on the effects of cold. In *Heat loss from animals and man: Assessment and control* (pp. 205–231). Elsevier Ltd.

Wijffels, G., Sullivan, M. L., Stockwell, S., Briscoe, S., Li, Y., McCulloch, R., Olm, J., Cawdell-Smith, J., & Gaughan, J. B. (2022). Comparing the responses of grain fed feedlot cattle under moderate heat load and during subsequent recovery with those of feed restricted thermoneutral counterparts: Plasma biochemistry. *International Journal of Biometeorology, 66*, 2205–2221.

World Organization for Animal Health. (2023). *Animal welfare and beef cattle production systems.*

World Population Review. (2023). *Beef production by state*.

Yadav, B., Singh, G., Verma, A. K., Dutta, N., & Sejian, V. (2013). Impact of heat stress on rumen functions. *Veterinary World, 6*, 992–996.

Young, B. A. (1981). Cold stress as it affects animal production. *Journal of Animal Science, 52*(1), 154-163.

Young, B. A. (1983). Ruminant cold stress: Effect on production [Lower critical temperature, adaptation]. *Journal of Animal Science, 57*(6), 1601–1607.

Yusuf, M., Swanson, K. C., Hulsman Hanna, L. L., Degges, R., & Bauer, M. L. (2022). Solar radiation and temperature as predictor variables for dry matter intake in beef steers. *Frontiers in Animal Science, 3*, 975093.

Zhang, Y., Wang, X., Li, J., & Liu, H. (2023). Characterization of feed efficiency-related key signatures in different cattle breeds. *PLOS ONE, 18*(7), e0289939.

Zimmerman, L. (2012). Nearly 75% of U.S. cattle are black-hided; A look behind the numbers. *Beef Magazine*.