Estimation of genetic parameters for hair shedding score and relationship to performance in Angus, Charolais, and Hereford dams

By

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The objectives were to determine the association of hair shedding to performance in beef cattle and estimate genetic parameters for hair shedding scores. Dams were observed for shedding and given a score of 1 to 5. The month of first shedding (MFS) was determined when a female reached an average shedding score of 3.25 or less. Performance data included calf bw and d205wt and were considered as a trait of the dam. Hereford dams with a MFS of March weaned calves 18.37 ± 8.85 kg heavier than dams with a MFS of June (P < 0.01). Angus dams with a MFS of March had calves with bw 7.75 ± 1.64 kg greater than dams with a June MFS (P < 0.001). The heritability estimate for MFS was 0.11 ± 0.06. Timing of hair shedding may have an influence on growth performance for certain breeds.
DEDICATION

I would like to dedicate this thesis to one of the best ladies I’ve known, my grandmother Dorothy Winton. I’ll always cherish all the time we spent together, and I’m so grateful you were part of my life.
I would first like to thank Dr. Trent Smith for all of his support and guidance and express my gratitude for taking me on as a graduate student. I could not have asked for a more understanding, helpful, and encouraging major professor. I would also like to thank the members of my committee including Dr. Jane Parish, Dr. Rhonda Vann, and Dr. Bob Godfrey for all their assistance and advice during my time at Mississippi State University.

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CHAPTER I
INTRODUCTION

Heat stress from elevated temperature and humidity can have a significant impact on performance in beef cattle herds. When temperature humidity index values exceed 23.3° C, cattle performance declines (LCI, 1970). In the Southeastern United States, a large percentage of the year exceeds this temperature resulting in substantial economic losses. Brown-Brandl et al. (2003) observed that increasing ambient temperature resulted in increased respiration rate, increased rectal temperature, and decreased feed consumption in feeder steers. Feedlot heifers exposed to thermal stress without shade or misting had lesser average daily gains and lighter carcass weights than heifers provided shade or mist (Mitolhner et al., 2001).

Methods to alleviate heat stress could drastically impact production efficiency. Selecting environmentally adapted cattle negate these performance losses and subsequently increase productivity. This can be accomplished through selection of adapted breeds or selection within a breed. Genetic selection for increased environmental adaptability to elevated temperatures and humidity within the temperate Bos taurus breeds is one possible method to increase performance traits while maintaining carcass and growth traits of these breeds.

One trait which warrants attention is hair coat. Significant variability has been shown to exist in traits of the hair coat with associations to performance measures. In a
study conducted in Queensland, Australia, Yeates (1955) tested Shorthorn calves for heat
tolerance at 40.5° C dry-bulb temperature in a large animal psychometric chamber. It was
noted that animals with a wooly coat showed distress and failed to stabilize heat
regulation where as smooth coated animals stabilized body temperature after 2 h. Gray et
al. (2011) reported a positive moderate genetic correlation between weaning weight and
hair coat shedding in Angus females with dams that shed their winter hair coat earlier in
the season weaning heavier calves than dams which shed later in the season. These
findings suggest an association between shedding and performance and that selection for
hair shedding can impact environmental adaptability.

Based upon these findings, the objectives were to:

(1) Evaluate a hair shedding scoring system in beef cattle,

(2) Determine the association of shedding scores to performance in beef cattle,

and

(3) Estimate genetic parameters for hair shedding scores
CHAPTER I
LITERATURE REVIEW

Introduction

The objective of this literature review is to discuss the conditions and effects of heat stress in cattle, thermoregulatory mechanisms, factors influencing heat stress, and selection of cattle for adaptability through molecular and quantitative methods. Additionally, the physiology of hair anatomy and growth will be reviewed.

Heat Stress

Heat stress from elevated temperature and humidity has a significant impact on performance in beef cattle herds. Heat stress is defined as elevated body temperature resulting from a negative balance between the net amount of energy flowing from the animal to its surrounding environment and the amount of heat energy produced by the animal (St-Pierre et al., 2003). These conditions occur when the environmental temperature exceeds the thermo neutral zone of the animal (NRC, 1981). Thermo neutral zones are the environmental conditions in which cattle do not suffer heat or cold stress and is influenced by species, physiological status of the animal, the relative humidity, solar radiation, and velocity of the air.

Livestock species raised extensively in outdoor environments, such as cattle, are particularly susceptible to heat stress inducing conditions. These conditions result in
substantial production and economic losses with St-Pierre et al. (2003) reporting that the livestock industry annually incurs economic losses between $1.69 and $2.36 billion dollars due to heat stress, with $370 million occurring in the beef cattle industry alone. These economic losses stem from decreased performance in production traits.

**Production Losses**

Heat stress has a considerable effect on growth traits. In Texas, Cartwright (1955) conducted a study to determine effects of heat stress on physiological characteristics in Hereford, Brahman, and Hereford-Brahman cross cattle in a climate-controlled heat chamber. It was reported that Hereford cattle exhibited increased respiration rates and increased body temperatures when exposed to 40.5° C in the heat chamber. In addition, Hereford cattle had significantly lesser gain over the summer compared to Brahman or Hereford-Brahman cross cattle suggesting that Herefords are more susceptible to heat stress than Brahman or Brahman cross cattle. Similarly, feed intake can be affected for feeder steers subjected to heat loads greater than the thermo neutral zone compared to steers subjected to ambient temperatures in the thermo neutral zone. Brown-Brandl et al. (2003) subjected crossbred *Bos taurus* feeder steers to three heat treatments, one in the thermo neutral zone and two in heat stressed conditions in a heat chamber. Steers subjected to heat stressed conditions displayed decreased feed intake as well as increased rectal temperatures resulting in decreased average daily gains. Similar results were reported for feeder heifers in heat stressed conditions. Mitzler et al. (2001) reported that crossbred *Bos taurus* feedlot heifers exposed to thermal stress without shade or misting had lesser average daily gains and lighter carcass weights than heifers provided shade or mist.
As with growth traits, reproductive performance is affected by heat stress. Vincent (1972) reported that heat stress decreased estrous activity, increased abortions, and increased anestrus rates in beef cattle. Dunlap and Vincent (1971) placed post-pubertal Hereford heifers in a controlled environmental chamber immediately post-breeding to determine the effects of post-breeding thermal stress on conception rates. Heifers in the heat stressed treatment had conception rates of 0% and rectal temperature of 40°C while heifers in the control treatment displayed 48% conception rates. Results from this study suggest that heat stress significantly affects conception rates and that rectal temperature is indicative of heat stress. As in females, heat stress alters conception rates through reduced fertility in males. Meyerhoeffer et al (1985) reported that yearling Angus bulls exposed to 35 ±1 °C had decreased percentage of motile sperm compared to control bulls and that sperm motility did not return to normal until 8 wk after the heat treatment indicating prolonged effects of heat stress on fertility levels in Bos taurus bulls due to the lag between when developing spermatocytes are exposed to heat stress and maturation.

Thermoregulation

Cattle dissipate heat and regulate body temperature through a process known as thermoregulation. Thermoregulation is defined as the maintenance of a particular temperature of the living body. The thermoregulation mechanisms by which cattle regulate body temperature is evaporative heat transfer through sweating of the skin and respiration (Hahn, 1997). Berman (2005) reported that skin water loss begins at initial phases of heat stress, followed by recruitment of respiratory heat loss. Skin water loss increases with increasing ambient temperature to a ceiling value relative to the maximum
skin water loss rate of the animal. At lesser ambient temperatures, greater air velocities increase convective heat loss, and thereby decrease demand for evaporative heat loss. At greater ambient temperatures, greater evaporation rates required are decreased when air velocity on the body surface is less due to conservation of sweat.

For respiratory heat loss, heat transfer takes place at the interface between inhaled air and the surface of the respiratory tract over which air flows. In 2003, Brown-Brandl et al. (2003) conducted an experiment in which crossbred *Bos taurus* feeder steers were subjected to three sinusoidal temperature treatments (18 ± 7°C, 30 ± 7°C, 34 ± 7°C) for 11 d in each treatment with heat production, respiration rates, and core body temperatures measurements taken. Steers subjected to the 30 ± 7°C and 34 ± 7°C treatments had greater respiration rates and core body temperatures than steers exposed to 18 ± 7°C. Results from this study suggest that increasing ambient temperature results in increased respiration rate and rectal temperature in feeder steers suggesting that respiration rate is a mediating mechanism for reducing core body temperature.

The classical criteria for an acclimated physiological state are normal heart rate, body temperature, and respiration rate (Horowitz, 2001). Heat stress occurs when temperatures exceed the range for an acclimated physiological state. Commonly used thresholds for heat stress, classified as thermal heat index or THI, are classified using the Livestock Weather Safety Index. In the Livestock Weather Safety Index, thresholds are defined based on the severity of the heat event with temperature-humidity index values of ≤ 74 classified as normal, 74 < THI < 79 as alert, and 79 ≤ THI < 84 as danger, and ≥ 84 classified as emergency (LCI, 1970). Hahn (1985) reported that the critical ambient temperature range for optimal performance and nominal performance losses is from 0 to
25°C for mature *Bos taurus* cows with a lower critical temperature of -17°C and an upper critical temperature of 28°C. Similarly, Cartwright et al. (1955) documented that cattle originating from temperate regions begin to show signs of stress from heat at an air temperature of about 29°C. To increase heat tolerance in beef cattle, expansion of the optimum performance temperature range and nominal performance loss temperature range within a population is paramount to reducing performance losses.

Factors which effect heat stress are numerous and include physiological differences and management techniques. Yeates (1955) noted that Polled Shorthorn calves with a wooly coat showed distress and failed to stabilize heat regulation while smooth coated animals stabilized body temperature after 2 h when tested for heat tolerance at 40.5°C dry-bulb temperature in a large animal psychometric chamber suggesting that hair coat type impacts susceptibility to heat stress. Feed intake has also been observed to impact thermoregulation. In a restricted feeding study, Mader et al. (1999) housed feedlot steers under thermo-neutral or danger environmental conditions. Steers were offered a 6% roughage finishing diet ad libitum, the same diet at 85% to 90% of ad libitum DMI levels, or a 28% roughage diet ad libitum. Steers fed the high roughage diet tended to have lesser respiratory rates and significantly lesser body temperatures under hot conditions than steers fed a high energy diet indicating that ME intake prior to exposure to excessive heat load influences the ability of cattle to cope with the challenge of hot environments. Brown-Brandl et al. (2005) conducted an experiment to determine the effect of shade on physiological traits and feed intake (treatments of shade or no shade provided) in crossbred *Bos taurus* feeder steers exposed to alert, danger, and emergency temperature-humidity index values. Access to shade was found to
significantly impact physiological responses of respiration rate and core body temperature for all temperature humidity index values with access to shade reducing respiration rate and core body temperature in all-weather categories. Steers without access to shade consumed more feed from 2:00 pm through the remainder of the day, but total daily feed consumption was not different from non-shaded cattle due to greater consumption of feed by non-shaded cattle during cooler times of the day. These findings correspond to those of Mader et al. (1999) in that ME consumption is depressed in heat stressed conditions.

**Physiology of Hair**

The presence of hair is characteristic of mammalian species and it exerts a wide range of tasks including physical protection, thermal insulation, camouflage, dispersion of sweat and sebum, sensory and tactile functions, and social interaction. Hair is an outward growth of keratinized epithelial cells which originate from the dermis in mammalian species originating from the underlying hair follicle (Schneider et al., 2009). This outward hair growth is composed of three distinct cell lineages comprising the cuticle which forms the hair surface, the cortex which is the primary site of keratinization, and the medulla which is characterized by the presence of air spaces that are formed by a shrinking of medulla cells during differentiation. These different cell types contribute to the appearance of the shaft by affecting its structure, shape, light absorption, reflection, and refraction (Schlake, 2007).
**Hair Follicle**

Hair follicle formation largely takes place during fetal and perinatal skin development with little or no hair follicle development occurring after birth (Schneider et al., 2009). The hair shaft originates from the hair follicle which is comprised of several distinct structures. These structures are, beginning at the skin surface, the hair canal region which extends from the surface to the epidermal-dermal junction, infundibulum region that comprises the space between the hair canal and the sebaceous gland, isthmus which begins at the sebaceous gland and ends at the area of the bulge, and lower follicle which includes the keratogenous zone and extends from the bulge to the hair bulb which is the lowest portion of the hair follicle and envelops the follicular papilla (Goldsmith et al., 2008). Hair follicles vary considerably in size and shape depending upon their location on the host resulting in drastically different hair shafts (Paus, 1999).

**Hair Follicle Cycle**

The hair follicle undergoes regular cycles of involution and regeneration throughout an animal’s life (Schneider et al, 2009). This cycle is characterized by three distinct stages: growth (anagen phase), involution (catagen), and rest (telogen). Recently, a fourth phase has been investigated known as exogen or shedding of the hair follicle (Goldsmith et al, 2008).

The anagen stage is initiated by the formation of the new hair follicle through proliferation of secondary germ cells in the bulge (Paus, 1999). In physiological conditions, approximately 85% of hair follicle are in the anagen phase with 15% in the other phases (McElwee et al., 2008).
The catagen stage comprises a highly controlled process of involution that reflects a burst of programmed cell death (apoptosis) in follicular keratinocytes (Paus, 1999). Apoptosis of keratinocytes is characterized by abrupt ceasing of proliferation and initiation of terminal differentiation so that the lower follicle involutes and regresses. During the catagen phase, melanocytes in the matrix portion of the bulb cease melanin production, resorb their dendrites, and undergo apoptosis (Goldsmith et al., 2008). Toward the end of the catagen phase, the dermal papilla condenses and moves upward, coming to rest under the bulge prior to the initiation of hair shaft formation in the bulge (Paus, 1999).

The telogen stage is characterized by the hair developing a club-shaped proximal end within the hair follicle which is subsequently shed (Goldsmith et al., 2008). Length of the telogen phase is dependent upon several factors including species and location of the hair follicle on the animal (Schneider et al., 2009). Hair follicles of the merino sheep breed are thought to be in a permanent state of anagen and never transitioning to the telogen phase (Goldsmith et al., 2008). Shedding of the hair shaft is a facilitated process which, if not shed, can result in an inactive hair shaft being present adjacent to the active hair shaft. It is unclear whether the telogen stage is an active process or a passive event coinciding with the onset of the subsequent anagen stage (Paus, 1999).

The process of hair shedding has been investigated as an active and highly controlled process known as exogen rather than a passive process (McElwee et al., 2008). This term describes the relationship between the hair shaft and the base of the telogen follicle rather than the cycling activity of the underlying follicle (Goldsmith et al., 2008). The morphology of the hair root suggests that the exogen process involves a proteolytic
event in the cells of the telogen shaft base in which loss of certain hormones, desmoglein 3, is associated with anchorage of the hair shaft to the telogen hair follicle (McElwee et al., 2008).

**Seasonality**

Circannual patterns in hair coat have been observed in many species. Yeates (1955) observed that reversing the natural photoperiod in winter resulted in shedding of the hair coat in cattle indicating that light was the controlling mechanism for the seasonal hair cycle. The circannual pattern is biologically associated with the hormones melatonin and prolactin.

Melatonin is synthesized within the pineal gland and is secreted in response to the circadian rhythm recognized through the retino-hypothalamic tract (Arendt, 1998). In most species, concentrations of melatonin, secreted by the pineal gland, are greater during periods of darkness than during light periods (Wetterman et al, 1990). Artificial administration of melatonin has been shown to illicit the same response as naturally produced melatonin. Mink receiving melatonin implants in summer molted their summer pelage and grew winter pelage earlier than control (Rose et al., 1984). Hereford and Hereford x Angus steers administered melatonin orally possessed 38% more hair weight at the shoulder than non-treated steers after a 12 wk trial (Wetterman et al., 1990). In contrast to the above study, hair length was not different in Mouflan sheep between a control group and a melatonin implanted group when measured at the end of the season (Santiago–Moreno et al., 2003). These results suggest that melatonin supplementation does not increase the total volume of hair produced in a cycle but that supplementation initiates hair growth earlier in the growing period.
Prolactin is a polypeptide hormone that is synthesized in and secreted from specialized cells of the anterior pituitary gland (Freeman et al., 2000). Prolactin follows a circannual and circadian rhythm opposite of melatonin with greater concentrations present during periods of increasing sunlight (Roy and Prakash, 2007). Prolactin administration has been observed to induce hair shedding in mares during winter (Thompson et al., 1997). Although prolactin does affect the hair cycle, the degree of its involvement needs to be tested. In mouflan sheep, only 14% of hair length can be attributed to prolactin, which indicates that other hormones or unidentified factors play a significant role in the hair cycle (Santiago–Moreno et al., 2003).

As melatonin and prolactin production are affected by varying photoperiods, an interaction between the two hormones could be present. In melatonin implanted Mouflans, mean plasma prolactin concentrations in summer were lower than in controls (Santiago–Moreno et al., 2003); however, altering increments of melatonin by infusion or feeding mechanism does not affect prolactin levels in beef calves (Stanisiewski et al., 1988). An interaction between melatonin and prolactin could affect periods of hair growth but could be species dependent. In addition to photoperiod and hormones, temperature can affect the hair cycle. Winter conditioned Bos taurus females began shedding and had shorter hair coat depth than controls when transitioned to a 32° C chamber while exposed to a winter photoperiod (Bond, 1972). These findings suggest that multiple factors are involved in hair physiology.

Hair Coat in Cattle

The hair coat in cattle expresses the same general characteristics in hair follicle anatomy, cyclic growth and regression pattern, and seasonality as in other mammalian
species. Experiments have been conducted in cattle on several continents to determine the effect of specific hair characteristics on performance and physiological parameter. These characteristics include annual hair follicle growth cycles, hair shaft color, and length of hair shaft.

**Hair Follicle Characteristics**

Research has documented that some hair follicles are always in the growth phase at all seasons of the year. In Australia, Dowling and Nay (1960) obtained midrib skin tissue samples in five seasons (Winter 1955, Spring, Summer, Autumn, and Winter 1956) from Australian Illawarra Shorthorns, Africander, Shorthorn, Red Poll, and Zebu cross Shorthorn cattle in which 250 fibers were measured and 100 follicles were scored as being quiescent or actively growing. Dowling and Nay reported that the proportion of hair follicles in the growth phase reached a peak in September and another greater peak in March (coinciding with seasonal changes in photoperiod in Australia) in all breeds indicating that two hair coats are grown yearly with a short hair coat in the summer and a long hair coat in the winter and noted that the winter hair coat is actually new growth and is not an elongation of the summer coat.

Research in hair follicle physiology in *Bos taurus* and *Bos indicus* indicate differences between the two subspecies. Dowling et al (1955) examined differences in density of hair follicles between Zebu, crossbred Zebu, and purebred Shorthorn cattle of various ages. In this experiment, skin samples were taken using a 1 cm² trephine from multiple sites on the rib and hindquarter. Density of hair follicles was significant for both age and breed with follicles per cm² decreasing as an animal ages and Zebu and Zebu crosses having larger numbers of follicles per cm² than Shorthorns. Differences in hair
follicle density between ages are attributed to growth of the skin and the increased
distance between hair follicles due to new hair follicles not being developed after in utero
development. When comparing density of hair follicles between Zebu and Shorthorns at
one year of age, Zebu cattle had significantly denser hair follicles (2022.5 follicles per
cm²) than Shorthorns (1324.7 follicles per cm²) while Zebu x Bos taurus animals had an
intermediate number of follicles (1756 per cm²). In addition to these factors, Dowling
observed difference in hair follicle density due to body condition. Hair follicle density
was greater in drought stressed animals due to decreased surface area of the skin resulting
from BW loss due to drought conditions. In a previously discussed study, Dowling and
Nay (1960) reported considerable variation between breeds for follicle number per square
centimeter and hair weights by season. For follicle number per square centimeter,
Africander cattle had the lowest number of follicles, Zebu cross Shorthorn having the
greatest number, and the purebred Bos taurus breeds being intermediate but not different
from one another. For hair weights by season, Zebu x Shorthorn cattle had lighter hair
weights than all other breeds in all seasons. Africander cattle possessed lighter hair
weights in winter than purebred Bos taurus breeds, however, they were not different in
the other seasons.

**Hair Color**

In addition to differences in the hair follicle, color of the hair shaft can influence
performance and physiological measurements. In a study examining the effects of hair
coat color on growth and solar radiation absorption, white Shorthorn steers had
significantly greater BW gain and absorbed significantly less solar radiation (40 to 42%)
than red Shorthorn steers (61 to 64%) (Finch et al., 1983). In another study, Mader et al.
(2002) observed that dark coated (primarily black) steers panted more and had tympanic temperatures that were over 0.5° C greater during the afternoon than white steers. Hutchinson and Brown (1969) reported that black hair coats absorb more solar radiation than do white ones, but that the radiation penetrated further into the white than black coats. In white or light coated *Bos indicus* steers, the authors theorized that the short and dense hair coats of these steers compensate for the light coloration by limiting solar radiation.

**Hair Coat Evaluation**

Research into variation of the hair coat of *Bos taurus* and *Bos indicus* cattle has been conducted by several researchers in various locations. The method most often used to evaluate the hair coat is a visual numeric scoring system developed to evaluate various characteristics of the coat. Turner and Schleger (1960) appraised the hair coat of offspring from Hereford and Shorthorn dams and Hereford, Shorthorn, Africander, and Brahman sires for appearance and length using a one to seven scale with the least score indicating an extremely short and sleek coat whereas the greatest score indicated a very wooly hair coat. In a larger scale scoring system, Butts et al. (1971) developed a 17-point subjective and visual numeric scale to evaluate body condition, conformation, and hair coat of two distinct lines of Hereford cattle in two locations. Animals deemed to be fatter, more desirable in conformation, and to have smoother, shorter, and sleeker hair coats received higher scores for their respective traits. To compensate for subjectivity, cattle were evaluated by five experienced graders. Another hair coat characteristic researched using a visual numeric scale is shedding of the winter hair coat. Williams et al (2006) evaluated coat length and shedding in Limousin cattle in the United States and Brazil.
using a one to five scale with a one being short, straight, and sheds early and a five being long, curly, and late shedding. Similar to this study, Gray et al. (2011) evaluated hair coat shedding in Angus cattle in the southeastern United States using a one to five scale with a score of one being a slick and short summer coat, two being a coat that is mostly shed, three representing a coat that is halfway shed, four being a coat that exhibits initial shedding, and a five representing a full winter hair coat.

The experiments in Williams et al. (2006) and Gray et al. (2011) focused on variation in seasonal hair shedding. Seasonality in the hair coat has been observed in all cattle subspecies. In a South African study, Peters et al. (1982) evaluated seasonal differences in coat type and relationship to performance between offspring from British beef breeds, European dual purpose breeds, Africander and Africander-Brahman cross cattle, and crosses between these types. Distinct seasonal differences in coat type were reported to exist in the breed types and crosses; however, no difference in performance was observed. In Australia, Hayman and Nay (1960) conducted a series of studies to describe normal hair growth and shedding in female Bos taurus (Jersey, Red Poll, Illawara Shorthorn, and Friesan), Bos indicus (Sindhi and Sahiwal), and crosses between them (Guzerat bull and Bos taurus dams). Differences were reported in shedding pattern and commencement of spring hair coat shedding. The first observed signs of the summer hair coat were on the neck and thighs with the areas increasing along the shoulder and hindquarter and extending toward the midrib of mature Bos taurus females while Bos indicus females shed completely along the side with the last remaining unshed area being on the back. Bos indicus cattle had lighter weight summer and winter hair coats than Bos taurus cattle with hybrid animals having similar summer hair coat weights to Bos indicus
and similar winter hair coats to *Bos taurus*. *Bos indicus* females had the shortest hair length in both summer and winter. For commencement of spring hair coat shedding, differences were observed in the rate of shedding with *Bos indicus* animals exhibiting a faster rate than *Bos taurus* or crosses.

**Nutrition and Hair Coat**

Several studies have shown nutrition to influence hair coat. In a previously discussed South African study, Peters et al. (1982) reported that cows with a long and wooly hair coat had lower weights than those with short coats indicating an interaction between the animal’s nutrition and its hair coat. Yeates (1958) observed that undernourished Shorthorn heifers in Australia retained their winter hair coat throughout the summer and the hair had a harsh, dry, and bleached appearance; however, when those heifers were placed on a normal plane of nutrition normal hair shedding commenced the following spring. In the control group of Shorthorn heifers, two of the four controls partially retained their winter hair coat however; their hair was healthy appearing indicating that a retained hair coat could be due to nutrition or a seasonally inherent component.

Type of forage can also influence the hair coat. This influence is most commonly reported in cattle grazing the toxic endophyte-infected cool-season forage tall fescue (*Festuca arundinacea*) through a condition refered to as fescue toxicosis. Fescue toxicosis commonly results in a rough hair coat, due to winter hair coat retention during the summer months, with decreased tolerance to heat stress (Porter and Thompson, 1992). The effect of fescue toxicosis results from ingestion of a toxic fungal endophyte present in some cultivars of tall fescue (Bacon et al., 1970). The mechanism behind this
effect appears to be decreased prolactin secretion due to consumption of toxic endophyte-infected tall fescue (Boling et al., 1989). Research has suggested that the effect of fescue toxicosis is relative to the amount of fungal endophyte in the forage consumed. Coffey et al. (2001) observed that steers consuming tall fescue infected at lesser rates with a toxic endophyte had shorter and sleeker hair coats than steers consuming tall fescue infected at a greater rate with a toxic endophyte. In addition, loss of hair coat condition in cattle that graze toxic endophyte-infected tall fescue is suggestive of copper deficiency (Minson, 1990). Tall fescue infected with a toxic endophyte had lower concentrations of Cu in the aerial plant parts than when the endophyte was absent with this affect being exacerbated by the lesser DM consumption of toxic endophyte-infected tall fescue (Dennis et al., 1998). Coffey et al. (2002) documented steers that grazed toxic endophyte-infected tall fescue became Cu deficient by the end of the grazing season. Similar results were reported by Saker et al. (1998), with the authors reporting that steers that grazed toxic endophyte-infected tall fescue had a decline in Cu-dependent immune function compared with steers that grazed endophyte tall fescue.

**Heat Tolerance**

Due to the adverse effects of heat stress, methods to alleviate heat stress can substantially increase production of cattle in heat stressed environments. One method to minimize these effects is through the use of heat tolerant genetics. Multiple types of heat tolerant genetics can be incorporated in beef cattle operations including sub-tropically adapted breeds and selection for heat tolerant cattle within a population.
Sub-tropically Adapted Genetics

The most common management practice to minimize heat stress in the Southeastern United States is the use of *Bos indicus* genetics. *Bos indicus* genetics demonstrate lower rectal temperatures and respiration rates when compared to temperately adapted *Bos taurus* indicating greater heat tolerance (Hammond et al., 1996). In addition, substantial heterosis is also expressed when *Bos indicus* are crossed with *Bos taurus* breeds resulting in increased weaning weights, increased hip height at weaning, and BW per day of age among other traits (Baker et al., 2001). Although *Bos indicus* genetics have many beneficial characteristics, a few negative concerns have been noted. *Bos indicus* genetics, on average, produce carcasses with less intramuscular fat, less tenderness, and more variability in tenderness than *Bos taurus* animals (Crouse et al., 1993). Consequently, *Bos indicus* influenced feeder cattle commonly receive a discounted sale price due to these perceived negatives. These discounts lead many producers to search for alternative methods to using *Bos indicus* genetics.

Similar to *Bos indicus* genetics, sub-tropically adapted *Bos taurus* genetics display characteristics conducive to heat tolerance. Senepol, Romosinuano, and other sub-tropically adapted *Bos taurus* genetics demonstrate decreased rectal temperatures and respiration rates when compared to temperately adapted *Bos taurus* indicating greater heat tolerance (Hammond et al., 1996). Scharf et al. (2010) observed increased sweating rates as well as increased serum leptin, creatinine, and cholesterol concentrations when comparing Angus steers to Romosinuano steers in a controlled environment indicating decreased heat stress in the Romosinuano steers. Unlike *Bos indicus* influenced cattle, sub-tropically adapted *Bos taurus* cattle do not have the negative perception of less
desirable carcass characteristics. For tropically adapted *Bos taurus* breeds, carcass traits have been reported to be similar to temperate adapted *Bos taurus* breeds for quality grade and yield grade (Chase et al., 1998).

Although sub-tropically adapted *Bos taurus* breeds have similar carcass characteristics to temperate *Bos taurus* breeds, they possess other traits which have limited their use. Romosinuano steers have been reported to have lesser ADG than temperate *Bos taurus* animals (Phillips et al., 2006). Romosinuano have been observed to have lesser respiratory rates and rectal temperatures in both thermo neutral and heat stressed conditions than Angus steers indicating a reduced metabolic rate for this breed indicative of decreased growth rates (Scharf et al., 2010). These negatives often lead to perceived and actual decreased value for animals with tropically adapted genetics. In a report by Olsen et al. (2003), crossbred calves exhibiting the slick haired phenotype of sub-tropically adapted *Bos taurus* breeds were discounted by order buyers.

**Molecular Genetics**

Research into molecular genetics specifically major genes and single nucleotide polymorphisms related to heat tolerance shows promise in selecting cattle more adapted to heat stressed environments. A short and sleek hair coat present in some sub-tropically adapted *Bos taurus* breeds has been associated with a “slick hair gene”. The slick hair phenotype has been identified as a single dominant phenotype indicating a major gene (Olsen et al., 2003). Cattle expressing the slick hair phenotype had larger sweat glands and reduced hair length when compared to normal hair phenotype contemporaries (Landaeta-Hernandez 2010). The slick hair phenotype has been observed in Senepol as well as New World naturalized breeds. In Venezuela, the naturalized *Bos taurus* breed
Criollo Limonero primarily possesses a slick hair coat with a minority having a hair coat typical of *Bos taurus* breeds (Landaeta-Hernandez, 2010).

An investigation into identification of the molecular marker for the slick hair gene revealed candidate genes in the HSA-5 equivalent region which also includes the prolactin receptor gene (Mariasegaram, 2006). Although a larger data set is needed to validate results, these findings imply a possible controlling mechanism for the slick hair coat in the relationship between the slick hair gene and the prolactin receptor gene. As increased prolactin secretion is associated with increasing daylight and spring hair shedding, presence of the slick hair gene could impact prolactin secretion.

Olsen et al. (2003) identified the slick hair phenotype in the majority of Senepol cattle. This phenotype resulted in a short sleek hair coat with Senepol crossbred calves that were coded as slick having significantly lower clipped hair weights and rectal temperatures than calves coded as non-slick. Although slick haired calves had lower rectal temperatures, they reported no difference in weaning weights and post weaning gain were between slick haired calves and normal haired calves. The authors theorized that the effect of both slick and non-slick calves having slick coated dams in Olsen’s study could have influenced the results which suggests that the maternal influence of the dam’s hair coat is significant to weaning weights. In contrast, Williams (2006) reported that purebred progeny of Limousin sires which were slick haired had higher weaning weights and post-weaning BW gain than progeny of non-slick sires. In this study, the cattle were not identified as carrying the slick hair gene but were visually appraised as having a slick hair coat.
Selection for Heat Tolerance

Selection within breeds for heritable hair traits impacting heat tolerance has potential to increase adaptability to tropical and subtropical environments. Numerous studies have observed variability in hair coats between breeds. Breed differences were observed in winter coat type between *Bos taurus* breeds with Red Poll cattle having a mixed hair coat of long and short length hairs whereas Jersey cattle had an observable short undercoat underlying a longer outer coat (Hayman and Nay, 1960). Carter and Dowling (1960) observed that Jersey cattle had noticeably more follicles than the other *Bos taurus* breeds (Carter and Dowling 1960).

In addition to among breeds, genetic variations in hair coat characteristics have been cited within breeds. In four genetic lines of shorthorn cattle, differences in hair follicle density were seen between strain and between ages (Dowling, 1955). Butts et al. (1971) conducted a study to evaluate genotype by environment interaction using two distinct lines of Hereford cattle in two locations. The two lines used were a linebred herd from Miles City, Montana and a herd from Brooksville, Florida adapted to Florida conditions over 10 yr. These herds were divided with half of the Montana origin herd being transferred to Florida and half of the Florida origin herd was transferred to Montana. These herds were then evaluated for performance measures and phenotypic characteristics to determine any genotype by environment interactions. They observed a significant genotype by environment interaction for weaning weight and pregnancy rate with Florida origin cattle having greater weaning weights than Montana origin cattle in Florida while cattle from Montana outperformed Florida origin cattle in Montana. The sleekness score of hair was determined to be independent of environment in that Hereford
cattle originating from the subtropical environment possessed sleeker hair coats than Herefords originating from the temperate environment in both the temperate and the subtropical environment indicating that hair sleekness score is repeatable and not environmentally influenced.

With genetic variation apparent within a breed, heritability and repeatability of the trait and the traits relationship to performance measures must be determined. One trait, timing and rate of hair coat shedding, could impact performance measures. Research in Australia reported that visual scoring hair for length resulted in a heritability of 0.63 for hair score (Turner and Schleger, 1960). Gray et al. (2011) observed that there is a moderate negative genetic correlation between weaning weight and hair coat shedding with dams that shed their winter hair coat earlier in the season weaning heavier calves than dams which shed later in the season in the Angus breed. In Limousin cattle, hair slickness score was moderately heritable \( h^2 = 0.33 \pm 0.07 \) with no phenotypic or genetic correlation between hair score and post weaning gain and weaning weight in the United States; however, a negative correlation between hair score and weaning weight (\( r_p = -0.17 \)) and post weaning gain (\( r_p = -0.30 \)) was present in Brazilian Limousin cattle (Williams, 2006). Based on these results, the effect of hair coat shedding on performance could be environment specific.

**Summary**

Thermal heat stress can substantially impact productivity and profitability of beef cattle production in the Southeastern United States. Cattle mediate the effects of heat stress through the thermoregulatory responses of sweating and respiration rate. When thermal conditions exceed the ability of the animal to mediate its body temperature
through these responses, heat stress occurs. Economic and performance losses from heat stress occur through diminished growth, reproductive, and carcass traits. Selection for certain adaptive traits can aid in alleviating these conditions.

An adaptive trait which can impact production is hair. The hair shaft originates from the hair follicle which produces a differentiated hair shaft based upon multiple factors such as species and specific site on the animal. This hair follicle undergoes a growth and regression cycle which can be seasonally influenced depending on the species. This seasonality in hair follicles is influenced by numerous hormones primarily impacted by photoperiod.

In cattle, the hair coat displays considerable variability in multiple traits. Researchers have observed differences both between and within *Bos indicus* and *Bos taurus* species. These traits include hair coat length, hair color, as well as differences in hair coat shedding. Cattle which display hair characteristics more conducive to sub-tropical environments have been reported to generally outperform cattle which do not.

Methods to alleviate heat stress have traditionally focused on using tropically adapted genetics, but these methods have actual and perceived disadvantages which inhibit profitability of Southeastern cattle producers. Genetic selection for adaptive traits, such as hair coat, can aid in alleviating these disadvantages to allow cattle producers in sub-tropical environments to achieve their full productive and economic potential.
CHAPTER II
MATERIALS AND METHODS

Introduction

The objective of this chapter is to describe the specifics of this study. Sources of data, data collection procedures, statistical analysis, and components of the model are explained in detail.

Source of Data

All procedures and methods were approved by the Institutional Animal Care and Use Committee (IACUC) of Mississippi State University. Cattle used in this study were purebred Angus (n = 430), Charolais (n = 166), and Hereford (n = 97) primiparous and multiparous dams (2 to 13 years of age) and their corresponding purebred progeny housed at the Leveck Animal Research Center (LARC) in Starkville, Mississippi. Dams calved in both autumn (September to November) (n = 575) and spring (January to March) (n=117) and were managed as separate herds. Grazing consisted of warm-season perennial forages [bermudagrass (Cynodon dactylon), bahiagrass (Paspalum notatum), and dallisgrass (Paspalum dilatatum)], cool-season annual forages [annual ryegrass(Lolium multiflorum)], and a small percentage of cool-season perennials [tall fescue (Festuca arundinacea)]. Cattle were maintained under normal management protocol under the supervision of the staff at LARC throughout the duration of this study.
Progeny were the product of Angus (n = 48), Charolais (n = 41), and Hereford (n = 29) sires. All progeny were raised by their dams until weaning at 6 to 8 months of age, corresponding to autumn born calves being weaned in May and spring-born calves being weaned in October. After weaning, no further information was collected on calves.

Hair Shedding Scores

Data were collected from 2008 through 2013, beginning in March and continuing for 5 mo until July at 28-d intervals. Two trained technicians evaluated purebred females for hair shedding using a subjective, categorical, and visual scale adapted from Gray et al. (2011). The scale consisted of a one to five categorical system to evaluate timing of hair shedding (Table 1). A score of one corresponded to an animal whose coat appeared slick and short with shedding being completed, a score of two corresponded to a coat which is mostly shed (~75%), and a score of three indicated a coat which is half shed (~50%). A score of four was mostly unshed, but initial shedding had commenced (≤25%). A score of five indicated a full winter coat which had not initiated shedding. Scores were independently taken by each technician and then averaged.

Dams were then classified into five groups based upon the first month in which a dam reached an average shedding score of ≤3.25. Cows which never reached a score of 3.25 or less in the study were classified into the July category. An average score of 3.25 or less was used instead of a greater score to ensure that shedding had commenced and cows which had not begun to shed were misidentified as having started to shed. These categories were termed a dam’s month of first shedding (MFS) with MFS being used for statistical analysis. Distributions were constructed for number of cows in each MFS category for each breed. The distributions were constructed across years.
Hair Samples

Additional data were collected in March, May and July for years 2008 and 2009 for Angus dams (n = 127). A hair sample was clipped in one pass using a #10 clipper head from a 5.08 x 10.16 cm area directly behind the shoulder approximately 15.24 to 20.32 cm below the topline of the animal and collected in a plastic bag. The sample was collected from the same 5.08 x 10.16 cm area each month. The weight of the individual hair sample was calculated by obtaining the total weight of the hair and the bag, removing the hair from the bag to a temporary tray, and then weighing the empty bag. The difference in the two weights was recorded as the weight of the sample. A pulled hair sample of at least 30 hairs was obtained from each animal adjacent to the clipped area. The pulled samples were then separated and classified based upon length. These categories were short (S, < 2 cm), medium (M, 2 to 4 cm), or long (L, > 4 cm). The hair length distribution was calculated on a percentage basis from the 30 hairs obtained at random from the pulled sample. Remaining hair from the pulled sample was then counted and placed in short, medium, or long categories. The total number of hair from the pulled sample was then used to calculate the total hair number in the clipped sample as follows:

Step 1. Weight of pulled sample ÷ number of hairs in pulled sample = weight per hair

Step 2. Weight of clipped sample ÷ weight per hair from pulled sample = total number of hairs per sample

Thermal Images

Thermal images were collected in March, May and July for years 2008 and 2009 for Angus dams (n=127) using a Flir ThermaCAM® S60 (Flir Systems, Boston, MA)
infrared thermography camera. Images were taken of the 5.08 cm x 10.16 cm clipped sample area and adjacent unclipped area. Temperatures for both the clipped and unclipped areas were then analyzed using ThermaCAM Researcher Pro 2.7 software (FLIR Systems). Average temperature of the shaved area (AvgCl) was determined by constructing a rectangular polygon corresponding to the spot and analyzing temperatures with this area. The exact polygon was transferred to the unclipped area and an average surface temperature calculated for the unclipped area (AvgUn). The same polygon was used to ensure a standard surface area was being measured.

**Calf Performance**

Performance data on purebred Angus (n = 430), Charolais (n = 167), and Hereford (n=98) were collected by the LARC staff and from respective breed associations. Data included birth weight and adjusted 205-d BW (d205wt). For birth weights, calves were weighed within a 24-h period after birth by the staff at LARC. Calf d205wt records were supplied by the American Angus Association, American International Charolais Association, and the American Hereford Association.

**Statistical Analysis**

**Phenotypic Correlations**

Pearson correlation coefficients were calculated using the PROC CORR method in SAS™ (SAS Institute). Phenotypic correlations were calculated between average shedding score, AveCl, and AveUn with hair measurements. These measurements included hair number and percentage of hairs classified as short (< 2 cm), medium (2 to 4 cm), and long (> 4 cm) and thermal temperatures for AvgCl and AvgUn. Phenotypic
correlations were also estimated for birth weight and d205wt with MFS.

**Phenotypic Analysis**

A mixed model analysis, PROC MIXED in SAS™, was used to obtain least square means (LSmeans) of average clipped temperature and average unclipped temperature for average shedding score. The model included fixed effects of year, visual score, and ambient temperature. Least square means were separated with the pdiff designation in SAS.

A mixed model analysis was used to obtain least square means (LSmeans) of each response variable for MFS. Least square means were separated using the pdiff designation. Analysis was performed for each breed individually and not cumulatively. Response variables for performance were birth weight and d205wt, both of which were considered as traits of the dam. The model for d205wt and birth weight included the fixed effects of year, gender, and MFS with the random effect of sire. Age of dam was included as a fixed covariate for birth weight as birth weights were actual unadjusted values.

Additionally, a mixed model analysis was used to obtain least square means of MFS for age of dam. Analysis was again performed for each breed individually. The model included fixed effects of year, season, age of dam, and body condition score. After preliminary analysis, body condition score was not significant and was removed from the model.
Genetic Analysis

Variance and covariance components were estimated for MFS, birth weight, and d205wt using an Animal Model in ASReml 3 (Gilmour et al, 2009). A three generation pedigree of known parentage was used in the model. The relationship matrix included 1610 animals. An animal model was fit with fixed effects of year and age of the dam with the random effect of animal. The mixed model is generally expressed as follows:

\[ y = Xb + Za + e \]  

(Eq. 1)

where,

- \( y \) = \( n \times 1 \) vector of observations; \( n \) = number of records
- \( b \) = \( p \times 1 \) vector of fixed effects; \( p \) = number of levels for fixed effects
- \( a \) = \( q \times 1 \) vector of random animal effects; \( q \) = number of levels for random effects
- \( e \) = \( n \times 1 \) vector of random residual effects
- \( X \) = design matrix of order \( n \times p \), which relates records to fixed effects
- \( Z \) = design matrix of order \( n \times q \), which relates records to random effects

Solutions to the mixed model were computed by constructing the right hand side and left-hand side of the equation and subsequently adding the inverse of the additive relationship matrix multiplied by lambda to \( Z'Z \). The inverse of the additive relationship matrix was added to \( Z'Z \) to account for relationships among individuals. Lambda was multiplied by the inverse of the additive relationship matrix to account for the heritability of the trait being evaluated. After constructing, the mixed model equation appears as follows:
\[ \alpha \alpha \alpha \alpha \]  

(Eq. 2)

where,

\[ \Lambda^{-1} = \text{the inverse of the additive relationship matrix derived from the pedigree file} \]

\[ \lambda = \text{the ratio of residual variance to additive variance, } \lambda = \frac{\sigma_e}{\sigma_a} \]

\[ y = n \times 1 \text{ vector of phenotypic measurements} \]

\[ \alpha: p \times 1 \text{ vector of fixed effect estimates; } p = \text{number of levels for fixed effects} \]

\[ \alpha: q \times 1 \text{ vector of random animal effect estimates; } q = \text{number of levels for random} \]

To solve for estimated values for fixed and random effects, the inverse of the portion of the right hand side not containing our estimates was taken to form the equation:

\[ \alpha \alpha \]  

(Eq. 3)

The left-hand side was then calculated to provide estimates of fixed and animal effects. After variance components were estimated, heritability was calculated for MFS, d205wt, and birth weight using the formula \( h^2 = \frac{V_a}{V_p} \) with \( V_a \) being the variance in additive animal effects and \( V_p \) being the total variance in phenotype.
CHAPTER III

RESULTS

Introduction

This section includes results of statistical analysis for phenotypic correlations, effect of MFS on performance measures, and genetic parameters for MFS.

Distribution of MFS by Breed

The distribution of Angus dams by MFS is presented in Figure 1. The greatest percentage of cows reached their MFS in April with the least percentage of cows reaching their MFS in July. The distribution of Charolais dams by MFS is presented in Figure 2. The greatest percentage of Charolais dams reached their MFS in March and the least percentage reached their MFS in July. As month progressed, the percentage of Charolais dams with corresponding MFS declined. This indicates that some Charolais cows may have reached their MFS prior to March. The distribution of percentage of cows by MFS for Hereford dams is presented in Figure 3. The greatest percentage of Hereford cows reached their MFS in April with the least percentage occurring in July. The majority of Hereford dams had an MFS in March and April.

Phenotypic Correlations

Estimates of phenotypic correlation between number of hair percentage short, medium, and long hairs with shedding score are presented in Table 2. Correlations between shedding score and phenotypic hair measurements were varied. Correlation
estimates for shedding score with percentage short, medium or long hair lengths were -0.79, 0.73, and 0.39, respectively ($P < 0.001$). In percent medium and percent long hair, the high and moderate positive correlation estimates indicate that the percentage of medium and long hairs tends to increase as shedding score increases. In short hair, a high negative correlation estimate indicates that the percentage of short hairs tend to decrease as shedding score increases. These correlations support the validity of the shedding scale used in this study given that as shedding score increases the amount of shed hair declines resulting in a larger percentage of long and medium length hairs. The high negative correlation between shedding score and percentage of short hairs also supports the shedding scale. This indicates that the shedding scale used accurately estimates hair length. The correlation estimate for shedding score with number of hair was 0.17 ($P < 0.001$) indicating a low positive correlation in the two traits. This estimated correlation suggests that the shedding score used in this study is not an effective method to determine differences in number of hairs per animal.

Estimates of phenotypic correlation between percentage short, medium, and long hairs with AvgCl and AvgUn are presented in Table 2. Correlation estimates between AvgCl with percentage short hairs and percentage long hairs were -0.18 ($P < 0.05$) and 0.22 ($P < 0.05$) respectively. Results indicate no relationship between AvgCl and percentage of medium length hairs or number of hairs. The low negative correlation between percentage short hairs with AvgCl suggests that as AvgCl temperature increases the percentage of short hairs tends to decline. The moderate positive correlation between percentage long hairs and AvgCl indicates that as percentage of long hairs increases the
AvgCl temperature tends to increase. Correlation estimates indicate no relationship between AvgUn temperature and phenotypic measures.

Estimates of phenotypic correlation between MFS and birth weight or d205wt are presented in Table 10. Correlation estimates between MFS and birth weight or d205wt were -0.21 ($P < 0.001$) and -0.10 ($P < 0.05$) respectively. The moderate negative correlation between MFS and birth weight and the low negative correlation between MFS and d205wt suggest that as MFS increases birth weight and d205wt tend to decline.

**Least Squares Analysis**

Least square means and standard errors for AvgCl and AvgUn by shedding score for March, May, and June are given in Table 3, Table 4, and Table 5, respectively. In March, shedding score was not significant for AvgCl or AvgUn. In May, shedding score was not significant for AvgUn, but was for AvgCl ($P < 0.05$) with a shedding score of 4.5 having greater surface temperatures than all other scores. In July, shedding score was significant for both AvgCl ($P < 0.05$) and AvgUn ($P < 0.001$). Angus dams with a shedding score of 4.5 had greater AvgUn temperatures than all other shedding scores. Dams with a shedding score of 5 had significantly greater AvgUn surface temperature than 1, 1.5, 2, and 3 but smaller than a 4 and similar to a 2.5. Angus dams with a shedding score of 4.5 had significantly greater AvgCl surface temperature than 1, 1.5, 2, 2.5, and 3 but was similar to a 5. A shedding score of 5 was not different than a 1 through 3.

Least square means and standard errors for birth weight by MFS for each breed are given in Table 6. In Angus dams, MFS least square means for birth weight ranged
from 29.81 ± 2.10 to 37.6 ± 11.50 kg. Dams with a MFS of March and April gave birth to heavier calves when compared to dams with a MFS of June and July ($P < 0.001$). Birth weights of calves from dams with a MFS of May were not statistically different than March, April, or June, but were significantly heavier than July. June shedding dams produced birth weights significantly lighter than March and April, but heavier than July. Dams with a MFS of July produced the lightest calves. In Hereford and Charolais dams, MFS was not significant for birth weight.

Least square means and standard errors for d205wt by MFS for each breed are given in Table 7. For Angus and Charolais dams, no significant differences for d205wts were observed due to MFS. In the Hereford breed, least square means for d205wt by MFS ranged from 204.09 ± 4.58 to 252.12 ± 13.61 kg. Dams with a MFS of March, April, and May weaned calves significantly heavier than July shedding dams ($P < 0.05$). June shedding dams were not significantly different from April, May, or July, but were significantly lighter when compared to progeny from March shedding dams.

Least square means and standard errors for MFS by age of dam for each breed are reported in Table 8. Age of dam was not significant for MFS in Charolais dams, but was significant in Angus ($P < 0.05$) and Hereford dams ($P < 0.05$). In Angus dams, two year old dams shed significantly later than ten and thirteen year old dams ($P < 0.05$). Three year old dams shed significantly later than 6, 8, 9, 10, 11, and 13 year old dams ($P < 0.05$). Four-year old dams shed significantly later than 10-year old dams ($P < 0.05$) while 5-year old dams shed significantly later than six, eight, nine, ten, eleven, and thirteen year old dams ($P < 0.05$). Dams age 6 through 13 were not different than one another. In
Hereford dams, 2 and 3 year old dams shed later than 4, 5, 6, 7, 8, and 9 year old dams ($P < 0.05$), but did not differ from dams age 10 through 13. Dams age 4 through 12 yr did not differ.

**Genetic Analysis**

Variance and covariance estimations for birth weight, d205wt, and MFS are reported in Table 9. Heritability estimates for MFS, birth weight, and d205wt were $0.11 \pm 0.05$, $0.24 \pm 0.06$, and $0.27 \pm 0.06$, respectively. The heritability estimates indicate that MFS is a lowly heritable trait whereas birth weight and d205wt are moderate.

Genetic correlations are reported in Table 10. For genetic correlations, there was a high positive correlation between birth weight and d205wt, $0.50 \pm 0.18$, indicating that as birth weight increases d205wt tends to increase. A moderate negative correlation was present between MFS and d205wt, $-0.27 \pm 0.26$, suggesting that as MFS is later d205wt tends to decrease. A highly negative genetic correlation was present between MFS and birth weight, $-0.77 \pm 0.20$, suggesting that as MFS occurs later birth weight tends to decrease.
CHAPTER IV
DISCUSSION

Introduction
This section will comprise the discussion of results of this study. Discussion includes analysis of results and comparison and contrasts of results with prior research.

Distributions
All three breeds displayed considerable variation in MFS indicating that selection for MFS is possible. Distributions of MFS in this study concur with previous research reporting considerable variation in hair coat characteristics in *Bos taurus* cattle. Hayman and Nay (1960) reported significant variation in coat type among *Bos taurus* breeds. Additionally, Butts et al. (1971) reported significant variation in coat type among two lines of Hereford cattle indicating variation in coat type within breeds. In regards to timing of hair shedding, Gray et al. (2011) and Williams et al. (2006) both reported considerable variation in hair shedding, but significance of hair shedding was variable. These distributions suggest that variation exists in timing of hair coat shedding in Angus, Charolais, and Hereford dams.

Phenotypic Correlations
Correlations between shedding score and percentage of short, medium, and long hairs were variable. A high negative correlation was present between visual shedding score and percentage of short hairs indicating that as shedding score increases the number
of short hair tends to decrease. A moderate positive correlation was present between visual hair score and percentage of medium hairs and a highly positive correlation was present between visual hair score and percentage of long hairs indicating that as shedding score increases numbers of medium and long hairs tend to increase. These results support the visual scale as a method to evaluate hair shedding in that greater shedding scores should theoretically coincide with a decline in the number of short hairs and an increase in the number of medium and long hairs due to less of the winter coat being shed. Yeates (1955) reported that reversing the photoperiod from summer to winter photoperiods in Shorthorn calves resulted in calves not shedding, retaining their hair coat, and hairs increasing in length while calves in control photoperiods commenced shedding. In addition, clipped hair weights were significantly heavier in calves in the winter photoperiod than calves exposed to the summer photoperiod. The increased hair weights and hair lengths in the winter coat indicate a larger percentage of medium and long hairs are present in the winter hair coat as opposed to the summer hair coat.

Number of hair had a low positive correlation with shedding score, 0.17, indicating that a weak relationship exists between the number of hair and shedding score. We would expect no association. This low correlation could be due to variation in the way we estimate hair number. Schneider et al. (2009) reported that hair follicle formation takes place prenatally and is static after prenatal development which would preclude increases in the number of hair follicles an animal possesses. Although expression of hair follicles can occur at different times in an animal’s life (eg new hair growth after puberty), the number of hair should not differ during a short term trial in animals. This
result suggests that visual shedding score is not an effective method to evaluate differences in hair follicle density.

Average surface temperature of the clipped area was lowly correlated with percentage short hairs, -0.18. Although the correlation was low, it indicates that as average surface temperature of the clipped area increases the percentage of short hairs tends to decrease. The correlation suggest that shorter hair coats are associated with decreased body surface temperatures This relationship is likely due to the thermal insulating properties of the hair coat. The negative correlation indicates that shorter hairs provide less thermal insulation than medium and long hairs resulting in less heat retention. Although a longer hair coat could retain more heat, it could be mediated by thermoregulation through evaporative heat transfer (Hahn, 1997). However when ambient temperatures exceed the ability of evaporative heat transfer to mediate heat stress, the thermal insulation properties of the hair coat becomes more important. Yeates (1955) reported that Shorthorn calves with a wooly coat failed to stabilize heat regulation while smooth coated animals stabilized body temperature after two hours when tested for heat tolerance at 40.5° C dry-bulb temperature in a large animal psychometric chamber. This result indicates that longer hair coats increase heat retention and body temperatures.

Correlations between average surface temperatures of the unclipped area and phenotypic measures indicate that correlations were not different than zero indicating no associations. The lack of relationships could be due to the fact that the unclipped area’s average surface temperature is less representative of the animal’s core body temperature due to the insulative properties of the hair coat.
Least Squares Analysis

Significance of shedding score for AvgCl and AvgUn surface temperatures were variable by month. In March, shedding score was not significant for AvgCl or AvgUn. In May, shedding score was not significant for AvgCl, but was for AvgUn. In July, shedding score was significant for both AvgCl and AvgUn. In May and July, greater shedding scores generally had increased surface temperatures than lesser shedding scores for AvgCl and AvgUn (July only). As previously discussed in correlations between phenotypic measures and average surface temperatures, this difference can be theorized to be due to the thermal insulation properties of the hair coat. Shedding score was significant for AveUn in July. Although ambient temperature was included as a covariate in the model, the differences by month could be attributed to differences due to season. In Mississippi, July is one of the months with the greatest average monthly temperature which could explain the difference in significance by month.

For birth weight, MFS was significant for the Angus dams but not for Charolais or Hereford dams. Angus dams which shed in March gave birth to calves $7.82 \pm 1.65$ kg heavier than dams which shed in July. The difference in significance among the breeds could be the result of many factors, including heat stress. The most obvious difference in adaptive traits in these breeds is coat color. Hutchinson and Brown (1969) and Finch et al. (1983) reported that cattle with dark colored hair coats absorbed more solar radiation than light colored hair coats. Additionally, Mader et al. (2002) reported that crossbred steers with darker hair coats had tympanic temperatures $0.5^\circ$ C higher during the afternoon than light colored steers. Physiological differences may have also influenced these results. Dowling (1955) and Dowling and Nay (1960) reported differences in hair
follicle number between *Bos indicus* and *Bos taurus* as well as between breeds within these species. Results from this study lead us to suggest that the significance of MFS on birth weight could be breed specific.

Angus dams used in this study were from both autumn and spring calving herds. In autumn-calving cattle, it can be theorized that carrying an unshed coat through late spring and summer could result in decreased birth weights due to heat stress from the unshed coat. Butts et al. (1971) reported that Hereford cows with longer hair coats had reduced birth weights in a sub-tropical environment compared to Hereford cattle in a temperate environment. However a proportion of these females were spring calving indicating that MFS is significant for birth weight in both spring and autumn-calving Angus females in Mississippi.

For d205wt, MFS was significant for Hereford dams, but not for Charolais or Angus. Hereford dams which shed in March weaned calves 48.12 ± 14.25 kg heavier than dams which shed later. The significance of shedding on performance could be due to breed or location. Gray et al. (2011) reported that Angus dams in North Carolina and Mississippi which began to shed by the end of May had d205wts 11.1 kg heavier than Angus dam which began to shed after May. Records from Angus dams in 2008 and 2009 used in this study represented the Mississippi cattle in Gray et al. (2011) plus additional Angus records up to 2013. However, MFS was not significant in this study. In North Carolina, the diet of the dams evaluated was primarily toxic endophyte-infected tall fescue. Porter and Thompson (1992) reported that consumption of toxic endophyte-infected tall fescue can result in a retained hair coat. The diet could have influenced the
evaluation of hair coat shedding in North Carolina. Differences in nutrition between the two studies could explain the difference in significance. Williams et al. (2006) reported no genetic or phenotypic correlation present between shedding score and weaning weight for Limousin cattle in the United States; however, shedding score was negatively correlated with weaning weight in Limousin cattle in Brazil. The authors theorize that the difference in significance due to locations could be attributable to differences in environment. These varied results suggest that the significance of shedding score on performance could be environment and genotype specific.

Age of dam was significant for MFS in Angus and Hereford dams, but not for Charolais. In both the Angus and Hereford dams, differences in MFS due to age were primarily in younger dams. The cause of these differences is unknown, but could be due to growth and development in the young dam. In regards to hair physiology, Dowling (1955) reported that hair follicle density is influenced by age with hair follicle density decreasing as an animal’s age increases. Although hair follicle formation occurs prior to birth, expression of hair follicles can be depressed until certain periods in life. A common example of this is initiation of hair shaft growth in many species coinciding with puberty. The influence of puberty on hair follicle expression in cattle has not been studied, but warrants research. Differences in MFS due to age were significant and warrant further investigation into the mechanism behind these differences.

**Genetic Analysis**

Heritability estimates for birth weight, d205wt, and MFS 0.27 ± 0.06, 0.24 ± 0.06, and 0.11 ± 0.05, respectively. Estimates for birth weight and d205wt were included for
The heritability estimate for MFS is lower than previously reported estimates of heritability for other hair characteristics. Turner and Schleger (1960) reported a heritability estimate of 0.63 for hair length score. In this study, the trait being evaluated was hair coat length evaluated at a standard time in the summer. This scale was different than the scale used in this study in that cattle were evaluated multiple times in a year and categorized based upon the point in which they reached a predetermined level of shedding (~50%). The differences in heritability estimates could be due to the trait being evaluated, when and how many times animals were evaluated, and the scale used to evaluate the animals.
The moderate negative phenotypic correlation between birth weight and MFS, -0.21, suggest that birth weight tends to decrease as MFS occurs later. This could be due to heat stress negatively impacting fetal growth due to the dam retaining a winter hair coat into the warmer seasons. Mader et al. (1999) reported metabolizable energy consumption is depressed in cattle experiencing heat stress. Decreased feed intake in a pregnant dam can negatively impact fetal growth and development (Funston et al., 2009). Dams with MFS occurring later could produce calves with decreased birth weights due to nutrition or other factors associated with heat stress. In preliminary analysis, calving season was included as a fixed effect but was not significant. The lack of significance suggests that MFS is negatively correlated with birth weight in both spring and autumn-calving animals in Mississippi.

A moderate genetic negative correlation was present between MFS and d205wt, -0.27 ± 0.26, suggesting that as MFS occurred later d205wt tended to decrease. This correlation is similar to the genetic correlation between weaning weight and d205wt reported in Williams et al. (2006) and Gray et al. (2011). A high negative genetic correlation was present between MFS and birth weight suggesting that later MFS is associated with decreased birth weights. These correlations indicate that hair coat shedding negatively affects birth weight and d205wt. Although low birth weights are beneficial in preventing dystocia, they are negatively correlated with weaning weight. This is an important consideration for cow-calf producers in sub-tropical environments because weaning weight is associated with profitability. These negative genetic correlations suggest that MFS can impact birth weight and d205wt of Angus cattle in Mississippi.
Conclusion

Timing of hair shedding in beef cattle is variable. Angus, Charolais, and Hereford dams all displayed considerable variation in hair coat shedding and phenotypic hair coat characteristics with results indicating that the scale used in this study to evaluate hair shedding was appropriate. The significance of hair coat shedding on performance traits was variable with shedding being significant in some breeds for some traits and not in others. Month of first shedding was estimated to be lowly heritable, however shedding may be more heritable when using a different classification method. Negative genetic correlations were estimated for month of first shedding with performance traits which suggests that later hair shedding can negatively impact performance. Based upon these results, timing of hair shedding could impact performance in certain *Bos taurus* breeds in subtropical environments.
CHAPTER V
IMPLICATIONS

In conclusion, the shedding scale used in this study is an appropriate method for evaluating the state of hair shedding in these breeds. The significance of month of first shedding on performance was variable by breed and by trait evaluated indicating that month of first shedding does not affect performance in all beef cattle breeds in subtropical environments. Month of first shedding was estimated to be lowly heritable in Angus dams and was negatively correlated with performance traits suggesting that the later month of first shedding occurs the more birth weight and weaning weight decline. Although lighter birth weights are beneficial in preventing dystocia, the positive genetic correlation of birth weight with weaning weight result in decreased birth weights being associated with decreased weaning weights. Based upon these results, Angus producers should not select for later hair shedding to decrease birth weight, but should instead focus on sire selection to control birth weights. Producers selecting for increased weaning weight in some cattle breeds should consider culling females which have not shed fifty percent of their winter hair coat by July.
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APPENDIX A

TABLES

Table 1  Description of hair coat shedding scores.

<table>
<thead>
<tr>
<th>Hair Shedding Score</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Slick and short summer coat (100% shed)</td>
</tr>
<tr>
<td>2</td>
<td>Coat is mostly shed (~75%)</td>
</tr>
<tr>
<td>3</td>
<td>Coat is halfway shed (~50%)</td>
</tr>
<tr>
<td>4</td>
<td>Coat exhibits initial shedding (≤ 25%)</td>
</tr>
<tr>
<td>5</td>
<td>Full winter coat with no indication of shedding (0%)</td>
</tr>
</tbody>
</table>

Table 2  Correlations between surface temperatures and phenotypic measures

<table>
<thead>
<tr>
<th></th>
<th>Hair no.</th>
<th>% Short</th>
<th>% Medium</th>
<th>% Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shedding Score</td>
<td>0.16866</td>
<td>-0.79970</td>
<td>0.73078</td>
<td>0.39267</td>
</tr>
<tr>
<td>$P$-value$^i$</td>
<td>0.0010</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>AvgCl</td>
<td>-0.13073</td>
<td>-0.18034</td>
<td>-0.04984</td>
<td>0.22760</td>
</tr>
<tr>
<td>$P$-value$^p$</td>
<td>0.1445</td>
<td>0.0433</td>
<td>0.5794</td>
<td>0.0104</td>
</tr>
<tr>
<td>AvgUn</td>
<td>-0.12892</td>
<td>-0.01768</td>
<td>-0.03047</td>
<td>0.05104</td>
</tr>
<tr>
<td>$P$-value$^p$</td>
<td>0.1502</td>
<td>0.8442</td>
<td>0.7348</td>
<td>0.5703</td>
</tr>
</tbody>
</table>

$^i$Prob > |r| under H0: Rho =0
### Table 3
Least square means for average temperature by shedding score for March (°C)

<table>
<thead>
<tr>
<th>Shedding Score</th>
<th>AveUn, °C</th>
<th>AveCl, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>29.73 ± 1.88</td>
<td>32.94 ± 0.94</td>
</tr>
<tr>
<td>2.5</td>
<td>28.60 ± 1.32</td>
<td>33.32 ± 0.66</td>
</tr>
<tr>
<td>3</td>
<td>28.40 ± 0.47</td>
<td>33.63 ± 0.24</td>
</tr>
<tr>
<td>3.5</td>
<td>28.48 ± 0.65</td>
<td>34.26 ± 0.32</td>
</tr>
<tr>
<td>4</td>
<td>28.02 ± 0.38</td>
<td>33.98 ± 0.19</td>
</tr>
<tr>
<td>4.5</td>
<td>27.11 ± 0.88</td>
<td>34.11 ± 0.44</td>
</tr>
<tr>
<td>5</td>
<td>25.29 ± 0.95</td>
<td>33.49 ± 0.43</td>
</tr>
</tbody>
</table>
### Table 4
Least square means for average temperature by shedding score for May (°C)

<table>
<thead>
<tr>
<th>Shedding Score</th>
<th>AveUn</th>
<th>AveCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35.99 ± 0.83</td>
<td>36.58 ± 0.63&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>1.5</td>
<td>35.86 ± 0.59</td>
<td>35.81 ± 0.45&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>35.92 ± 0.31</td>
<td>36.44 ± 0.24&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2.5</td>
<td>36.25 ± 0.58</td>
<td>37.10 ± 0.45&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>35.59 ± 0.30</td>
<td>37.04 ± 0.23&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>3.5</td>
<td>36.54 ± 0.68</td>
<td>37.50 ± 0.52&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>35.11 ± 0.49</td>
<td>37.54 ± 0.37&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>4.5</td>
<td>37.78 ± 1.86</td>
<td>39.73 ± 1.42&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>33.96 ± 1.86</td>
<td>37.39 ± 1.42&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a,b,c</sup> LS Means with different superscripts within column differ \( P < 0.05 \)
Table 5  Least square means for average temperature by shedding score for July (°C)

<table>
<thead>
<tr>
<th>Shedding Score</th>
<th>AveUn</th>
<th>AveCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36.65 ± 0.18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35.88 ± 0.32&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>1.5</td>
<td>36.52 ± 0.32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35.73 ± 0.58&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>37.19 ± 0.27&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.27 ± 0.49&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2.5</td>
<td>37.75 ± 0.98&lt;sup&gt;ac&lt;/sup&gt;</td>
<td>35.47 ± 1.76&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>36.75 ± 0.53&lt;sup&gt;a&lt;/sup&gt;</td>
<td>34.73 ± 0.95&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>4.5</td>
<td>39.96 ± 1.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>40.30 ± 1.87&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>38.30 ± 1.38&lt;sup&gt;c&lt;/sup&gt;</td>
<td>37.69 ± 2.48&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a,b,c</sup> LS Means with different superscripts within column differ *P* < 0.05

Table 6  Least square means for birth weight by MFS<sup>1</sup> by breed

<table>
<thead>
<tr>
<th>MFS&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Angus</th>
<th>Charolais</th>
<th>Hereford</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>37.61 ± 1.50&lt;sup&gt;c&lt;/sup&gt;</td>
<td>44.61 ± 1.58</td>
<td>38.29 ± 1.65</td>
</tr>
<tr>
<td>April</td>
<td>37.45 ± 1.48&lt;sup&gt;c&lt;/sup&gt;</td>
<td>44.41 ± 1.61</td>
<td>39.23 ± 1.54</td>
</tr>
<tr>
<td>May</td>
<td>36.12 ± 1.52&lt;sup&gt;cb&lt;/sup&gt;</td>
<td>44.77 ± 1.75</td>
<td>36.93 ± 1.58</td>
</tr>
<tr>
<td>June</td>
<td>35.03 ± 1.55&lt;sup&gt;b&lt;/sup&gt;</td>
<td>41.83 ± 1.72</td>
<td>42.02 ± 2.16</td>
</tr>
<tr>
<td>July</td>
<td>29.81 ± 2.10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>41.53 ± 2.69</td>
<td>35.14 ± 3.28</td>
</tr>
</tbody>
</table>

<sup>a,b,c</sup> LS Means with different superscripts within column differ *P* < 0.05

<sup>1</sup> Month of First Shedding
Table 7  Least square means for d205wt by MFS\textsuperscript{1} by breed

<table>
<thead>
<tr>
<th>MFS\textsuperscript{1}</th>
<th>Angus</th>
<th>Charolais</th>
<th>Hereford</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>251.38 ± 3.93</td>
<td>262.16 ± 4.97</td>
<td>252.12 ± 4.58 \textsuperscript{c}</td>
</tr>
<tr>
<td>April</td>
<td>250.25 ± 3.39</td>
<td>251.66 ± 5.33</td>
<td>243.10 ± 4.81 \textsuperscript{cb}</td>
</tr>
<tr>
<td>May</td>
<td>248.75 ± 3.99</td>
<td>262.27 ± 6.70</td>
<td>238.64 ± 6.63 \textsuperscript{eb}</td>
</tr>
<tr>
<td>June</td>
<td>241.79 ± 3.95</td>
<td>253.04 ± 1.72</td>
<td>233.75 ± 7.63 \textsuperscript{ab}</td>
</tr>
<tr>
<td>July</td>
<td>234.20 ± 8.91</td>
<td>256.25 ± 14.59</td>
<td>204.09 ± 13.61 \textsuperscript{a}</td>
</tr>
</tbody>
</table>

\textsuperscript{a,b,c} LS Means with different superscripts within column differ $P < 0.05$

\textsuperscript{1} Month of First Sheding
Table 8  Least square means for MFS\(^1\) by age of dam

<table>
<thead>
<tr>
<th>Dam age</th>
<th>Angus</th>
<th>Charolais</th>
<th>Hereford</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.62 ± 0.17(^{cd})</td>
<td>2.26 ± 0.24(^a)</td>
<td>3.55 ± 0.41(^c)</td>
</tr>
<tr>
<td>3</td>
<td>2.82 ± 0.15(^d)</td>
<td>2.08 ± 0.28(^a)</td>
<td>2.70 ± 0.35(^{bc})</td>
</tr>
<tr>
<td>4</td>
<td>2.56 ± 0.15(^{ad})</td>
<td>2.30 ± 0.23(^a)</td>
<td>2.28 ± 0.34(^{ab})</td>
</tr>
<tr>
<td>5</td>
<td>2.60 ± 0.16(^{ad})</td>
<td>2.12 ± 0.26(^a)</td>
<td>1.89 ± 0.32(^{ab})</td>
</tr>
<tr>
<td>6</td>
<td>2.33 ± 0.15(^{abc})</td>
<td>2.03 ± 0.24(^a)</td>
<td>1.91 ± 0.34(^{ab})</td>
</tr>
<tr>
<td>7</td>
<td>2.50 ± 0.18(^{abcd})</td>
<td>1.93 ± 0.29(^a)</td>
<td>1.43 ± 0.32(^a)</td>
</tr>
<tr>
<td>8</td>
<td>2.28 ± 0.21(^{abc})</td>
<td>1.78 ± 0.53(^a)</td>
<td>2.27 ± 0.37(^{ab})</td>
</tr>
<tr>
<td>9</td>
<td>2.24 ± 0.27(^{abc})</td>
<td>2.91 ± 0.61(^a)</td>
<td>1.96 ± 0.49(^{ab})</td>
</tr>
<tr>
<td>10</td>
<td>1.74 ± 0.38(^{bc})</td>
<td>2.06 ± 0.60(^a)</td>
<td>2.22 ± 0.73(^{abc})</td>
</tr>
<tr>
<td>11</td>
<td>1.83 ± 0.44(^{c})</td>
<td>-</td>
<td>2.72 ± 0.73(^{abc})</td>
</tr>
<tr>
<td>12</td>
<td>2.40 ± 0.74(^{abcd})</td>
<td>2.43 ± 0.76(^a)</td>
<td>3.21 ± 1.02(^{abc})</td>
</tr>
<tr>
<td>13</td>
<td>1.53 ± 1.05(^{abc})</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^{a,b,c,d}\) LS Means with different superscripts within column differ \(P < 0.05\)

\(^1\) Month of First Shedding

Table 9  Variance component estimates and genetic correlations

<table>
<thead>
<tr>
<th>Trait</th>
<th>Additive Variance</th>
<th>Residual Variance</th>
<th>Heritability</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFS(^1)</td>
<td>0.132</td>
<td>1.056</td>
<td>0.11 ± 0.05</td>
</tr>
<tr>
<td>D205wt</td>
<td>1179.39</td>
<td>3687.53</td>
<td>0.24 ± 0.06</td>
</tr>
<tr>
<td>Birth weight</td>
<td>46.562</td>
<td>125.99</td>
<td>0.27 ± 0.06</td>
</tr>
</tbody>
</table>

\(^1\) Month of First Shedding
Table 10  Phenotypic and genetic correlations among MFS\(^1\) and performance\(^2\)

<table>
<thead>
<tr>
<th>Trait</th>
<th>MFS(^1)</th>
<th>D205wt</th>
<th>Birth weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFS(^1)</td>
<td>-</td>
<td>-0.27 ± 0.26</td>
<td>-0.77 ± 0.20</td>
</tr>
<tr>
<td>D205wt</td>
<td>-0.10807</td>
<td>-</td>
<td>0.50 ± 0.18</td>
</tr>
<tr>
<td>Birth weight</td>
<td>-0.21963</td>
<td>0.43435</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^1\) Month of First Shedding

\(^2\) Phenotypic correlations are in the lower triangle and genetic correlations are in the upper triangle
APPENDIX B

FIGURES

Figure 1  Distribution of Angus MFS
Figure 2  Distribution of Charolais MFS
Figure 3  Distribution of Hereford MFS