EVALUATION OF BREED AND TEMPERAMENT EFFECTS ON COW REPRODUCTIVE TRAITS AND LONGEVITY IN A CROSSBRED CATTLE POPULATION

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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December 2019

Major Subject: Animal Breeding

ABSTRACT

The genetics of longevity in beef cattle production is a critical aspect of efficiency, thus making it an economically important trait. Variation in longevity has been observed between different breeds, and is dependent on individual animal reproductive performance amongst other traits. The effects of temperament on cow longevity has not been assessed before. The objective of this study is to evaluate the effects of breed type and temperament on longevity and reproductive traits in a predominantly *Bos indicus* x *Bos taurus* beef cow herd at the E. G. Morrison Brown Loam Research Station in central Mississippi.

Cows (n = 1,285) involved in the study were categorized by breed type (i.e. ≥ 0.25 and < 0.25 proportion *Bos indicus* influence) and temperament. Temperament categories were constructed based on exit velocity records (n = 747) and were distributed equally within 4 groups. The groups consisted of a categorization between 1 through 4, where most temperamental animals were placed in the 4th category and the most docile in the 1st temperament category. Calving and weaning records (n = 5,052) were utilized for evaluation of cow reproductive traits. Longevity data was analyzed using a threshold model with a probit function. Age category of the dam was a significant source of variation in calving rates ($P < 0.001$), weaning rates ($P < 0.001$), and 205-day weight ($P < 0.001$). Variation for breed effects within ages were significant ($P < 0.005$) in analysis of longevity.

In conclusion, cows that were greater than or equal to a proportion of 0.25 *Bos indicus* background tended to remain productive at advanced ages, while cows of less

than 0.25 *Bos indicus* influence were observed to leave the herd at a younger age. Temperament did not play a significant role in differences of longevity or reproductive traits within this study, but the inclusion of more temperament records could provide a more precise estimate.

DEDICATION

This work is primarily dedicated to Mr. Abiel R. Peña, my father. He was the person whom believed in me the most, especially in times when I did not believe in myself. May he rest in peace.

ACKNOWLEDGEMENTS

I would like to express my utmost gratitude to my committee chair, Dr. David G. Riley, for allowing me the chance to pursue a graduate degree and for his infinite patience in the process. I would also like to thank my committee members, Dr. Herring, Dr. Sanders, Dr. Vann, and Dr. Forrest for the opportunities that presented themselves along the way and for their valuable insight throughout my research endeavors. To Dr. Dan Hale, many thanks for the opportunities that you bestowed upon me.

Many thanks to Dr. Salvador Romo, Dr. Adalberto Garza, and Dr. Servando Rodriguez Saldivar for sharing their expertise that opened many doors for me; To Dr. Paul Holland and Dr. Jose Delgadillo for their support in difficult times;
Finally, to my mother and all my friends for their encouragement along the way, as it was almost impossible without them.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Cow longevity is one of the most economically important traits in beef cattle production (Sanders, 2012). Longevity is defined as the maximum age the cow achieved before becoming subfertile (Cartwright, 1970) or the age when culled from the herd because she is no longer expected to be profitable. The costs associated with the replacement of females and heifer development are usually mitigated within an older, more productive cow herd (Nunez-Dominguez et al.,1991). The lower productivity of younger females compared to older females must also be taken into consideration within the discussion of cow longevity.

Bos indicus x *Bos taurus* crossbred cows have often been recognized by their long reproductive lifespans due to their adaptation to harsher environments and preweaning productivity derived from heterosis effects (Riley et al., 2001a; Thrift and Thrift, 2003). Additionally, animals of *Bos indicus* influence have also been recognized as more temperamental than those of no *Bos indicus* influence (Voisinet et al., 1997) and have persistently been discounted as feeder and fed cattle within the United States beef industry for unfavorable carcass characteristics (Crouse et al., 1989). What remains important, however, is the animal's ability to survive and reproduce in tropical and sub-tropical conditions, which is considered a primary reason for the utilization of *Bos indicus* breeds in beef cattle production systems in the Southern United States (Riley, 2012).

The relationship between temperament and cow longevity is currently not well understood. Given the reputation of the *Bos indicus* x *Bos taurus* cow in the sub-tropics, it is critical to investigate the genetic relationship of temperament on longevity in addition to cow reproductive traits.

The objective of this study was to assess breed (proportion *Bos indicus* influence) and temperament effects on cow longevity and cow reproduction traits in cows of a predominantly crossbred cow herd at the Mississippi Agricultural and Forestry Experiment Station in Raymond, MS.

2. LITERATURE REVIEW

2.1. Crossbreeding and its importance

Crossbreeding in livestock production is utilized extensively to bring together desirable traits from two parent breeds that differ genetically. The value of crossbreeding over straightbreeding lies in exploitation of heterosis effects and complementarity, which requires the appropriate breed combinations to suit the environment and production system (Hammack, 1998). Depending on the structure of the system, and the local conditions in which they are implemented, substantial increases in animal performance and farmer income can be observed from crossbreeding in livestock production (Roschinsky et al., 2015).

Heterosis, or hybrid vigor, is a measure of performance of crossbred progeny over the average of the straightbred parents. The main benefit of crossbreeding is heterosis, which can either be positive or negative, and is a result of increased heterozygosity of an individual's genotype. As described by Wakchaure et al. (2015), hybrid vigor is observed from three sources: paternal, maternal and the animal itself. Paternal heterosis is observed in crossbred sires, although assessment of paternal heterosis is not common. Maternal heterosis is derived from the maternal character of a crossbred mother which contributes to the productivity of the offspring. Lastly, the progeny directly exhibit heterosis as a result of inheritance of a heterozygous genotype from the sire and the dam.

2.2. Crossbreeding systems

The concept of modern livestock production systems is to strategically take advantage of heterosis effects in the context of complementary breeding, with goals to improve levels of production and subsequently increase profitability. Terminal crossbreeding systems aim to produce an animal that has tremendous growth ability and is marketed for meat. This strategy usually involves a highly productive cow that expresses acceptable maternal abilities to produce progeny that is not destined to be kept as a replacement, hence the name "terminal". Rotational crossbreeding strategies are most often used in systems where crossbred cows are utilized and are alternatively mated to sires of different breeds, based on their respective breed composition. The objective is to take advantage of the hybrid vigor expressed in a crossbred dam's maternal ability, which can positively contribute to the progeny's performance. Although heterosis levels are usually lesser in rotational crossbreeding than in terminal crossbreeding programs, the production of replacement females can be advantageous. The production of composite breeds, on the other hand, is also a well recognized breeding strategy in livestock production with known benefits. Although there is potential for heterosis exploitation in this method, the stabilization of the novel breed takes multiple generations to be reached. The complementary genetic make-up of at least two parent breeds, in this instance, are utilized for benefit. The need for replacements are minimal, if any, and can be considered an economical advantage for many commercial producers when compared to other crossbreeding strategies. Table 1, derived from Leroy et al.

(2016), portrays the merits and weakness of the previously mentioned, and most commonly recognized crossbreeding strategies.

Table 1: Merits and weaknesses of various crossbreeding strategies[1]

Crossbreeding type	Use of Heterosis	Use of adapted genes	Conservation of local breeds	Genetic composition of products	Constraints
Terminal crossbreeding	Yes	Yes	Yes	Stable	Need of continuous supply of genetic material (Both Sexes)
Rotational crossbreeding	Yes	Yes	Yes	Variable	Need of continuous supply of genetic material (Males only)
Upgrading/Breed Substitution	No	No	No	Stable after several generations	Adaptation constraints
Development of composite	No	Yes	No	Stable after several generations	Several generations required

[1]Table 1 reproduced from Leroy et al. (2016).

2.3. **Bos indicus** ***cattle in crossbreeding***

Cattle of *Bos indicus* descent have been repeatedly documented for their ability to withstand the hot, humid climates in the Southeast and Gulf Coast regions of the United States (Thrift and Thrift, 2003). A smooth hair coat and well-developed sweat glands contribute to their capability to thrive in warmer environments (Turner, 1980). Parasite resistance and calving ease are also attributes observed in the hybrid females, and are considered a contributing factor to their longer, more productive lives (Thrift and Thrift, 2003).

Evidence of *Bos indicus* x *Bos taurus* crosses versus *Bos taurus* x *Bos taurus* crosses expressing higher levels of hybrid vigor has been widely acknowledged (Chase et al., 2005), especially in female reproductive traits (Table 2; Riley, 2012) where improvement is not greatly influenced by selection.

Table 2: Brahman, Angus, and Romosinuano straightbred and crossbred cow reproductive traits[1]

	N	Pregnancy rate	Calving rate	Weaning rate
Straightbred				
Brahman	175	0.76	0.76	0.70
Angus	161	0.84	0.84	0.82
Romosinuano	194	0.82	0.82	0.78
F_1				
Brahman x Angus	420	0.95	0.95	0.93
Brahman x Romosinuano	462	0.89	0.89	0.86
Romosinuano x Angus	397	0.87	0.86	0.81
Heterosis				
Brahman x Angus		0.15 (18%)	0.15 (19%)	0.17 (22%)
Brahman x Romosinuano		0.10 (13%)	0.10 (13%)	0.12 (16%)

[1]Table 2 reproduced from Riley (2012).

The crossbred progeny of *Bos indicus* with *Bos taurus* cattle breeds are well known for their cow productivity and efficiency, especially in the Southern United States (Riley et al., 2001) but also in the more temperate Great Plains. The multi-cycle GermPlasm Evaluation (GPE) project at the US Meat Animal Research Center further confirmed the high productivity of *Bos indicus* crossbreds. Females of *Bos indicus* influence reach sexual maturity much later than *Bos taurus* cattle, but their superior productivity as multiparous cows was assessed in the GPE project. The performance of F_1 females from 3 to 7 years of age consistently ranked at or near the top in several production traits that were measured during the study (Table 3; Cundiff, 2005).

Table 3: Sire breed least square means for reproduction and maternal performance of F_1 cross females calving at 3 through 7 years of age[1]

Sire breed of female	Number		Calf crop		Unassisted calving %	**Calving diff. sc.	Birth weight (lb.)	205-day weight	
	Cows exposed	Calves born	% Born	% Weaned				Per calf	Per cow exposed
Hereford	470	439	93.8	88.7	95.2	1.25	93.0	483	430
Angus	376	354	93.6	86.3	96.4	1.18	90.5	503	434
Brahman	621	575	92.8	84.3	98.8	1.04	82.1	527	444
Boran	655	604	93.1	86.2	96.9	1.12	81.6	498	429
Tuli	722	650	90.1	84.1	96.8	1.17	84.4	481	405
Longhorn	333	312	96.4	89.4	98.5	1.04	85.9	455	411
Nellore	319	303	97.5	91.4	99.7	1.08	81.9	513	467

[1]Table 3 derived from Cundiff (2005)
**Calving difficulty score; higher scores indicate more difficult births.

The United States beef industry identified cuts from animals of *Bos indicus* influence to be a problem because of their relative lack of tenderness (Crouse et al., 1989) which often results in discounts on carcasses or live animals with identifiable *Bos indicus b*ackground. Additionally, the temperament study by Voisinet and colleagues (1997) reported worse temperament scores for animals of *Bos indicus* influence. Within the same report, more temperamental animals experienced lower average daily gains than their more docile contemporaries suggesting a relationship between temperament and performance. Thrift et al. (2010) articulated the known issues identified within the Brahman breed, reinforcing the idea that no single breed excels in all traits (Cundiff et al., 2000). The notable market pressure placed on crossbred animals does not overshadow the value of adaptability when utilizing breeds of *Bos indicus* descent in beef cattle production systems in harsher environments and such has catalyzed research efforts to understand and improve the Brahman breed.

2.4. Cow reproductive traits

Reproductive traits are usually considered the economic foundation of most cattle producing enterprises. Superior weaning and calving rates have been documented in *Bos indicus* x *Bos taurus* cross cows (Cundiff et al., 1993; Riley et al., 2015) over *Bos taurus* cattle, further reinforcing the positive effects of heterosis on traits depicting maternal efficiency.

Calving rates illustrate the percentage of females that calved (full-term) relative to the number of exposed females exposed to breeding. This trait encompasses the proportion of females that successfully produce a calf. Similar in nature, weaning percentages encompass the total amount of calves weaned per cow exposed to a breeding opportunity. Naturally, some calves do not survive to weaning, thus making weaning rates lower than calving rates. Weaning percentages provide information on females that were unable to wean a calf successfully in a given year but may have given birth. By understanding weaning and calving percentages it is possible to conclude whether calves or their respective cows are at fault.

2.5. Longevity

Longevity is a complex trait that is dependent on an array of factors, and it is deemed to be economically important. In dairy cattle, cows with increased levels of longevity had positive effects on milk production by reducing replacement costs and increasing the proportion of mature, high producing cows in a herd (Vukasinovic et al., 2001). An improvement in longevity reduces the annual production costs associated with raising replacement heifers, reduces the number of involuntarily culled cows, and increases the number of high producing mature cows (Rogers et al., 2004). It also enables a greater selection response, because fewer animals have to be replaced and, thus, higher selection intensity of cows is possible. An increase in selection intensity is not only economically beneficial for producers, but also generally considered advantageous in focusing on improving production or functional traits (Vukasinovic et al., 2001). The heritability of longevity traits is generally considered to be very low. Vollema (1998) documented heritabilities below 0.10. Stayability essentially refers to a cow's ability to wean a certain number of calves by a given age, for example 5 calves by 6 yr of age (Engle et al., 2018). The heritability of stayability traits are generally lower (around 0.04) than that of lifetime traits (around 0.09 Vollema, 1998).

2.6. Temperament

In beef cattle production, temperament is defined as the reaction of cattle to human presence as well as novel environments (Fordyce et al., 1998). Temperamental behavior in cattle is considered another economically important trait as it has been observed to be associated with reduced growth rates, compromised immune function, management difficulties, and inferior carcass characteristics (Adamczyk et al., 2013; Cafe et al., 2011; King et al., 2006).

Subjective and objective methods of cattle temperament evaluation have been assessed (Schmidt et al., 2014) and the use of Temperament Score has been adopted by some researchers as a holistic approach to evaluate cattle temperament by combining objective and subjective measures of assessment some. Other forms of measurement in temperament trials include exit velocities and pen scores.

In the study by Littlejohn et al. (2018) using cattle from the research population used in this thesis research, the magnitude of additive genetic effects observed confirmed previously reported heritability estimates for beef cattle (Riley et al., 2014b; Schmidt et al., 2014). Over time, it was evident that the inherited temperament traits in beef cattle become predominantly influenced by permanent environmental effects as the animal ages, suggesting acclimatization. Nevertheless, the additive genetic component of temperament traits that are observed in early life provide an opportunity for the development of methods in selection against temperamental animals.

2.7. Cow and calf reasons for removal from herd

Profitability in a cattle production enterprise is usually the primary driver in culling decisions of the herd. In general, commercial beef females are culled from the herd when they cannot consistently give birth to and wean a calf on an annual basis. In some research herds, cows are usually allowed to remain years after they are profitable in order to extract information that is useful when assessing longevity and lifetime production traits (Sanders, 2012). In some instances, cows were allowed two opportunities to miss a calving season before being culled, but after the age of 14 they were only allotted one failure to produce a calf (Riley et al., 2001).

The females that express longevity in a herd usually experience a lack of soundness problems (Sanders, 2012). The lack of problems is associated with superior reproductive performance at older ages, thus resulting in high-producing females at advanced age but establishes a connection between herd culling criteria and longevity. Other common culling parameters entail females that exhibit significant signs of tooth wear (and/or lost teeth), udder problems, eye problems, poor body condition of the cow, lameness or skeletal unsoundness of the cow, death of her calf, light or unthrifty calf at or before weaning, and age of the cow (independent of other factors) (Sanders, 2012).

3. MATERIALS AND METHODS

3.1. Cattle populations

All animal procedures were in compliance with the Guide for the Care and Use of Agricultural Animals in Research and Teaching and were approved by the Mississippi State University Animal Care and Use Committee (IACUC #08- 049 and #13-010).

Records were utilized from a predominantly *Bos indicus* x *Bos taurus* beef cattle herd at the E. G. Morrison Brown Loam Research Station in central Mississippi. *Bos taurus* breed types represented in this population included Angus, Hereford, Red Angus, Gelbvieh, Maine-Anjou, Charolais, and Limousin. *Bos indicus* breed types represented in this population included Brahman and Gyr. Proportion of *Bos indicus* (the vast majority of cows with *Bos indicus* background had Brahman background) was of primary interest. Table 4 shows the distribution of cows in two breed categories based on that *Bos indicus* background.

Table 4: Categorization of cows based on proportion *Bos indicus* influence

Proportion *Bos indicus*[1]	*n*
< 0.25	732
≥ 0.25	553
Total	1285

[1]Cows were categorized based on the proportion of *Bos indicus* inheritance to assess breed effects.

The cows in the study (*n* = 1,285) ranged from 0 to 0.6875 proportion *Bos indicus* influence. Some cows in the research herd were purebred, but were excluded from the data analysis due to their small numbers. Cows ranged from 2 to 18 years of age. Calving and performance records (*n* = 5,052) of cows ranged from the years 2000 through 2017. Annual calving and weaning records were created for each year that each cow had the opportunity to breed. Values of 1 were assigned to cows that successfully calved or weaned (respectively); values of 0 were assigned to those that did not. Longevity was defined as the maximum age in years the cow reached at the time of exiting the herd.

In general, females produced at the experiment station were first exposed to bulls as yearlings, regardless of breed composition, with an objective to calve at 2 years of age. Some, however, were not exposed to bulls until 2 years of age because of size or other reasons; this was believed to be a small group of females. This information was not available. Therefore, for calving and weaning rate analyses, all cows were assumed to have been exposed to breeding first as yearlings. Cows were generally removed from the herd due to functional issues such as teeth degradation, udder soundness, eye problems, and excessive temperamental behavior. Cows were most commonly removed after failure to give birth and wean a calf on two occasions, but there were a few exceptions to this policy. Other reasons for removal included cow mortality and health issues, decline in productivity, and research transfers.

3.2. Temperament evaluation

Three measures of temperament, pen score (a subjective measurement; Hammond et al., 1996), exit velocity (an objective measurement; Burrow et al., 1988), and an overall temperament score (King et al., 2006), were assessed at weaning. Pen score was recorded prior to the other two measurements. Pen score was determined by an experienced observer who visually evaluated (scored on a scale of 1 to 5) individual animals in groups of three to five within a pen. The same experienced observer scored all animals. Subsequently, each group of animals was herded into a separate adjacent pen, where they remained until pen score was documented for all animals within the study. After pen scoring, animals were walked into an enclosed handling facility and individually entered a squeeze chute for restraint. Exit velocity was defined as the rate (in m/s) at which an animal traveled a distance of 1.83 m from the squeeze chute upon exiting. An infrared beam sensor system (FarmTek Inc., North Wylie, TX) was utilized to record the velocities. Temperament score was defined as the numerical average of pen score and exit velocity, as previously reported (King et al., 2006; Littlejohn et al., 2018).

Not all cows had records for any temperament trait. Fewer cows had pen scores (and also therefore temperament scores), so cows were classified by exit velocities in order to maximize the size of the evaluated data. Animals were categorized into four groups based upon their exit velocity recorded when they were weaned. This categorization was constructed to represent temperament based on the weaning exit velocity recorded for each female and to equalize the numbers in each category as much as possible. Table 5 presents those 4 categories, their boundaries in terms of exit velocity (defined in m/s), and the numbers of cows in each.

Table 5: Temperament categorization of cows based on exit velocities at weaning

		Exit velocity boundaries (m/s)	
Temperament category	*n*	Low	High
1	187	≤	1.986
2	164	1.987	2.6645
3	209	2.6646	3.342
4	187	≥	3.343
Total	747		

3.3. Statistical analyses

Reproductive traits, including calving rate, weaning rate, 205-day weight, cumulative weight weaned per cow, and longevity were evaluated using mixed linear models with ASReml (Gilmour et al., 2009). Calving rate and weaning rate were analyzed assuming both a binomial and normal distribution utilizing a generalized mixed linear model with a logit link function applied. Weight traits were evaluated as normally distributed variables and considered traits of the cow. Weight adjusted to 205 days (with adjustments for age of the calf and sex per Beef Improvement Federation guidelines; Cundiff et al., 2018) was evaluated in two distinct analyses. In the first, the actual records were evaluated. In the second, cows that failed to wean a calf were given trait values of 0 for this trait, and thus penalizing the cow for that failure.

Longevity data were analyzed with a multiple threshold model. Proportions in ordered categories contingent to breed type were used to calculate cumulative proportions, which were modeled with a probit link function.

Fixed effects of interest within the study were breed category (proportion *Bos indicus*; 2 categories) and temperament (4 categories) as classification variables. These were investigated in separate analyses. Season (two levels for calves born in the fall and spring, respectively) and sire breed of the calf (12 different breeds) was investigated for weight traits. Year of record was included in analyses of reproductive traits and calf weight. Fixed effects investigated included year, season, age, and interactions. Reasons for removal for the two breed groups were tested against $\chi 2$ expectation using the FREQ procedures of SAS (SAS Inst., Inc., Cary, NC). Cow birth year was included in analyses of longevity and cumulative calf weight weaned. Animal (cow) was modeled as random by including pedigree information. Permanent environmental variance was modeled for traits in which cows had repeated records.

4. RESULTS AND DISCUSSION

4.1. Calving rate

Calving rate was analyzed distinctly assuming a binomial distribution and separately assuming a normal distribution. Fixed effects included breed category, age group and temperament.

Breed category approached significance in analyses of calving rates (P = 0.073, P = 0.065, in analyses assuming binomial or normal distribution of calving rates, respectively). As observed in Table 6, cows with proportion of 0.25 or more *Bos indicus* influence had higher calving rates than those below 0.25. Crossbred cows with *Bos indicus* influence are well recognized for ability to calve without assistance (Cundiff et al., 2005) and tend to have greater calving rates in contrast to cows that are a result of *Bos taurus* x *Bos taurus* crosses (Riley, 2012).

Table 6:Calving rate means for breed category[1]

	Assumed distribution			
Proportion *Bos indicus*	Binomial	Normal	Unadjusted	SD
< 0.25	0.71 $\pm$ 0.664	0.73 $\pm$ 0.018	0.83	0.378
≥ 0.25	0.75 $\pm$ 0.697	0.77 $\pm$ 0.020	0.85	0.354

[1]Breed categories were based on proportion *Bos indicus* in cows;

Age group effects were significant (P <0.001, for both analyses assuming binomial and normal distribution of calving rates) on the variance of calving rate in the cows involved in the study. Table 7 portrays the differences in means as explained by age categories, where cows older than 10 years of age held the lowest calving rates (0.26 and 0.46, for binomial and normal distribution of calving rates, respectively) compared to cows that were in any other age category. Cows that were 2 years of age (first calving record) displayed highest calving rates among all age groups, followed by cows that were from 4 to 10 years of age, and then 3-year-olds. Comparison to the unadjusted means in Table 7 shows that both analyses (assuming either a binomial or a normal distribution) made large adjustments to the mean of cows 10 or older. The analysis based on a binomial distribution similarly made a large adjustment to the means of cows in the two intermediate age categories. This suggests a possible imbalance of age categories with respect to the other fixed effects in the models.

Table 7: Calving rate means for age group[1]

	Assumed distribution			
Age (years)	Binomial	Normal	Unadjusted	SD
2	0.72 ± 0.719^{a}	0.80 ± 0.036^{a}	0.89	0.314
3	0.48 ± 0.483^{c}	0.65 ± 0.037^{c}	0.74	0.441
4 to 10	0.60 ± 0.604^{b}	0.73 ± 0.036^{b}	0.86	0.343
Older than 10	0.26 ± 0.262^{d}	0.46 ± 0.070^{d}	0.77	0.422

[1]Cows were inserted into contemporary groups based on year of calving records
[a,b,c,d]Values with superscripts differ significantly ($P < 0.001$).

Within this management system, females were first exposed to bulls as yearlings with the objective to calve at 2 years of age. The decline in calving rates from 2 to 3 years of age is not unusual, and commonly viewed as the cow's physiological capacity to return to estrus. First-calf heifers have also demonstrated difficulty producing a second calf at 3 years of age when parturition occurs late in calving season (Lesmeister et al., 1973). Cows of ages 4 to 10 years are expected to consistently conceive and calve. Cows older than 10 years of age must have continually demonstrated the ability to successfully produce a calf consistently throughout their life span to achieve the age category, but it is also more probable for them to reveal issues that affect reproductive performance at this age (Thrift and Thrift, 2003; Sanders, 2012).

Temperament was not a significant basis of variation in calving rate as a binomial or normally distributed trait (*P* = 0.113 and *P* = 0.141, respectively).

Estimates of heritability for calving rate were 0.27 ± 0.052 (binomial distribution) and 0.07 ± 0.016 (normal distribution).

4.2. Weaning rate

The proportion of *Bos indicus* influence in the cow was not found to be a significant source of variation in weaning rates (*P* = 0.068, *P* = 0.06, for binomial and normal distribution, respectively). However, cows that were greater than or equal to 0.25 *Bos indicus* influence had higher weaning rates than those that were below 0.25 *Bos indicus* influence (Table 8). Superior weaning rates for Angus x Brahman cross females have previously been documented (Riley, 2012). Means from both analyses were lower than the unadjusted means, but ranked the same as the unadjusted means.

Table 8: Weaning rate means for breed category[1]

	Assumed distribution			
Proportion *Bos indicus*	Binomial	Normal	Unadjusted	SD
<0.25	0.66 ± 0.625	0.70 ± 0.019	0.79	0.408
≥0.25	0.71 ± 0.663	0.74 ± 0.021	0.81	0.392

[1]Breed categories were based on proportion *Bos indicus* in cows

Age group effects were a significant source of variation in weaning rates observed in the cows within the study (*P* < 0.001, for both binomial and normal distribution). Similar to the trends seen in calving rates in Table 8, the 2 year-olds displayed the highest weaning rates and cows older than 10 years of age displayed the lowest. Cows at the age of 3 had lower weaning rates than the cows in the age category of 4 to 10 years of age. Unadjusted weaning rate means were patterned similarly to calving rate means. As was the case for both analyses of calving rate, but especially that in the context of a binomial distribution, the analyses produced means with very large adjustments (compared to unadjusted means in Table 9). This may be the result of imbalances in some age categories with respect to other fixed effects in the model.

Table 9: Weaning rate means for age group[1]

	Assumed distribution			
Age (years)	Binomial	Normal	Unadjusted	SD
2	0.64 ± 0.719^{a}	0.76 ± 0.039^{a}	0.82	0.381
3	0.45 ± 0.483^{c}	0.62 ± 0.040^{c}	0.70	0.457
4 to 10	0.54 ± 0.604^{b}	0.70 ± 0.038^{b}	0.73	0.376
Older than 10	0.26 ± 0.262^{d}	0.46 ± 0.074^{d}	0.83	0.447

[1] Cows were inserted into contemporary groups based on year of calving records
[a,b,c,d] Values with superscripts differ significantly ($P < 0.001$)

As was seen in calving rate analysis, temperament was not a significant source of the variation observed in weaning rates ($P = 0.596$ assuming binomial distribution, $P = 0.64$ assuming normal distribution).

Estimates of heritability for weaning rate were 0.24 ± 0.051 (binomial distribution of weaning rate) and 0.06 ± 0.015 (when treated as a normally distributed variable).

4.3. 205-day weight

Two analyses were conducted for 205-day weaning weight: 1) actual records, and 2) inclusion of values of 0 for cows that did not wean a successfully wean a calf due to any reason.

Breed category approached significance ($P = 0.075$) only in the analysis that involved actual records, where cows greater than or equal to 0.25 *Bos indicus* influence produced calves with heavier 205-day weights (238.59 kg) than those cows that were less than 0.25 *Bos indicus* (Table 10) influence (238.59 vs. 235.01).

Table 10: 205-day weight (kg) by breed type

Proportion *Bos indicus*	205-day weight[1]
< 0.25	235.01 $\pm$ 2.19
$\geq$ 0.25	238.59 $\pm$ 2.40

[1]205-d weights derived only from analysis involving actual records

Results suggest that calves out of cows that were of greater *Bos indicus* influence tended to be slightly heavier. This is usually the case because of exploitation of maternal heterosis effects from favorable, genetically divergent *Bos indicus* x *Bos taurus* crosses (Olson et al., 1990). In addition, elevated weaning weights for *Bos indicus* x *Bos taurus* cross calves are attributed also to their tremendous growth ability (Thrift and Thrift, 2003) due to direct heterosis effects.

Age category also explained substantial variation in 205-day weights ($P < 0.001$) for both analyses. Calves out of cows that were older than 10 years of age had higher 205-day weights (Table 11) than all other groups and calves out of 2 year-olds recorded the lowest 205-day weights. Cows in older age categories generally weaned calves with heavier 205-day weights. As was observed in the results from the Germplasm Evaluation Project, multiparous, crossbred cows from ages 3 to 7 years of age were recognized as highly productive (Cundiff, 2005). This is not surprising, although sometimes aged cows wean somewhat lighter calves.

Table 11: 205-day weight (kg) by age category

Age	Actual records	Including 0 values	Unadjusted	SD
2	225.77 $\pm$2.09[d]	207.97 $\pm$ 3.63[c]	386.86	193.88
3	230.21 $\pm$2.10[c]	214.50 $\pm$3.71[c]	351.00	237.06
4 to 10	234.90 $\pm$ 1.69[b]	223.85 $\pm$ 2.83[b]	424.42	203.60
Older than 10	256.31 $\pm$6.14[a]	255.55 $\pm$ 12.212[a]	373.03	240.22

[a,b,c,d]Values with superscripts differed (*P* < 0.001)

Season effects were important (*P* < 0.001) in analyses of 205-day weight. Fall born calves were heavier (Table 12) than spring born calves (240.0 kg and 233.6 kg, respectively). The same was observed in results from the analysis including values of 0 for weaning weight (229.1 kg and 221.9 kg, respectively).

Sire breed of the calf was highly significant (*P* < 0.001) on 205-d weight analyzed with or without the adjusted records on cows that failed to wean a calf for certain years.

Estimates of heritability were 0.24 ± 0.028 and 0.08 ± 0.02 for analyses of actual records and those with weights of 0 included. The inclusion of 0 values may make this trait more of a reproductive trait, as it penalized the cow for not successfully weaning a calf and thus resulting with lower heritability, which is usually the case with most reproductive traits.

Table 12: 205-day weight (kg) by season effects

Season[1]	Actual records	Including zero values
Spring	233.56 $\pm$ 2.117[a]	221.89 $\pm$ 3.833[a]
Fall	240.03 $\pm$ 2.475[b]	229.05 $\pm$ 4.424[b]

[1]Seasons based on Beef Improvement Federation (Cundiff et al., 2018) date ranges; Spring ranges from January to June and Fall ranges from July to December.
[a,b]Values with superscripts differ significantly (*P* < 0.001)

Fall performance records have been reported to be less favorable than those in the Spring months (Buchanan and Frahm, 2005), particularly in cows and calves that range from 0.25 to 0.5 proportion *Bos indicus*. However, the cows with some proportion *Bos indicus* influence still outperformed those that were simply of *Bos taurus* descent in the fall months.

4.4. Longevity

Longevity was preliminarily considered a normally distributed variable using general linear mixed models. Results produced included heritability estimates ($h^2 = 0.77$) that were far above what is observed in previous studies. Ensuing analysis of longevity data was performed using a multiple threshold model to produce cumulative proportions (Table 13) in ordered categories contingent to breed type due to the extreme right-skewed nature of the data. Proportions were modeled with a probit link function. The heritability estimate produced by this analysis ($h^2 = 0.373$) approaching previously reported ranges for longevity (Vukasinovic et al., 2001).

Breed effects were a significant source of variation ($P < 0.005$) within age for longevity. The results revealed that proportion of cows below 0.25 *Bos indicus* influence were found to exit the herd before cows that were greater than or equal to 0.25 *Bos indicus* influence. Approximately two-thirds (0.671) of the cows within the contemporary group that was less than 0.25 *Bos indicus* influence had exited the herd by the age of 7, in contrast to cows that were of greater than or equal to 0.25 *Bos indicus* (0.582). Similar tendencies have been observed in previous evaluations of cow longevity in crossbred cows (Bailey, 1991), where greater proportions of F_1 *Bos indicus* cows remained in production in contrast to *Bos taurus* straightbreds and *Bos taurus* x *Bos taurus* crosses.

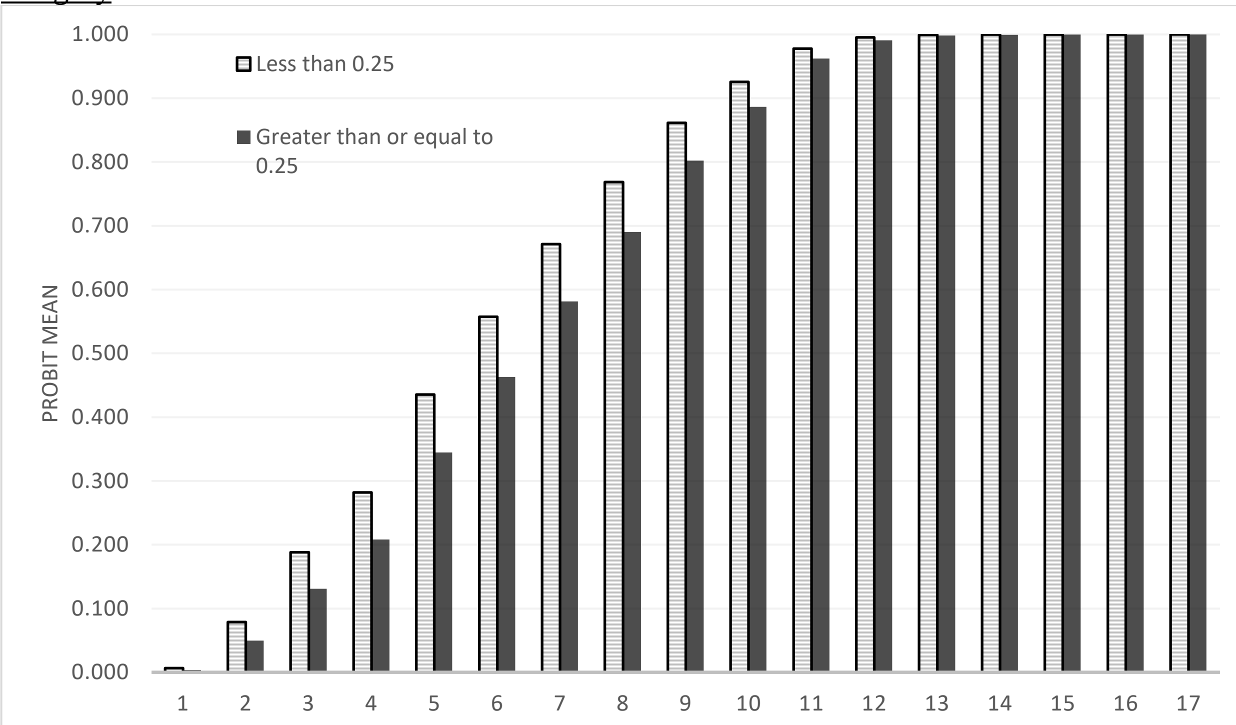
Table 13: Cumulative proportions of cows that exited herd by year

	Proportion *Bos indicus*	
Year[1]	<0.25	≥0.25
1	0.0067	0.0034
2	0.0789	0.0495
3	0.1882	0.1311
4	0.282	0.208
5	0.4354	0.3448
6	0.5574	0.4632
7	0.6711	0.5816
8	0.7686	0.6905
9	0.8614	0.8023
10	0.9257	0.8864
11	0.978	0.9623
12	0.9953	0.9909
13	0.9993	0.9984
14	0.9997	0.9993
15	0.9999	0.9997
16	0.9999	0.9998
17	1	1

[1]Within ages 1 through 6, breed category is different ($P < 0.005$).

Figure 1 portrays the trend of cumulative proportions of cows that have left the herd per year. It is a graphic representation of the proportion of cows approaching the maximum number of years that they remained in production, and thus were not culled from the herd. By 17 years in production, it was estimated that all cows regardless of breed type, had exited the herd. Temperament category was not influential in analyses of longevity ($P = 0.585$).

Figure 1: Cumulative proportions of cows that had exited the herd per year by breed category



4.5. Cumulative weight weaned

Dam performance over time was analyzed to produce values of cumulative weight weaned. In these analyses, cow age was modeled as a linear covariate. That covariate was unique within breed categories (P <0.001). The regression coefficient estimate for the proportion of 0.25 *Bos indicus* or greater was 204.9 ± 2.64 kg. The estimate in the other breed category was 201.6 ± 2.43 kg. These estimates seemed reasonable; as the age of the cow increased by one year, the cumulative weaning weight increased slightly more in the breed category that contained cows of greater *Bos indicus* influence. This may be due to greater maternal heterosis for weaning weight of cows in that group. In the aspect of lifetime production, Gaetner et al., (1992) did not observe a decline in productivity in a study involving Simmental sired calves out of Brahman x Hereford cows from ages 12 to 17 years. Within the same study, weaning weights of the calves out of older cows were 2 kg heavier than Brahman x Hereford cross cows of ages 3.5 to 12 years of age.

Temperament was not a significant source of variation (P = 0.421) in cumulative weight weaned. The estimate of heritability for cumulative weight weaned was 0.33 ± 0.093.

4.6. Reasons for leaving the herd

Culling parameters of cows involved in the study can be observed in Table 14. Cows were most commonly removed from the herd due to subfertility (*n*= 762), which was interpreted as cows that were open for longer than 365 days. Functional issues that present themselves in older animals, such as teeth degradation and udder soundness are considered to play a role in reproductive performance as the animal must eat to maintain body condition, and therefore be healthy enough to cycle back and conceive. In this scenario, females remained in the herd much longer after their most productive phase of their lives, which is a necessary to capture information considered valuable for longevity analysis (Sanders, 2012). Females who left due to a decline in productivity produced calves that had 205-day weights much lower than in their previous years, weaned light calves, or gave birth but had calves die before weaning. Cows that were reported to have died fell within the category of health issues and death. Animals classified with unknown reasons for leaving the herd sometimes entailed extreme circumstances, such as being affected by adverse weather conditions (e.g. Lightning, flooding) and/or insufficient evidence was available to make a precise estimate for their removal from the research herd.

Reasons for removal by breed group differed from χ2 expectation (P < 0.0001). As portrayed by Table 14, cows that were less than 0.25 *Bos indicus* influence predominantly left due to subfertility (*n* = 449) in contrast to cows that were greater than or equal to 0.25 *Bos indicus* (*n* = 313) influence.

Table 14: Dam reason for exiting herd by breed category[1]

	Proportion *Bos indicus*		
Reason for leaving	< 0.25	$\geq$ 0.25	Total
Unknown	138	125	263
Subfertility	449	313	762
Functional	15	26	41
Health/Death	50	33	83
Drop in Productivity	72	51	123
Research Transfers	8	5	13
Total	732	553	1285

[1]Breed group proportions differed from χ^2 expectation (P < 0.0001).

Cows that experienced functional issues, such as teeth degradation and udder soundness, were most often found within the breed category of greater than or equal to 0.25 *Bos indicus* influence (*n* = 26). As has been observed, these functional issues tend to present themselves at more advanced ages in crossbred cows with some proportion of *Bos indicus* in their background, but not to the extent of cows who were purely of *Bos taurus* descent (Nunez-Dominguez et al.,1991 and Riley et al., 2001). These factors play a role in decreased weaning weights, reproductive performance and health issues. However, it can be deduced from this data that cows with a higher proportion of *Bos* *indicus* influence achieved ages in which such functional issues present themselves to a severity in which they must be culled, rather than for subfertility.

5. SUMMARY

Cattle were categorized based on their proportion of *Bos indicus*: less than 0.25 and greater than or equal to 0.25. In addition, they were grouped into 4 temperament categories, depending on their exit velocity records. Given the skewed nature of the data, longevity was analyzed using a threshold model with a probit mean function to produce cumulate proportions of cows as they exited the heard for various reasons. cow breed category within age had significant effect on longevity, where cows that were of 0.25 or greater of proportion *Bos indicus* tended to remain productive for a longer period of time, than those that fell below the threshold of 0.25 *Bos indicus* influence. Differences were observed between contemporary groups of age in years in the evaluation of calving and weaning rates, suggesting that cows are more productive at certain points of their lifetime. Temperament categories did not have a significant impact on cow longevity, or any other traits that were analyzed in this study. However, more precise estimates can be drawn from the acquisition of greater observations and perhaps a more holistic value than only exit velocities.

Cows that are over 25% *Bos indicus* influence can be considered as a suitable and efficient choice for cow-calf producers in the southern United States because of their ability to remain productive at more advanced ages.

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