CALF PERFORMANCE AND FEMALE REPRODUCTIVE TRAITS IN SECOND GENERATION RECIPROCAL NELLORE-ANGUS CROSSES

A Thesis

by

DANA MARIE MICKEY

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Chair of Committee, James O. Sanders
Co-Chair of Committee, Andy D. Herring
Committee Member, David G. Riley

Head of Department, G. Clifford Lamb

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ABSTRACT

The objectives of this study were to analyze calf performance traits and female reproductive traits in reciprocal F_2 Nellore-Angus calves (n = 539) born 2010-2015 and calves out of these F_2 females through 4 yr age (n = 443) born 2012-2018. The F_2 animals were produced using reciprocal F_1 Nellore-Angus sires and dams (AN and NA, sire breed is listed first followed by dam breed). The F_2 breed types included ANAN, ANNA, NAAN, and NANA where the first two letters are the animal's sire type and the third and fourth are its dam type (i.e., ANNA were sired by F_1 AN bulls and out of F_1 NA cows). Calf performance traits were analyzed using mixed models and female reproductive traits were analyzed through PROC GLIMMIX in SAS. Dam type influenced Julian birth date ($P < 0.05$) in the F_2 calves with those out of AN cows being born earlier than those out of NA cows. Sire type and dam type affected birth weight ($P < 0.05$) but not weaning weight of the F_2 calves. The interaction between sire type and dam type accounted for weaning weight differences ($P = 0.038$). Sire type also accounted for important variation in the calf sex distribution at birth among F_2 calves ($P < 0.005$). Percent male at birth and weaning among the F_2 calves exceeded the expected ratio for calves with NA sires, calves out of AN dams, and NAAN and NANA calves ($P \leq 0.05$). The opposite trend appeared in calves from F_2 females with calves out of NA-sired dams and NANA dams having more females at birth and weaning ($P \leq 0.05$). The sole significant breed effect for calves out of F_2 females was sire type × dam type × sex for weaning weight (P = 0.010) where only among calves from ANNA and NANA dams were males heavier than females. These results suggest that some of the calf weight reciprocal differences typically observed among F_1 *Bos indicus-Bos taurus*

crosses can continue into later generations. Reciprocal breed effects were insignificant for reproductive traits in young F_2 Nellore-Angus females.

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INTRODUCTION

Crossbred cattle are popular among commercial producers due to their combined breed characteristics as well as hybrid vigor, the typical increased performance over the purebred average. Hybrid vigor is particularly valuable for improving lowly heritable traits such as reproductive traits. Many of the female reproductive traits such as pregnancy rates and calf weaning rates, are crucial for beef producers' profitability, especially cow-calf producers, since the number of calves sold is typically their main source of income. F_1 animals, the first generation of a cross between two different purebreds, are exceptionally valuable due to maximal hybrid vigor expression. Previous research has focused on the differences in performance of reciprocal crosses in F_1 cattle. Studies have shown large reciprocal differences for F_1 *Bos indicus-Bos taurus* crosses in calf performance traits, and several studies indicate differences in maternal, cow performance traits (Brown et al.,1993; Key, 2004; Boenig, 2011; Bohac, 2015).

Less is known about reciprocal differences in F_2s (from matings of F_1 sires and F_1 dams) involving *Bos indicus* and *Bos taurus*. Early research at Rockhampton and Florida that used Brahman and British and/or Continental breeds to make crossbred cattle indicated that how the F_2 cows were made (i.e., having a *Bos indicus* sired sire versus a *Bos taurus* sired sire) may play a significant role in their performance (Seifert and Kennedy, 1972; Seebeck, 1973; MacKinnon et al., 1989; Olson et al., 1993). Later studies that used Brahman as the *Bos indicus* breed and Hereford or Angus as the *Bos taurus* breed supported this hypothesis and found large differences between the reciprocal F_2 cows for reproductive traits (Boenig, 2011; Bohac, 2015). Further investigation is required to determine if this is a novelty for Brahman or if these differences are present in other *Bos indicus* breeds. Also, additional research is needed due to the expense of replacing F_1 cattle and projections for composite populations.

OBJECTIVES

The objectives of this thesis are to: (1) analyze differences in birth weight and weaning weight among reciprocal F_2 Nellore-Angus calves, and (2) analyze differences in reproductive performance and calf performance traits from reciprocal F_2 Nellore-Angus females through 4 yr of age. Both of these objectives are to investigate potential reciprocal cross effects in second-generation animals that have been reported among F_1 *Bos indicus-Bos taurus* crosses.

LITERATURE REVIEW

Breeds

Domestic cattle consist of two subspecies, *Bos taurus* and *Bos indicus*. Many *Bos taurus* breeds have British and Continental European origins and are popular choices for beef production in the United States. Angus cattle are particularly popular for beef production due to their marbling ability and value-added programs such as Certified Angus Beef. Additionally, Angus are known as an excellent maternal breed with superior udder soundness (J.O. Sanders, personal communication). Better udder soundness improves cow longevity reducing the need for replacement females (Bradford et al., 2015). However, many *Bos taurus* breeds are not adequately adapted to perform optimally in tropical or subtropical conditions due to their origin in European environments.

Bos indicus cattle typically originate from India, are tropically adapted, and are noted for their heat tolerance and parasite resistance (FAO, 1953). They were originally imported into the Gulf Coast states to improve cattle adaptation in climates that had greater humidity, higher temperatures, and poorer forage quality (Cartwright, 1980; Turner, 1980). The Brahman breed of Zebu (*Bos indicus*) cattle especially has greatly influenced the cattle industry in South and Southeastern states (Franke, 1980). Nellore cattle, a breed of *Bos indicus*, are a foundation breed for the popular U.S. Brahman breed (Sanders, 1980). They are known for their mothering ability, long and prolific reproductive life, and ability to fatten easily on grassland (FAO, 1953). Nellore are popular as a beef breed in Brazil, largely due to the bulls' tight sheaths and the cows' small teat size (Sanders, 1980). Additionally, in Brazil Nellore account for the largest number of cattle for the *Bos indicus* subspecies which is the primary population for beef production (Peripolli et al., 2018).

Bos indicus-Bos taurus crosses have been shown to outperform their purebred *Bos indicus* and *Bos taurus* parent breeds for several economically important traits, especially reproductive traits (Turner, 1980). As a result, crossbreeding *Bos indicus* and *Bos taurus* cattle is prevalent among commercial producers. Studies have found that crossbred Brahman calves outperform *Bos taurus* x *Bos taurus* calves with higher calf survival rates and heavier weaning weights (Franke, 1980; Cundiff et al., 2000). Crossbreeding *Bos taurus* and *Bos indicus* cattle is a particularly popular practice for producers in tropical and subtropical climates because it allows them to incorporate heat tolerance and maternal calving ease from *Bos indicus* breeds and earlier age of puberty and better carcass quality (i.e., marbling) from *Bos taurus* breeds. Cundiff et al. (1993) found that out of *Bos taurus* and *Bos taurus-Bos indicus* crossbred heifers in Clay Center, Nebraska all fed a 50% corn silage and 50% alfalfa or grass haylage plus protein or mineral supplement, *Bos taurus* heifers generally had an earlier onset of puberty, approximately 317 days old for Jersey and 359 days old for Shorthorn. *Bos indicus* heifers such as Brahman typically reached puberty later than *Bos taurus* heifers with an age at puberty ranging from about 592 days to 690 days (Randel, 2005).

Mating *Bos indicus* breeds with breeds that have an earlier onset of puberty can decrease age at puberty (Patterson et al., 1992). For example, among Brahman (*Bos indicus*) and tropical composite (~50% *Bos indicus* and ~50% *Bos taurus*) heifers in northern Australia, tropical composite heifers had their first corpus luteum about 100 days sooner than Brahman heifers (650 d vs. 750 d) (Johnston et al., 2009). An earlier age at puberty allows for cattle to start calving sooner potentially increasing their stayability. Engle (2019) speculated that for phenotypes associated with stayability, the most significant genetic drivers were likely related to heifer age at puberty for Nellore-Angus crossbred cows in Central Texas.

Reproductive and calf performance traits are driving factors for producer profitability. Among crossbred cattle, the first cross of two distinct breeds or subspecies (the F_1) tend to perform better than the average of the purebreds; this concept is referred to as hybrid vigor. How the F_1 is made (i.e., which breed is used as the sire breed or dam breed), especially when crossing *Bos indicus* and *Bos taurus* subspecies, can greatly affect differences in crossbred offspring performance.

The offspring resulting from the *inter se* mating of F_1 animals are referred to as F_2. The F_2 animals generally display less hybrid vigor than F_1 animals. There appears to be significant variation in the degree of hybrid vigor expressed in F_2 *Bos indicus* and *Bos taurus* crosses. A 1973 study in Northern Australia reported a greater loss of hybrid vigor between the F_1 and F_2 generations of Brahman crossbred cows than predicted by the dominance model, less than the expected degree of heterozygosity (Seifert and Kennedy, 1972; Seebeck, 1973; MacKinnon et al., 1989). The F_2 animals were produced from Brahman-sired F_1 bulls and cows. However, Olson et al. (1993) reported hybrid vigor that was closer to what the dominance model predicted for F_2 Brahman-Angus, F_2 Charolais-Angus, and F_2 Brahman-Charolais cows in Florida at about a 50% decrease in hybrid vigor when compared to the F_1 cows of the corresponding breed type.

Additionally, F_2 Brahman-Charolais cows from the same study displayed higher hybrid vigor than predicted by the dominance model at 72.1%. Both F_1 Brahman x Charolais and F_1 Charolais x Brahman bulls were potentially available to produce the F_2, but no information is available on which or what proportion were actually used (J.O. Sanders, personal correspondence). The discussion that follows focuses on *Bos indicus* and *Bos taurus* comparisons in particular, and where different crosses are discussed, the sire breed is written first followed by the dam breed (i.e., Nellore x Angus indicates Nellore sires bred to Angus females, etc.). The same trend applies for breed abbreviations. For two letter breed abbreviations (i.e., F_1s), the first letter is the animal's sire breed and the second letter is its dam breed. For four letter breed abbreviations, (i.e., F_2s), the first two letters are the animal's sire breed (the first letter denotes the sire's sire and the second denotes his dam) and the third and fourth letters are its dam's breed (the third letter denotes the dam's sire and the fourth denotes her dam).

Birth weight. Large birthweights can be detrimental to producers as they can increase incidence of dystocia, particularly in young cows. Therefore, it is important for producers to understand the risks associated with using different sire breeds when selecting bulls for their operation. Many *Bos taurus* breeds tend to have higher birth weights than *Bos indicus* breeds. Neufeld Arce (2006) found that straightbred Angus cows produced calves with heavier birth weights than straightbred Nellore cows at approximately 36 kg and 30 kg, respectively.

In crossbred cattle, the combination of sire and dam subspecies is crucial in dictating birth weight (Cartwright et al., 1964; Ellis et al., 1965). Brown et al. (1993) found that in Northwestern Arkansas for F_1 Angus-Brahman cattle, calves with Angus sires weighed less at birth than those with Brahman sires by 7.4 (31.0 vs. 38.4) for heifer calves and 13.7 (32.1 vs. 45.8) kg for bull calves. Dillon et. al (2015) specifically focused on the effect of amount of *Bos indicus* in the sire on birth weights in reciprocal Brahman-Simmental crossbred offspring. Decreased birthweight was associated with a lower fraction of Brahman in the sire than in the dam. Calves with 50% Brahman 50% Simmental sires and 100% Brahman dams had the lowest average birth weight at 31.3 kg and Brahman sired F_1 calves had the heaviest average birth weight at 44.5 kg (Dillon et al., 2015).

Boenig (2011) evaluated reproductive and maternal trait differences in all possible reciprocal F_1 and F_2 Brahman-Hereford (BH) crossbred cows. Boenig found that calves out of F_2 BH cows had the heaviest overall mean birth weight at 36.6 kg. Calves out of F_2 HBBH dams (F_1 HB sire crossed with F_1 BH dams) had the lightest mean birth weight at 33.9 kg. Additionally, BH-sired F_2 calves had about a 1.8 kg to 2.7 kg higher birth weight than HB-sired F_2 calves. Similar results with Brahman and Angus cattle were reported in reproductive and maternal traits of F_1 and F_2 Brahman-Angus (BA) cows (Bohac et al., 2016). Calves out of F_2 BABA cows had the heaviest birth weights at 38.7 kg when compared to calves out of F_2 ABBA cows and F_1 BA cows (Bohac, 2015). It is important to note that this study only made one type of F_1 (B sires x A dams) and two types of F_2s (BA x BA and AB x BA).

Weaning weight. The opposite pattern observed for birth weight differences have been reported for weaning weight for purebred *Bos taurus* and *Bos indicus* cattle. Calves out of Angus and Nellore cows had a numerically different weaning weight of 195.4 kg and 200.1 kg, respectively, at the McGregor Research Center in Central Texas (Neufeld Arce, 2006). Additionally, for Angus-Brahman crosses at the McGregor Research Center, Bohac (2015) found that as two-year olds, cows that were Brahman sired F_1 BA's had the heaviest average calf weaning weight at 223.4 kg, when compared to two reciprocal F_2 crosses. However, the F_2 cows with F_1 AB sires' calves had a numerically higher average weaning weight than those out of cows with F_1 BA sires by 5.61 kg as two-year olds, 203.07 kg v (vs) 197.46 kg, and by 13.76 kg as mature cows (5 to 10 years of age) at 241.53 kg and 227.77 kg (Bohac, 2015). Similarly, Boenig (2011) showed that among reciprocal F_1 and F_2 crosses of Brahman and Hereford in Central Texas, the calves with the heaviest weaning weight were out of cows with a *Bos indicus* sire (Brahman) and *Bos taurus* dam (Hereford) at 240.9 kg, and calves out of F_2 cows with F_1

Bos taurus x *Bos indicus* (HB) dams had heavier weaning weights than those with F_1 *Bos indicus* x *Bos taurus* (BH) sires (230.2 kg for HBHB and 219.2 kg for HBBH v 208.4 kg for BHBH and 223.5 kg for BHHB).

Sex ratio. Sexually reproducing species are typically expected to have a 1:1 male to female sex ratio as explained by Fisher's principle (Fisher, 1930). Fisher showed that natural selection favors parents that equally invest their energy into making both sexes (Fisher, 1930). However, Darwin hypothesized that some species could experience a significant shift into a sex biased ratio, although the cause of this shift is uncertain (Rosenfeld and Roberts, 2004). Trivers and Willard (1973) suggested that under certain circumstances, parental "condition" could create a deviation in this ratio. In a population of animals where the dams' condition ranges from poor to good, those with good condition are thought to potentially produce more fit offspring than those in poor condition (Trivers and Willard, 1973). Assuming there is a tendency for the initial condition of both types of these offspring to be maintained to breeding age and that condition more strongly effects male offspring reproductive success than females, dams in good condition that produce male progeny will in turn have more surviving grandprogeny than dams in good condition that produce female offspring. The opposite effect occurs in dams with poor condition; those producing female offspring will have more surviving grandprogeny than those producing male progeny.

Research has also indicated that effects such as maternal diet, parental hormone levels, and parental age may impact sex ratio (Kent, 1995; Rosenfeld and Roberts, 2004; James, 2008; Santos et al., 2015). Rosenfeld and Roberts (2004) found that in mice, mature does, aged 20-27 wk before breeding, on a low-fat diet (LF) tended to have more female pups while those on a high-fat diet (VHF) tended to have more male pups. For both diet types, they found a significant deviation from 0.50 male with LF mice's sex ratio averaging 0.38 male and VHF mice's sex ratio averaging 0.64 male. These results appear consistent with Trivers and Willard sex-allocation theory.

James (2008) theorized that parental hormonal levels may be influential for sex ratio deviation. For example, high testosterone concentrations appear to result in a male skewed sex ratio under certain circumstances. This can be seen in women exposed to diethylstilbestrol (DES), a synthetic form of estrogen, *in utero* and hepatitis B virus (HBV) carriers who tend to have more sons than daughters (James, 2008). Other conditions that appear to result in a biased sex ratio due to abnormal hormone levels include, but are not limited to, certain types of cancer (i.e., Non-Hodgkin's lymphoma testicular cancer and post-menopausal breast cancer), possessing a particular gene, such as a male carrier of the HLA-B15 gene, and exposure to endocrine disruptors (i.e., dioxin and dioxin like chemicals).

Younger parental age may be associated with increased male offspring. Santos et al. (2015) found a significant deviation from the expected sex ratio in horses between mares aged 10 yr or younger and mares aged 10-20 yr old. Mares aged 10 or younger averaged 1.2 males, mares 10 – 15 yr averaged 0.78, and those 15 yr or older averaged 0.64. Kent (1995) reported a related trend in sheep with ewes averaging 2 yr old to 4.58 yr old displaying a steady increase in frequency of males from 49.56% to 54.29% as age increased ($P < 0.05$), but then switching to a female bias between 4.58 yr old to 4.76 yr old, from 54.29% to 45.42% males, respectively ($P < 0.05$). The oldest ewes in the study were these 4.76 yr olds.

Calf crop born. Young *Bos taurus* heifers typically have a higher calf crop born than young *Bos indicus* heifers. Neufeld Arce (2006) reported calf crop born in 2 yr old Angus of approximately 80.4% while 2 yr old Nellore cattle had a calf crop born of only about 5.8%.

Nellore cattle reach puberty later than Angus and generally do not have their first calf until 3 to 3.5 years of age when well managed (FAO, 1953). At three years of age, the Nellore cows' calf crop born increased to approximately 85.7%, which was similar to Angus at about 87.8%. Overall, Nellore cows had a lower calf crop born than Angus cows at 0.674 compared to 0.845 for ages two through five. However, this difference is likely due to the poor performance of two-year old Nellore heifers. As two-year olds, Nellore had a calf crop born of 0.058 but as three to five yr olds, Nellore cows had an increased calf crop born of 0.857, 0.827, and 0.950 ±, respectively.

Calf crop born results have varied among crossbred females depending on the amount of each subspecies in the sire of the animal. Obeidat (2013) found that F_1 Nellore-Angus (NA) cows in Central Texas generally had the highest calving rates across breed types at all ages. Breed types included F_1 NA cows and two types of ⅜ N ⅝ A cows (¾ A ¼ N sire x ½ N ½ A dam and ½ A ½ N sire x ¾ A ¼ N dam). At 4 years of age, the F_1 NA cows had the significantly highest calving rate at 0.99. Those results were consistent with Bohac (2015) where F_1 BA cows had the highest calf crop born at 92% as compared to an average of about 84% for F_2 cows (ABBA and BABA) and around 82% for straightbred cows. Additionally, Obeidat (2013) showed that the ⅜ N ⅝ A 2 yr old heifers with a greater amount of Angus in their sire, ¾ Angus bulls that were sired by straight bred Angus bulls and out of F_1 NA dams, had significantly better calving rates than those with 1/2 Angus in their sire (by 0.05 at 0.92). Similarly, F_2 BA crosses from F_1 AB sires have had a 24% higher calf crop born than those from F_1 BA sires (Bohac, 2015).

Key (2004) and Boenig (2011) had similar results for purebred, F_1, and F_2 cows for calf crop born. Both studies used cows from the same herd but evaluated them at different points in their life. Key (2004) analyzed their reproductive traits as young cows, from ages 2 through 5, and Boenig (2011) evaluated their lifetime reproductive performance. Key (2004) found that for Hereford, Brahman, and for all possible F_1 and F_2 crosses of Hereford and Brahman cows in Central Texas, HB-sired F_2 females had the highest average calf crop born at 0.98 for F_2 HBHB and 0.97 for F_2 HBBH. F_2 cows that had a BH sire and BH dam had the lowest calf crop born at 0.69. Boenig (2011)'s found that HB-sired F_2 females had the highest calf crop born at 92.8%, while cows with BH sires and BH dams had the lowest at 67.8%.

Calf crop weaned. Calf crop weaned for each breed within the different subspecies yielded similar results to calf crop born. At two years of age, Angus heifers had a calf crop weaned of 0.568 while Nellore heifers had a calf crop weaned of 0.029 (Neufeld Arce, 2006). As previously mentioned, this difference is likely due to the later onset of puberty in Nellore heifers. Nellore cows' calf crop weaned increased by approximately 0.685 by the time they were three at 0.714. As mature cows, 5 years of age or older, Angus and Nellore cattle had similar calf crop weaned at about 80% and 75% respectively (Neufeld Arce, 2006). Overall, from ages two through five, Angus had a higher calf crop weaned than Nellore at approximately 75% compared to 48% (Neufeld Arce, 2006). This difference is likely due to a combination of having the largest records for 2 yr old heifers and Nellore heifer's later age at puberty.

Results for calf crop weaned were also similar to calf crop born for crossbred cows. F_1 BA cows had the highest crop weaned at 83% and F_2 BA cows with F_1 AB sires had a higher calf crop weaned than those with F_1 BA sires by 12% (81% and 69%, respectively; Bohac, 2015). In Obeidat's study (2013), the F_1 NA cows also generally had higher weaning rates when compared to their purebred and crossbred counterparts. As mature cows (5 years old or greater), they had the highest weaning rate at 0.90 compared to 0.84 for Angus and 0.84 for all first generation ⅜ N ⅝ A in the same age range. Additionally, the ⅜ N ⅝ A mature cows that had a higher fraction of

Angus in their sire and a higher fraction of Nellore in their dams (produced from ¾ A ¼ N bulls bred to ½ N ½ A cows) had a higher weaning rate by 0.13 at 0.87 compared to those produced from mating ¾ N ¼ A bulls to A cows at 0.74.

Key (2004) and Boenig (2011) had different results to Obeidat (2013) where F_2 cows outperformed the F_1 and straightbred cows. Key (2004) found that HB-sired F_2 females had the highest average calf crop weaned at 0.91 for F_2 HBHB and 0.92 for F_2 HBBH while F_1 BH and HB cows had a calf crop weaned at 0.78 and 0.88, respectively. For Boenig (2011), F_2 dams that were out of HB cows and sired by HB bulls had the highest average calf crop weaned at 90% while straightbred cows and F_1 cows had lower calf crop weaned at 73.8% for Hereford cows, 80.5% for BH cows, and 85.1% for HB cows (Boenig 2011).

Genetics of beef cow longevity and stayability

Length of cow reproductive lifespan greatly influences production and economic potential in beef herds. Stayability is generally defined as a cow's probability of surviving to a certain age given that she was provided the opportunity to reach said age (Engle et al., 2018). It encompasses reproductive and calf performance traits and is a result of genotype, environment, and genotype and environment interactions. Stayability is an important consideration for producers since a typical beef cow will not reach her financial breakeven if she calves annually until six years of age if she started calving as a 2 yr old (Hudson and Van Vleck, 1981; Snelling et al., 1995).

Cows that fail to produce a calf every year can result in significant loss of profit. Crossbred cows have a greater potential for reproductive longevity and stayability (Engle et al., 2019). This is likely a consequence of their hybrid vigor, adaptation, lower dystocia rates, and decreased incidence of teeth loss with age. Obeidat (2013) identified desirable heterosis for calf crop born and weaned in several types of crossbred Nellore-Angus cows through at least 5 years of age. Among 2 yr old cows calving rates, F_1 NA, ⅜ N ⅝ A (sired by ¾ A ¼ N bulls and out of ½ A ½ N dams), first generation ⅜ N ⅝ A, and second generation ⅜ N ⅝ A cows differed from Angus and Nellore cows ranging from 0.92 to 0.94 for the crossbred cows and 0.79 for Angus and 0.04 for Nellore cows ($P < 0.05$). However, as the cows aged, differences between breed types lessened. Among cows 5 yr old or older, the crossbred cows' calving rates were only numerical higher than the Angus cows' calving rate (0.92 - 0.97 vs. 0.91, respectively), with exception of the second generation ⅜ N ⅝ A cows (0.88). All crossbred cows differed significantly from the Nellore cows' calving rate at 5 yrs old or older (0.79).

Bohac et al. (2016) found that among Angus, Brahman, F_1 BA, and F_2 ABBA and BABA cows, F_1 BA and F_2 ABBA cows appeared to have better stayability than the straightbred Angus and Brahman cows. The proportion of Angus and Brahman cows in the herd decreased from 0.63 to 0.16 and from 0.71 to 0.07 respectively, from ages 5 yr old to 10 yr old. However, the proportion of F_1 BA and F_2 ABBA cows only decreased from 0.71 to 0.54 and from 0.63 to 0.42, respectively. These crossbred cows also had the highest average age of removal from the herd at 9.0 yr for F_1 BA cows and 8.4 yr for F_2 ABBA cows. Average age of removal of the F_1 BA cows differed from all other breed types except F_2 ABBA ($P < 0.05$)

Garcia et al. (2014) demonstrated increased economic value due to longevity in several F_1 *Bos indicus* x Hereford cows compared to F_1 Angus x Hereford cows. Among all breeds, F_1 Nellore-Hereford and F_1 Gir-Hereford cows remained profitable the longest, up until an average of 15 yr old, and F_1 Nellore-Hereford also had the highest average profit per cow, at $2,338. However, F_1 Angus-Hereford cows had one of the youngest average age of profit loss at 12 yr old as well as the lowest profit per cow at $246.

It is desirable to evaluate multiple female reproductive phenotypes that could contribute to genomic analyses and/or better prediction of beef cow longevity. A few studies have documented that beef females that calve earlier during their first calving season have improved chances for reproductive longevity (Arthur et al., 1993; Funston et al., 2011; Mousel et al., 2012). Although these reports have mainly been with *Bos taurus* females, Engle (2019) demonstrated this effect among F_2 Nellore-Angus. Calving date in general affects chance of reproductive success annually with controlled breeding seasons because later-calving females have fewer days to breed back before the end of the breeding season.

MATERIALS AND METHODS

Calf performance, sex distribution, and reproductive performance traits were evaluated using data from the F_2 Nellore-Angus (Cycle 2) herd of the McGregor Genomics Project at Texas A&M University's McGregor Research Center. All records were previously recorded under approved animal care and use protocols.

General Herd Management and Data

The McGregor Research Center is located at 31^o North, -97^o East. All animals in this project were born on the Research Center. Animals are housed year-round on predominantly warm-season, improved, perennial pastures with supplemental feeding typical during winter months of November through January. Herds are managed for Spring-calving with typical breeding seasons occurring in May through July annually. All females in this project were exposed to multiple-sire groups for natural service mating annually. Calves have birth date and birth weight recorded within 24 h of birth. Calves were vaccinated for clostridial diseases at 2 to 4 mo of age annually, and weaned at approximately 7 mo of age. Approximately 1 mo prior to weaning, calves are administered a bovine respiratory disease (BRD) vaccine. At calf weaning, calves are weighed and receive booster clostridial and BRD vaccinations. At this time (or at pre-weaning) cows are pregnancy checked, weighed and have body condition score assigned. In general, cows are managed to have body condition score of 5 to 6 (on 1-to-9 scale).

There was a total of 539 reciprocal crossbred F_2 Nellore-Angus calves born from 2010-2015. These included Nellore-sired (NA) and Angus-sired (AN) parental combinations of NA x NA (NANA), NA x AN (NAAN), AN x NA (ANNA), and AN x AN (ANAN). Out of the 539 F_2 cattle, 301 were male and 238 were female. Analyzed traits included (1) calf performance traits of Julian birth date, birth weight, and weaning weight among these F_2 crosses as well as calves from these F_2 dams, (2) percent male at birth and weaning in the F_2 calves and calves out of F_2 cows, and (3) female reproductive traits of calf crop born, calf crop weaned, first calving period, and cumulative calves. The reciprocal F_2 females were all bred to Angus bulls. Significance level was set at $P \leq 0.05$. Sire and dam were considered as random effects for all analyses except for calf crop born and calf crop weaned where F_2 cow was the random effect.

Calf Performance Traits

Julian birth date, calf birth weight, and weaning weight were evaluated using mixed models with SAS. Statistical models included independent variables of sire type (NA vs. AN), dam type (NA vs. AN), calf sex, birth year, and cow group age for Julian birth date (cows aged 3 to 4 yr, 5 to 9 yr, 10 to 12 yr, and 13 to 18 yr) or the regression on age at weaning for weaning weight; possible interactions involving sire type, dam type and calf sex were investigated. The regression on Julian birth date was included in the model for birth weight in preliminary analyses but was removed in the final model due to confounding effects. Additionally, dam age was investigated for birth weight and weaning weight and was found to be confounded with birth year. It was therefore removed from the weight trait models of the F_2 calves.

Calf Sex Ratio Frequencies

Percent male at birth and weaning were evaluated using binomial data (PROC GLIMMIX) with SAS and deviations from binomial expectations for sex ratio were tested in EXCEL using the binomial threshold function. Statistical models in SAS for sex frequencies included independent variables of sire type (NA vs. AN), dam type (NA vs. AN), interactions between sire type and dam type as well as cow group age in the F_2 calves or parity in calves from F_2 dams. Only two cow age group categories were evaluated in the F_2 calves (cows aged 3 to 4 yr vs. cows aged 5 to 18 yr). Preliminary analyses used four cow age groups (3 to 4 yr, 5 to 9 yr, 10 to 12 yr, and 13 to 18 yr) to create a more even distribution in total number of cows in each group. However, these initial analyses showed that cows aged 5 yr and older had calf sex ratios that were within a reasonable range of expectation (49.6% male to 54.3% male at birth and weaning) and were therefore combined into one group (5 to 18 yr).

Cow Reproductive Traits

Calving records from 2010 to 2018 were analyzed to evaluate reciprocal F_2 Nellore-Angus cows' reproductive traits using binomial and multinomial data (PROC GLIMMIX) with SAS. Cows ranged in age from approximately 2 yr old to 7 yr old at calving; however, due to the youngest cows being born in 2015, only records from 2, 3, and 4 yr old cows (n = 443) were evaluated. Calf crop born, calf crop weaned, and cumulative calves were based on whole-herd inventory procedures where all females in the database had a 1 or 0 associated with reproductive success (as 1) or failure (as 0) each year. Time period of first calving was evaluated by designating the calving season into four 21-d intervals then running an ordinal, multinomial analysis using a cumulative logistic link function in SAS. Statistical analyses included independent variables of cow type (ANAN, ANNA, NAAN, NANA) and cow age nested within birth year for calf crop born, calf crop weaned, and first calving period, or first calving period nested within birth year for cumulative calves. First calving period and cumulative calves were evaluated to analyze stayability to four yr of age.

RESULTS AND DISCUSSION

F_2 calf performance traits

A general summary of calf performance traits of the F_2 reciprocal calves is given in Table 1, and the summary of significance levels from the statistical analyses are provided in Table 2. Table 3 provides means for calf performance trait effects. Birth year ranged from 2010 to 2015 and the cow group ages for the dams were 3-4 years old, 5-9 years old, 10-12 years old, and 13-18 years old. Calf performance traits are individually discussed below.

Julian birth date. Dam type (NA vs. AN), birth year, and cow group age accounted for differences in Julian birth date ($P < 0.05$). Calf sex, sire type, and interactions involving calf sex, sire type, and dam type did not influence Julian birth date.

The F_2 calves out of AN dams were born about 6 d earlier than those from NA dams (70 ± 2.3 d vs. 75 ± 1.9 d). While not significant ($P = 0.134$), sire type of the F_2 calves had a similar pattern. Calves sired by AN bulls were born about 5 d earlier than those sired by NA bulls (70 ± 2.3 d vs. 75 ± 2.4 d). Franke et al. (2001) evaluated birth and weaning traits in two, three, and four-breed rotation crossbred cattle. For stabilized two-breed rotations, calves with *Bos taurus* sires were born sooner than those with *Bos indicus* sires. Angus and Hereford-sired calves were born 4 d and 6 d earlier respectively, than those with Brahman sires (50 d for both A × 1/3 A 2/3 B and H × 1/3 H 2/3 B vs. 54 d for B × 1/3 B 2/3 A and 56 ± 2 d for B × 1/3 B 2/3 H).

Calves born in 2015 had the earliest Julian birth date mean at 61 d while those born the year prior, 2014, had the latest at 84 d. These year effects might be due at least in part to differences in annual turn out time of the bulls. Additionally, calves out of older cows displayed a trend of having earlier Julian birth dates than those out of younger cows (69 ± 2.4 d for cows aged 13-18 yr vs. 78 ± 2.1 d for cows aged 3-4 yr). This dam age difference may be a product of culling practices; for instance, cows that calve later in the calving season have less subsequent time to breed back, and may be more likely to be culled over time. Cows in this study remained in the herd until they failed to wean a calf twice or had an obvious problem (i.e., health issues), up to 12 yr of age. Afterwards, they were culled for any failure to wean a calf.

Birth weight. Sire type, dam type, calf sex, and birth year all affected ($P < 0 .005$) birth weight in these reciprocal F_2 calves. Interaction between sire type and dam type and interaction involving calf sex, sire type, and dam type were not influential.

Calves that had a *Bos indicus*-sired sire or dam (NA) were heavier than those with *Bos taurus*-sired sires or dams (AN). The calves from NA sires weighed 3.5 kg more than those from AN sires. Calves out of NA dams were 2.4 kg heavier (35.8 ± 0.70 kg vs. 33.4 ± 0.73 kg) than those out of AN dams. These results with dam type are consistent with previous research on F_2 crosses involving Brahman (B) and Hereford (H), where Boenig (2011) found calves out of BH cows weighed 1.8 kg more at birth (36.5 kg) than those out of HB cows (34.7 kg). In evaluating backcross embryo transfer calves, Amen et al. (2007) observed that calves out of Angus cows that had F_1 AB sires were 2.7 kg heavier at birth than those with F_1 BA sires (39.4 kg vs. 36.8 kg), but no differences were seen in calves from AB vs. BA F_1 females.

Results in these F_2 calves seem to follow a related pattern to what has been seen in F_1 *Bos taurus-Bos indicus* crosses, but with a less severe difference between birth weights. For example, Roberson et al. (1986) found that for Brahman-Hereford crossbred calves, in general, birth weight increased with greater amount of Brahman in the sire compared to Brahman in the dam. First generation calves with Brahman sires were 7 kg heavier than those with Hereford sires (37.4 kg vs. 30.4 kg). Calves that had Hereford sires and F_1 dams or F_1 sires and F_1 dams had comparable birth weights at 32.1 kg and 31.9 kg, respectively. Additionally, in a more recent study, Dillon et al. (2015) found that F_1 Brahman × Simmental (S) calves were approximately 9.4 kg heavier than F_1 Simmental × Brahman calves (41.1 vs. 31.7, respectively).

Male calves in this study were heavier than female calves at birth (35.8 kg vs. 33.4 kg, respectively), and this difference is similar to what is reported in most other purebred and composite populations. The F_2 calves with *Bos indicus*-sired sires did not have large birth weight difference between sexes, like those seen in F_1 *Bos indicus* × *Bos taurus* calves. For example, in reciprocal Brahman-Angus crossbred calves, Brown et al. (1993) reported Brahman-sired bull calves were on average 13.7 kg heavier than Angus-sired bull calves (45.8 kg vs. 32.1 kg). Heifer calves followed the same trend with a 7.4 kg difference at birth between the two sire types (38.4 kg vs. 31.0 kg). However, there appeared to be a different trend occurring in the NA-sired F_2 calves. Bull and heifer calves had numerically similar birth weights with NAAN bull calves weighing only 1.1 kg more than NAAN heifer calves (36.5 ± 1.10 kg vs. 35.3 ± 1.32 kg) and NANA bull calves weighing 0.8 kg more than NANA heifer calves (37.3 ±0 .99 kg vs. 36.5 ± 1.08 kg). Male calves with AN sires had numerically larger birth weights averaging 3.9 kg heavier than females (34.8 kg vs. 30.9 kg).

Additionally, birth weights fluctuated through the study years with the heaviest calves born in 2012 (37.1 ± 0.84 kg) and the lightest born in 2015 (32.5 ± 1.61 kg). This may be a result of seasonal conditions affecting nutrient availability differently throughout the years and/or differences among individual sires. Conception date, gestational length, and family differences may all play a role in birth weight variation across years.

Weaning weight. Calf sex, birth year, weaning age, and the interaction between sire type and dam type accounted for weaning weight differences in these F_2 calves (P < 0 .005).

However, sire type, dam type, and the 3-way interaction between sire type, dam type, and sex were not important sources of variation. As calf age increased, weaning weight increased 0.83 ± 0.067 kg per day. This is a typical result of older calves having more time to gain weight.

Weaning weight followed a similar trend to birth weight for calf sex with male calves being 17.2 kg heavier than female calves (229.3 ± 2.52 kg vs. 212.1 ± 2.61 kg). Calves weaned in 2013 ranked the heaviest across all years at 228.5 kg, and those born in 2015 were the lightest at 211.1 kg. The lightest weaning weight year corresponded with the lightest birth weight year while the years with the heaviest weaning weights and heaviest birth weights were different. However, 2012, the heaviest birth weight year, had the second heaviest weaning weight at 225.4 kg, only a 3.1 kg difference with the heaviest weaning weight year in 2013.

Calves with a *Bos indicus*-sired (NA) sire and a *Bos taurus*-sired (AN) dam were heaviest at weaning at 224.5 ± 3.68 kg. Calves out of NA-sired dams, ANNA and NANA, had the same weaning weight at 221.2 kg. The lightest calves had both a *Bos taurus*-sired sire and *Bos taurus*-sired dam, (ANAN calves), and weighed 215.9 kg. The weight differences between the reciprocal breed types were relatively small, with the greatest difference being only 8.6 kg between F_2 NAAN and F_2 ANAN calves (P = 0.075). Calves out of F_1 dams in Boenig's (2011) study had similar results with an even smaller difference of 6.0 kg between calves out of Brahman × Hereford cows (240.9 kg) compared to those out of Hereford × Brahman cows (234.9 kg).

Table 1. Summary of response variables of F_2 calves

Variable	n	Mean	Standard deviation	Minimum	Maximum
Julian birth date, d	496	73	16.0	17	138
Birth weight, kg	495	35.5	7.15	19.0	59.0
Weaning weight, kg	489	224.4	35.22	107.0	303.9
Weaning age, d	490	204	27.3	86	275

Table 2. Significance levels from analyses of Julian birth date, birth weight, and weaning weight of F_2 calves

Effects	Julian birth date	Birth weight	Weaning weight
Sire type	0.134	0.002	0.281
Dam type	0.010	0.048	0.708
Sex	0.914	< 0.001	< 0.001
Birth year	< 0.001	< 0.001	< 0.001
Sire type × Dam type	0.305	0.452	0.038
Sire type × Dam type × Sex	0.544	0.106	0.268
Cow group age	0.002	--	--
Weaning age	--	--	< 0.001

Table 3. Least squares means for Julian birth date, birth weight, and weaning weight of F_2 calves

Effect	n	Mean	SE	n	Mean	SE	n	Mean	SE
	Julian birth date			Birth weight (kg)			Weaning weight (kg)		
Sire type									
F_1 Angus × Nellore	217	70.1	2.31	257	32.9[a]	0.86	214	218.6	3.08
F_1 Nellore × Angus	277	74.7	2.39	299	36.4[b]	0.86	273	222.9	3.07
Dam type									
F_1 Angus × Nellore	180	69.6[a]	2.25	180	33.4[a]	0.73	174	220.2	2.89
F_1 Nellore × Angus	314	75.2[b]	1.86	313	35.8[b]	0.70	313	221.2	2.52
Sex									
Female	221	72.5	1.91	221	33.4[a]	0.73	218	212.1[a]	2.61
Male	273	72.3	1.86	272	35.8[b]	0.70	269	229.3[b]	2.52
Birth year (Calving dates)									
2010 (Jan 29 – Mar 20)	87	66.0	2.39	87	32.8	0.90	87	224.7	3.44
2011 (Feb 11 – May 4)	109	65.0	2.11	109	33.6	0.81	108	216.4	3.89
2012 (Feb 25 – May 18)	100	83.0	2.16	99	37.1	0.84	100	225.4	2.92
2013 (Jan 25 – Mar 17)	91	74.9	2.32	91	36.1	0.89	91	228.5	3.11
2014 (Feb 27 – May 2)	88	84.4	2.34	88	35.7	0.90	82	218.1	3.29
2015 (Jan 18 – Mar 13)	19	61.1	3.70	19	32.5	1.61	19	211.1	5.77
Sire type × Dam type[1]									
AN × AN	70	66.6	2.88	70	31.9[a]	1.07	67	215.9	3.85
AN × NA	147	73.5	2.41	146	33.8[ab]	0.92	147	221.2	3.27
NA × AN	110	72.6	2.86	110	35.9[bc]	1.03	107	224.5	3.68
NA × NA	167	76.8	2.48	167	36.9[c]	0.91	166	221.2	3.25
Cow age group, yr									
3 to 4	127	77.8[a]	2.11	--	--	--	--	--	--
5 to 9	156	71.3[b]	2.06	--	--	--	--	--	--
10 to 12	71	71.2[b]	2.76	--	--	--	--	--	--
13 to 18	140	69.3[b]	2.36	--	--	--	--	--	--

[1]AN = F_1 Angus × Nellore, NA = F_1 Nellore × Angus

[a,b,c,d] LS means within effects (rows) that do not share a superscript differ ($P < 0.05$).

Sex frequencies of F_2 calves

Table 4 provides a summary of significance levels for the percent of the F_2 calf crop that were males at birth and weaning. Analyses included calves born from 2010 to 2015. There were only two cow age group categories evaluated (cows aged 3 to 4 yr vs. cows aged 5 to 18 yr) since preliminary analyses showed cows aged 5 yr and older had calf sex ratios that were within a reasonable range of expectation. Table 5 provides means for each effect for these two variables as well as significance results of frequencies that deviate from binomial expectations.

Only sire type caused different sex ratios between F_2 calves for percent males at birth and weaning ($P < 0.05$). The F_1 AN bulls' calf crop displayed the expected 1:1 male to female sex ratio with an mean of 49.9% males at birth and 49.3% males at weaning while F_1 NA bulls had substantially more males at birth and at weaning with 66.6% and 66.5%, respectively. Additionally, these NA-sired calves deviated significantly from the expected sex ratio. Calves out of AN dams as well as those that were NAAN and NANA also deviated significantly from the typical 50% with average frequencies of 58.2%, 64.5%, and 58.3% male, respectively, at birth and weaning. Cow group age displayed a trend for percent males at birth and at weaning ($P = 0.058$ and $P = 0.057$, respectively). The younger cow group had 11.4% more males at birth and 11.6% more males at weaning (64.1% ± 5.21% vs. 52.7% ± 4.50%, and 63.8% ± 5.11% vs. 52.2% ± 4.37%). The 3 yr old to 4 yr old group was also significant for deviating from the expected sex ratio.

This trend is similar to what has been reported in horses. Santos et al. (2015) evaluated parental age effects on offspring sex ratio in a large number of Mangalarga Marchador horses (n = 59,950) and found that younger parents had a higher proportion of male offspring. There was a significant difference between sex ratios for mares aged 10 yr or younger with a sex ratio average of 1.2, 10 – 15 yr at 0.88, and 15 yr or older ranging 0.74 to 0.78. Stallion age was also influential and followed this trend, but the effects were less severe. Santos et al. (2015) also analyzed sex ratio in a smaller number of horses (n = 253) of several breeds and found a similar trend. As dam age increased, proportion of males decreased with mares 10 or younger averaging a sex ratio of 1.2, mares 10 – 15 yr at 0.78, and those 15 or older yr or older at 0.64. The difference between ages 10 or younger and 10 – 20 yr were significant. Santos et al. (2015) speculated that for this second trial, these results might be due to poor embryo quality of older dams. Equine embryos control their passage through the uterine tube; embryos from old mares tend to have delayed arrival in the uterus from the uterine tube which may result in asynchrony in the uterine environment. This asynchrony between the embryo and uterine environment may cause differential mortality between male and females possibly accounting for the bias seen in the mares aged 15 yr or older in their second trial.

Sheep may follow a related trend. Kent (1995) found a positive correlation between flock age and sex ratio in Suffolk cross ewes. Ewes averaging 2 yr old to 4.58 yr old displayed a steady increase in frequency of males from 49.56% to 54.29% as age increased ($P < 0.05$). Additionally, there was a switch in male to female bias between 4.58 yr old ewes and the oldest ewes, averaging 4.76 yr old, from 54.29% to 45.42% males, respectively ($P < 0.05$). Kent (1995) theorized that these results may be caused by parental intermediate age effects. A dam at intermediate age is typically at its peak maternal condition and is therefore better able to provide for her offspring. By producing male progeny during her peak performance, she increases the chance that her male offspring will become dominant breeding rams in the flock, passing along her genetics. The switch from male to female bias could be caused by the average flock age becoming older than the ideal intermediate age.

Table 4. Significance levels from analyses of percent male calves at birth and weaning among F_2 calves

Effects	Percent male at birth	Percent male at wean
Sire type	0.036	0.026
Dam type	0.937	0.820
Sire type × Dam type	0.394	0.368
Cow group age	0.058	0.057

Table 5. Least squares means for percent male at birth and weaning among F_2 calves

Effect	n Males	n Total	Mean	SE	n Males	n Total	Mean	SE
	Percent male at birth				Percent male at wean			
Sire type								
F_1 Angus x Nellore	105	219	49.9%[a]	5.62%	103	216	49.3%[a]	5.39%
F_1 Nellore x Angus	168	277	66.6%[bs]	5.32%	166	273	66.5%[bs]	5.13%
Dam type								
F_1 Angus x Nellore	105	180	58.3%[s]	5.03%	101	174	57.5%[s]	4.97%
F_1 Nellore x Angus	168	316	58.7%	4.56%	168	315	58.7%	4.41%
Sire type x Dam type[1]								
AN x AN	34	70	47.5%	7.47%	32	67	46.3%	7.38%
AN x NA	71	149	52.3%	6.27%	71	149	52.2%	6.05%
NA x AN	71	110	68.3%[s]	6.34%	69	107	67.9%[s]	6.24%
NA x NA	97	167	64.9%[s]	5.91%	97	166	65.0%[s]	5.71%
Cow group age (years)								
3-4	80	128	64.1%[s]	5.21%	79	127	63.8%[s]	5.11%
5-18	193	368	52.7%	4.50%	190	362	52.2%	4.37%

[1]AN = F_1 Angus x Nellore, NA = F_1 Nellore x Angus
[a,b] LS means within effects (rows) that do not share a superscript differ ($P < 0.05$).
[s] Unadjusted frequency deviated from binomial expectations ($P \leq 0.05$)

Calf performance traits out of F_2 females

Table 6 provides a general summary of the birth date and weight traits of calves produced from the reciprocal F_2 females, and the summary of significance levels from statistical analyses are given in Table 7. Table 8 provides means for these calf trait effects. Birth year ranged from 2012 to 2018 for the calves out of these F_2 cows and represents their calf production when they were 2 through 4 years old. These individual traits are discussed below.

Julian birth date. Only birth year and parity nested within dam age influenced Julian birth date ($P < 0.001$) for calves out of these young F_2 cows. Calf sex, sire type of dam, dam type of dam, and potential interaction among these effects were not influential.

Calves born in 2018 had the earliest mean Julian birth date at 66 ± 3.6 d and those born in 2014 had the latest at 84 ± 2.4 d. The latest Julian birth date year was the same in these calves as well as the F_2 calves. This may be a product of when the bulls were turned out as well as pasture conditions across years. Cows that were 4 yr old and had 2 calves gave birth earliest, and those that were 3 yr old and had 2 calves gave birth latest with a 14 d difference (69 ± 2.6 d vs. 83 ± 2.4 d). The oldest cows in the analysis with perfect calving records (4-yr-old cows with 3 calves) had a mean Julian birth date of 78 d.

Later Julian birth dates may be due to some of the F_2 heifers taking longer to reach puberty or reduced fertility. This could result in later conception dates and therefore later Julian birth dates. These effects could carry over to following breeding seasons as these heifers would have less time to bred back. This may also result in these cows missing a breeding season due to the decreased time to bred back. First calving period of these F_2 heifers showed that those that calved at both 2 and 3 yr old had about 13% more of their calves in the first two 21-day periods than those that calved at 2 yr old but missed at 3 yr old (77.4% vs. 64.4%). Additionally, heifers that calved at 2 yr old and missed at 3 yr old averaged 11.9% more calves in the third 21-d period than those with perfect calving records, three calves at 4 yr old (28.8% vs. 16.9%, respectively). Lastly, variation in conception date and gestation length could also impact Julian birth date.

Birth weight. Calf sex, birth year, and dam age nested within parity were the only effects influencing birth weight of calves out of these F_2 dams ($P < 0.005$). As expected, bull calves were 1.8 kg heavier than heifer calves (33.0 ± 0.65 kg vs. 31.2 ± 0.64 kg). The difference between sexes was numerically less than what was seen among the reciprocal F_2 calves (F_2 bull calves were about 2.4 kg heavier). The same heaviest and lightest birth weight years were seen in calves out of F_2 cows and among the F_2 calves. Calves born in 2015 had the lightest birth weight at 29.6 kg and those born in 2012 had the heaviest birth weight at 38.5 kg. In general, birth weights tended to decrease as year increased, but this could have been due to a combination of difference among individual sires and annual environmental fluctuations.

Cows aged 2 yr old with one calf had the lightest birth weight at 27.4 kg, and 4 yr old cows with three calves had the heaviest at 35.9 kg. Birth weight increased as cow age increased. Younger cows likely have lighter birth weight calves due to their immature body size since nutrients are utilized for growth and development of both the dam and the fetus.

Regarding cow sire type and dam type interaction with calf sex ($P = 0.08$), cows with both *Bos taurus*-sired parents (ANAN) had calves that displayed unusual results with bull calves and heifer calves having approximately the same average birth weight at 32.5 kg and 32.4 kg, respectively. Calves out of NANA dams had the largest sex difference with bull calves weighing 3.9 kg more than heifer calves (34.4 ± 1.01 kg vs. 30.5 ± 0.94 kg). Dams that were ANNA and

NAAN had calves that displayed a more typical sex difference in birth weight (1.2 to 1.9 kg). These results appear to follow an opposite trend to what was seen among the F_2 calves. Second generation ANAN bull calves were about 4.0 kg heavier than heifer calves (33.9 ± 1.34 kg vs. 29.9 ± 1.29 kg) whereas both sexes were about the same for calves out of AN-sired cows. Additionally, NAAN and NANA calves had numerically similar birth weights but offspring from NAAN and NANA dams showed differences in weight due to sex.

The F_2 cows' calves' birth weight follow a related pattern to what Boenig (2011) found in calves out of reciprocal F_2 Brahman-Hereford cows bred to Nellore-Angus bulls. Bull and heifer calves from HBHB, HBBH, and BHHB cows had similar birth weights despite being different sexes. Both females and males out of HBHB dams weighed on average 35.1 kg. Heifer calves out of HBBH dams weighed 34.6 kg while bull calves weighed 34.4 kg and heifer calves out of BHHB dams weighed 33.8 kg while bull calves weighed 33.2 kg. Cows with both *Bos indicus*-sired sires and dams (BHBH) had calves with large differences in weight due to sex where males averaged 4.8 kg heavier than females (36.7 kg vs. 31.9 kg).

Weaning weight. Influential effects ($P < 0.05$) for weaning weight of calves out of F_2 dams were birth year, parity nested within dam age, the interaction between sire type, dam type, and calf sex and calf age at weaning. Sire type, dam type, and their interaction did not account for important variation. Weaning weight increased with calf age with a regression of 0.80 ± 0.070 kg per day, and was close to the value observed in the F_2 calves (0.83 ± 0.067 kg/d).

No clear pattern was observed for weaning weight across all birth years. The average weaning weight was heaviest in 2012 at 230.8 kg and lightest in 2018 at 180.0 kg. The heaviest year, 2012, also had the heaviest birth weights for both F_2 calves, and calves out of F_2 dams. Parity nested within dam age displayed the same trend as birth weight. Calves out of dams with perfect calving records had the lightest and heaviest calves at weaning out of all possible age and parity combinations. There was a greater weight increase for dams with perfect calving records between their first and second calves at ages 2 and 3 yr compared to those without perfect calving records at ages 3 and 4 yr (27.8 vs. 7.1 kg, respectively). One might think that this may be a product of dams that missed a breeding season having more opportunity to grow and develop which could have allowed them to allocate more energy and nutrients into their progeny. However, weaning weights of calves from 4 yr old dams with 3 and 2 calving records were similar at 222.8 kg and 222.4 kg, respectively.

Cows with *Bos taurus*-sired dams had unexpected results for calf weaning weight with heifer calves weighing about the same as bull calves. Females out of ANAN dams averaged 202.9 ± 6.11 kg while males averaged 198.7 ± 6.21 kg. Additionally, heifer calves out of NAAN dams were 205.6 ± 6.45 kg compared to bull calves at 197.2 ± 6.79 kg. Cows with *Bos indicus*-sired dams displayed a more typical difference between calf sexes with bull calves averaging 11.0 kg heavier than heifer calves (206.2 ± 5.15 kg vs. 195.1 ± 4.93 kg) from ANNA dams, and from NANA dams (212.3 ± 5.71 kg vs. 201.4 ± 5.48 kg).

Boenig (2011) had similar results with calves out of F_2 Brahman-Hereford dams when only two of the reciprocal breed types, HBHB and HBBH cows, were bred to Angus bulls. Cows with *Bos taurus*-sired dams (HBHB) had bull and heifer calves with similar weaning weights with heifer calves weighing about 2.2 kg more than bull calves (238.3 kg vs. 236.1 kg). The HBBH cows had calves that displayed normal sex differences (215.8 kg for females vs. 226.4 kg for males).

Table 6. Summary of response variables of performance traits in calves out of F_2 cows

Variable	n	Mean	Standard deviation	Minimum	Maximum
Julian birthdate, d	447	77	18.69	24	181
Birth weight, kg	445	31.8	6.59	6.8	56.2
Weaning weight, kg	408	203.5	34.99	83.9	317.5
Weaning age, d	409	209	18.94	105	259

Table 7. Significance levels from analyses of Julian birth date, birth weight, and weaning weight of calves out of F_2 cows

Effect	Julian birth date	Birth weight	Weaning weight
Sire type	0.784	0.624	0.607
Dam type	0.382	0.377	0.426
Sex	0.863	0.002	0.376
Birth year	< 0.001	< 0.001	< 0.001
Sire type × Dam type	0.398	0.246	0.313
Sire type × Dam type × Sex	0.378	0.080	0.010
Cumulative calves (Dam age)	< 0.001	< 0.001	< 0.001
Weaning age	--	--	< 0.001

Table 8. Least squares means for Julian birth date, birth weight, and weaning weight of calves out of F_2 cows

Effect	n	Mean	SE	n	Mean	SE	n	Mean	SE
	Julian birth date			Birth weight (kg)			Weaning weight (kg)		
Sire type									
F_1 Angus × Nellore	225	75.4	2.19	226	31.8	0.76	208	200.7	4.44
F_1 Nellore × Angus	219	74.6	2.42	219	32.4	0.84	200	204.1	5.13
Dam type									
F_1 Angus × Nellore	147	74.1	2.15	148	32.4	0.73	135	201.1	4.12
F_1 Nellore × Angus	297	75.9	1.73	297	31.8	0.60	273	203.8	4.12
Sex									
Female	236	74.8	1.88	236	31.2[a]	0.64	217	201.2	3.67
Male	208	75.2	1.92	209	33.0[b]	0.65	191	203.6	3.75
Birth year (Calving dates)									
2012 (Feb 15 – May 13)	26	73.7	4.08	26	38.5	1.32	25	230.8	6.46
2013 (Jan 25 – Mar 22)	62	72.9	2.84	63	34.0	0.93	60	206.8	4.79
2014 (Feb 24 – May 22)	86	83.5	2.35	85	35.3	0.78	80	196.4	4.20
2015 (Feb 17 – May 15)	101	76.8	2.24	102	29.6	0.75	79	195.0	4.22
2016 (Feb 13 – May 9)	82	77.2	2.45	82	31.1	0.81	79	196.4	4.35
2017 (Feb 13 – May 11)	50	74.7	3.09	50	29.0	1.01	49	207.4	5.16
2018 (Feb 13 – May 15)	37	66.1	3.60	37	27.3	1.18	36	184.0	5.88
Sire type × Dam type[1] × Sex									
AN × AN × Female	34	73.6	3.55	33	32.4	1.17	31	202.9[abc]	6.11
AN × AN × Male	35	77.0	3.51	35	32.5	1.16	31	198.7[abc]	6.21
AN × NA × Female	78	77.5	2.65	78	30.6	0.89	73	195.1[a]	4.93
AN × NA × Male	78	73.5	2.77	80	31.8	0.93	73	206.2[bc]	5.15
NA × AN × Female	42	73.1	3.56	44	31.4	1.19	41	205.6[abc]	6.45
NA × AN × Male	36	72.7	3.74	36	33.3	1.24	32	197.2[ab]	6.79
NA × NA × Female	82	75.1	2.76	81	30.5	0.94	72	201.4[ab]	5.48
NA × NA × Male	59	77.3	2.97	58	34.4	1.01	55	212.3[c]	5.71
Cumulative calf number (Dam age in yr)									
1 (2)	155	72.9[ac]	2.13	156	27.4[a]	0.72	135	175.4[a]	4.08
1 (3)	37	74.6[ac]	3.23	37	33.8[bc]	1.05	36	215.3[b]	5.16
2 (3)	93	82.7[b]	2.40	93	32.8[b]	0.80	86	203.2[c]	4.32
2 (4)	81	69.0[c]	2.58	82	35.3[cd]	0.85	80	222.4[b]	4.48
3 (4)	78	78.0[ab]	2.53	77	35.9[cd]	0.84	71	222.8[b]	4.42

[1]AN = F_1 Angus × Nellore, NA = F_1 Nellore x Angus; interaction P = 0.398, P = 0.080, P = 0.010, for Julian birth date, birth and weaning rate, respectively

[a,b,c] LS means within effects (rows) that do not share a subscript differ (P < 0.05).

Sex frequencies of calves out of F_2 females

Table 9 displays significance levels for percentage of male calves at birth and weaning from the F_2 females, and Table 10 provides least squares means as well as binomial deviation significance for each effect. Sire type, dam type, and the interaction between them did not account for variation in either variable. However, parity showed a trend for percent male at birth ($P = 0.089$) and was influential for percent male at weaning ($P = 0.006$). There appeared to be a switch in bias from males to females for calves out of the F_2 cows versus the F_2 calves themselves.

Frequency of male calves out of dams from NA-sired sires were significantly different from the expected sex ratio with less males and more females at birth and weaning at 43.4% and 43.5%, respectively (values are unadjusted frequency of n male/n total). However, for the F_2 calves, NA bulls had more males at birth and weaning ($P \leq 0.05$) (Table 5). Dams that were NAAN and NANA showed numerically different means at birth at 45.8% and 41.0%, respectively, and at weaning at 43.6% and 41.5%, respectively. However, only NANA dams differed from 50% with more heifer calves at birth and weaning ($P \leq 0.05$). The reverse was true for F_2 NANA calves which had more males at birth with a mean of 64.9% and at weaning at 65.0% (Table 5). Primiparous cows had 42.4% males at birth and only 38.1% males at weaning while multiparous cows had 50.7% males at birth and 52.4% males at weaning. Primiparous cows deviated from 50% male to 50% female at birth and weaning ($P \leq 0.05$).

Table 9. Significance levels from analyses for percent male calves at birth and weaning from F_2 cows

Effects	Percent male at birth	Percent male at wean
Sire type	0.231	0.323
Dam type	0.605	0.854
Sire type × Dam type	0.690	0.838
Parity	0.089	0.006

Table 10. Least squares means for percent male at birth and weaning from F_2 cows

Effect	n Males	n Total	Mean	SE	n Males	n Total	Mean	SE
	Percent male at birth				Percent male at wean			
Sire type								
F_1 Angus x Nellore	113	225	49.6%	3.78%	102	207	47.9%	3.94%
F_1 Nellore x Angus	95	219	43.4%^{s}	3.65%	87	200	42.5%^{s}	3.78%
Dam type								
F_1 Angus x Nellore	71	147	47.9%	4.36%	63	135	45.7%	4.49%
F_1 Nellore x Angus	137	297	45.1%	3.11%	126	272	44.7%	3.22%
Sire type x Dam type[1]								
AN x AN	35	69	50.0%	6.26%	31	63	47.8%	6.52%
AN x NA	78	156	49.3%	4.20%	71	144	47.9%	4.35%
NA x AN	36	78	45.8%	5.88%	32	72	43.6%	6.05%
NA x NA	59	141	41.0%^{s}	4.35%	55	128	41.5%^{s}	4.54%
Parity								
Primiparous	81	192	42.4%^{s}	3.79%	65	170	38.1%^{s}	3.92%
Multiparous	127	252	50.7%	3.39%	124	237	52.4%	3.46%

[1]AN = F_1 Angus x Nellore, NA = F_1 Nellore x Angus

^{s}Unadjusted frequency deviated from binomial expectation ($P \leq 0.05$)

Reproductive traits of F_2 females

Although other records were available, only those from cows aged 2 to 4 years old were included in the analyses, with calf birth years from these cows ranging from 2010 to 2015. Four reproductive traits were evaluated: calf crop born, calf crop weaned, timing of first parity, and number of calves produced relative to cow age. Each trait is discussed below.

Calf crop born and calf crop weaned. Table 11 provides frequencies and means for calf crop born and calf crop weaned of these F_2 cows. Only cow age nested within cow birth year was influential ($P < 0.001$) for these traits. As 3 yr olds, cows born in 2014 had the worst calf crop born and weaned across all years at 33.6% and 34.2%, respectively. However, these cows as 4 yr olds had the highest calf crop born at 100% as well as calf crop weaned at 96.8%. Cow type did not account for important variation in either trait.

These results show a different pattern than what was observed by Boenig (2011) in reciprocal F_2 Brahman-Hereford cows where HB-sired cows had a higher calf crop born (92.8% vs. 69.8%) and weaned (88.9% vs. 63.0%) than F_2 BH-sired cows. Furthermore, Bohac (2015) found a significant difference between two types of reciprocal F_2s, ABBA and BABA, cows aged 2 and 3 yr, for calf crop born and calf crop weaned. For 2 yr old cows, ABBA had a higher calf crop born (0.88 vs. 0.64) and calf crop weaned (0.80 vs. 0.44) than BABA cows. The reverse was true for 3 yr old cows. Both had low calf crop born and weaned adjusted means, but BABA cows' were higher in comparison to ABBA cows' (0.65 vs. 0.28 for calf crop born and 0.49 vs. 0.22 for calf crop weaned, respectively). However, breed type did not account for variation in calf crop born and calf crop weaned between ABBA and BABA breed types as mature cows (cows aged 5 yr or older).

First calving period. Calving seasons were divided into four, 21-d intervals, (calving periods 1, 2, 3, and 4) which started when the first calf from the F_2 females was born for that year. Calving periods were only recorded for each cow's first calf. Overall, 42% of these F_2 dams had their first calf in the second 21-days of the calving season; 29% had their first parity in the first 21 days, followed by 22% in the third 21 days. Only cow age nested within cow birth year accounted for variation in first calving period among the F_2 dams ($P < 0.001$). Figure 1 provides a visual display of the cow age-birth year combinations relative to when they gave birth to their first calf.

Table 11. Frequencies and least squares means for calf crop born and calf crop weaned of the F_2 cows by cow type and cow age within their birth year

Effect	Calf crop born			Calf crop weaned		
Cow type[1]	n	Frequency (%)		n	Frequency (%)	
ANAN	70	76.1		65	70.7	
ANNA	158	79.8		147	74.2	
NAAN	79	77.5		75	73.5	
NANA	142	80.7		129	73.3	
Cow age (Birth year)	n	Mean	SE	n	Mean	SE
2 (2010)	29	0.931	0.0480	29	0.867	0.0631
3 (2010)	28	0.893	0.0600	28	0.897	0.0571
4 (2010)	26	0.961	0.0380	26	0.889	0.0612
2 (2011)	50	0.745	0.0630	50	0.688	0.0668
3 (2011)	45	0.717	0.0680	45	0.674	0.0710
4 (2011)	42	0.908	0.0450	42	0.815	0.0602
2 (2012)	42	0.690	0.0720	42	0.668	0.0731
3 (2012)	39	0.794	0.0650	39	0.668	0.0760
4 (2012)	35	0.943	0.0390	35	0.943	0.0393
2 (2013)	43	0.768	0.0640	43	0.582	0.0753
3 (2013)	39	0.616	0.0780	39	0.591	0.0788
4 (2013)	38	0.869	0.0550	38	0.843	0.0590
2 (2014)	33	0.813	0.0690	33	0.726	0.0783
3 (2014)	32	0.336	0.0840	32	0.342	0.0845
4 (2014)	31	1.000	0.0000	31	0.968	0.0320
2 (2015)	8	0.741	0.1580	8	0.756	0.1517
3 (2015)	8	0.870	0.1220	8	0.878	0.1147

[1] F_1 sire type is listed first followed by F_1 dam type (i.e., F_2 ANAN= F_1 Angus-Nellore sire x F_1 Angus-Nellore dam)

Two-year old dams gave birth to their first calves more commonly in earlier calving periods than 3-yr-old, first parity dams. Among age and cow birth year combinations for calving period one (first 21 d), 2 yr old heifers born in 2013 had the highest occurrence (45.5%), while 3 yr old heifers born in 2015 had the lowest (0.0%). Additionally, these 2015 born, 3 yr old heifers had more calves in the fourth 21-d calving period (33.3%) than all other cow age and birth year combinations.

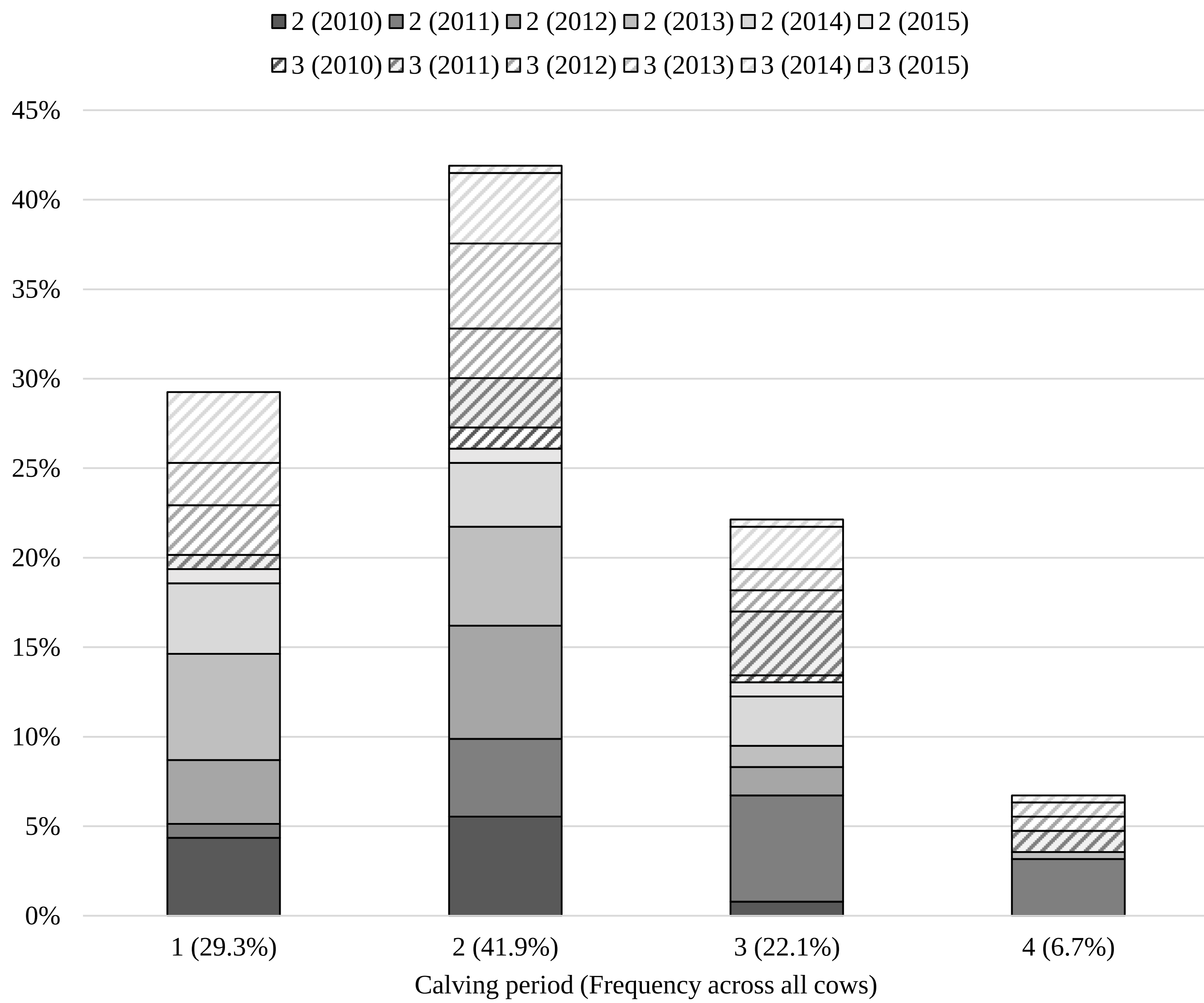

Figure 1. Distribution of first parity by 21-day calving season period by cow age and birth year.

Cumulative calves. Table 12 shows the distribution number of calves from F_2 cows across cow age group. In general, most dams had their first calf as a 2 yr old with a frequency of 77.6%. Dams aged 3 yr old and 4 yr tended to have similar frequencies between possible number of calves for their respective age group (ranging from 45.3% to 53.5%). Only cows aged 4 yr were included in the parity analysis. First calving period nested within F_2 animal birth year was the sole influential effect for cumulative calves ($P < 0.05$).

Table 12. Distribution of calf numbers across cow age group from F_2 cows that remained in the breeding herd

Cow age(yr)	n	Frequency (%)	n	Frequency (%)	n	Frequency (%)	n	Frequency (%)
	0 Calves		1 Calf		2 Calves		3 Calves	
2	38	19.4	158	80.6	0	0.0	0	0.0
3	0	0.0	96	50.5	94	49.5	0	0.0
4	0	0.0	0	0.0	92	54.1	78	45.9

Cows born in 2010 with their first parity in calving period one produced the highest number of calves (3.0) among all possible birth year and calving period combinations (Table 13). Additionally, 2010-born dams had the greatest average number of calves (2.8) calves through 4 years of age. Previous studies on *Bos taurus* cows have shown parturition within the first 21 d of a cows first calving season not only impacts the dam's performance, but her calf's performance as well. Cushman et al. (2013) and Damiran et al. (2018) showed that heifers that calved in the first 21 d of their first calving season had increased longevity compared to those that first calved 22 days or later in their first calving season. Also, Funston et al. (2011) found that *Bos taurus* heifer calves born in the first 21 d of the calving season had an increased likelihood of cycling by the start of their first breeding season as well as their first calf having an increased weaning weight compared to heifers born in later periods. In general, earlier first calving dates have been shown to be influential in weaning weights of a heifer's first and subsequent calves, regardless of sex. (Lesmeister et al., 1973; Arthur et al., 1993; Funston et al., 2011; Mousel et al., 2012).

Figure 2 shows frequencies for each cow type at 4 yr of age relative to the number of calves born. While cow breed type was not influential for parity, 4 yr old cows with AN dams tended to have less calves than those with NA dams. Only an average of 38.3% of cows with AN dams had three calves compared to 49.5% of cows with NA dams.

Table 13. Least squares means for number of cumulative calves of the F_2 cows by first calving period and cow birth year

First calving period (Cow birth year)	n	Mean	Standard error
1 (2010)	11	3.0	6.020E-34
2 (2010)	12	2.8	1.266E-01
3 (2010)	3	2.7	3.280E-01
1 (2011)	3	2.0	2.190E-12
2 (2011)	16	2.6	1.486E-01
3 (2011)	15	2.4	1.432E-01
4 (2011)	8	2.5	2.000E-01
1 (2012)	13	2.3	1.347E-01
2 (2012)	16	2.8	1.241E-01
3 (2012)	5	2.4	2.327E-01
4 (2012)	1	2.0	1.120E-03
1 (2013)	15	2.6	1.885E-01
2 (2013)	15	2.1	8.010E-02
3 (2013)	4	2.2	2.217E-01
4 (2013)	2	2.0	7.190E-10
1 (2014)	12	2.1	1.051E-01
2 (2014)	11	2.1	8.189E-02
3 (2014)	7	2.3	1.803E-01

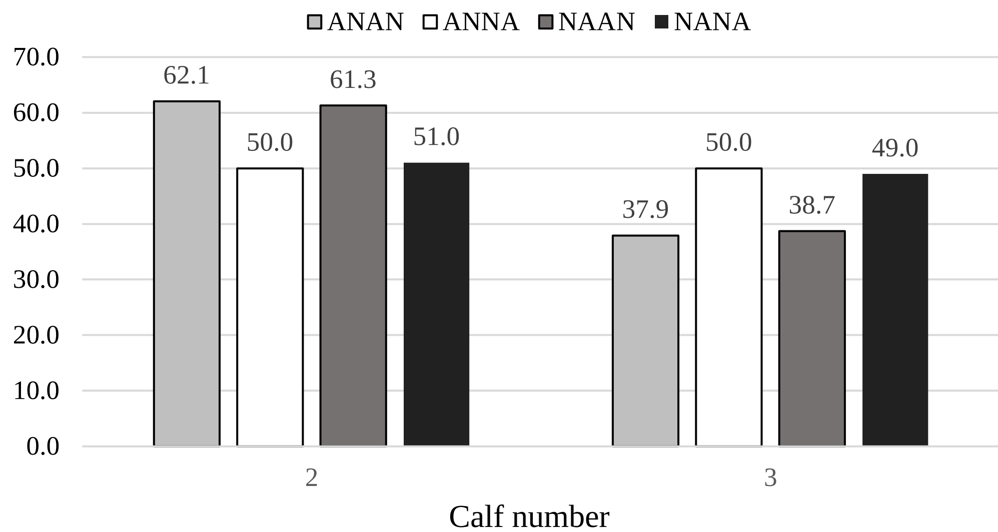

Figure 2. Frequency distribution of cumulative calf number born by cow type of 4 yr old F_2 cows.

Engle et al. (2019) evaluated first-calving period in Cycle 1 *Bos taurus-Bos indicus* crosses (all 50% *Bos taurus* and 50% *Bos indicus*), including Nellore–Angus × Brahman–Hereford, Nellore–Angus × Brahman– Angus, and F_2 Nellore–Angus, and found that those calving in the first 21 d period had a 92% chance of calving at 3 yr old and an 82% chance of calving at 4 yr old. These probabilities are not consistent with was observed in young cows in this study as illustrated in Figure 3. Figure 3 shows the distribution of total calves born in relationship to first calving period divided into four 21-day intervals. Cows are grouped by age at first calf, 2 yr old or 3 yr old, and by whether or not they missed a calving season. Only 33.3% cows that calved in period 1 and first calved at 2 yr old gave birth at 3 yr of age. Additionally, only 33.8% of cows that first calved in period 1 and had a perfect calving record, they never missed a calving season, had a calf at 4 yr old.

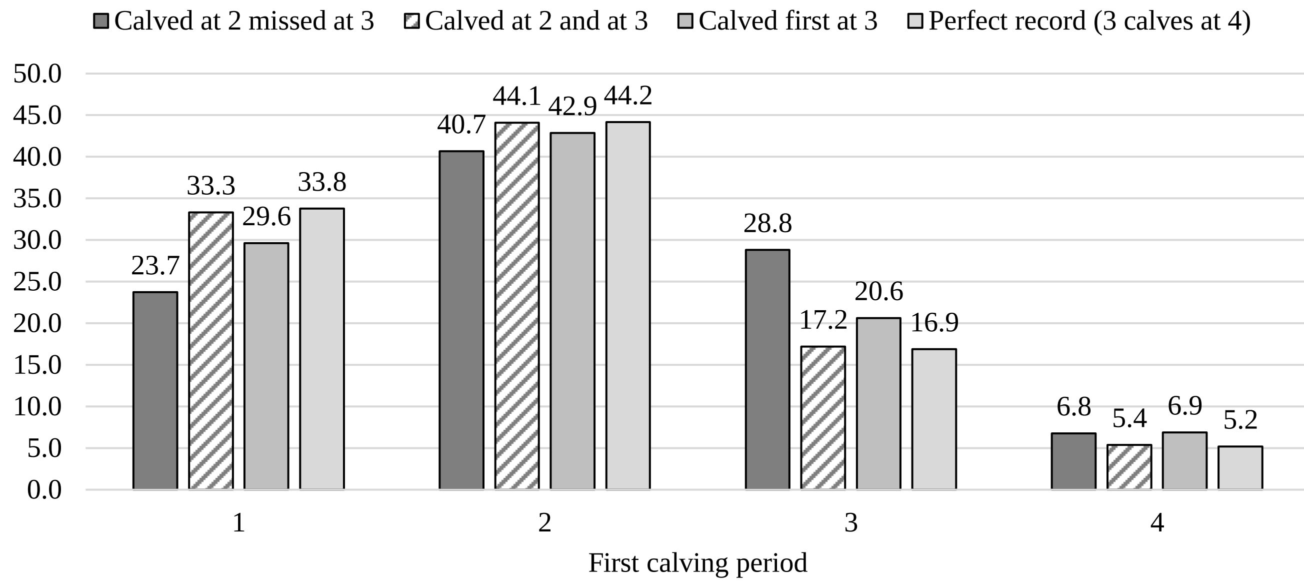

Figure 3. Distribution (%) of first-parity calving records by 21-day period among F_2 females of different fertility categories.

Contrary to previous research (i.e., Cushman et al., 2013 and Damiran et al., 2018), calving in the first calving period did not appear to be advantageous in subsequent calving seasons in these young F_2 cows. The majority of cows in this study first calved in the second 21 d period, regardless of age at first calf. One might think that heifers calving as 3 yr olds would give birth earlier in the calving season than their contemporaries that calved as 2 yr olds, but that was not the case in these females. If females did not breed to calve at 2 yr of age, people might speculate that result would occur when they failed to reach puberty in time; however, that does not seem to be the case here because 3-yr-old, first-parity females had similar calving distribution pattern as 2-yr-old, first-parity females.

SUMMARY AND CONCLUSIONS

The objective of this study was to further investigate reciprocal differences in *Bos indicus-Bos taurus* F_2 matings as previous research indicated that the parental cross of F_2 cows may play a significant role in their performance and the performance of their offspring (Seifert and Kennedy, 1972; Seebeck, 1973; MacKinnon et al., 1989; Olson et al., 1993; Boenig, 2011; Bohac, 2015); these previous studies utilized Brahman for *Bos indicus* influence. Therefore, this project analyzed calf performance traits and female reproductive traits in reciprocal F_2 Nellore-Angus calves and calves from these F_2 Nellore-Angus cows.

For calf performance traits in the F_2 NA calves, influential breed type effects were dam type for Julian birth date, dam type and sire type for birth weight, and the interaction between sire type, dam type, and sex for weaning weight ($P < 0.05$). Reciprocal F_2 NA calves out of AN (Angus-sired) F_1 cows were born earlier than those out of NA (Nellore-sired) F_1 cows. Sire type displayed a similar pattern, although it was not an important source of variation. The F_2 calves with a *Bos indicus*-sired (NA) sire or dam averaged 3.0 kg heavier at birth than those with *Bos taurus*-sired (AN) sire or dam. Boenig (2011) reported similar results for dam type effects in F_2 Brahman-Hereford crosses where calves with BH dams were 1.8 kg heavier than those with HB dams. Additionally, the results in the F_2 NA calves appear to follow a related, less severe pattern to birth weight trends in *Bos taurus-Bos indicus* crossbred calves where those with *Bos indicus* sires weighed up to 9.4 kg heavier at birth (Roberson et al., 1986; Dillon et al., 2015). Calves out of F_2 females had fewer significant breed type effects for calf performance traits with only the interaction between sire type, dam type, and sex accounting for variation in weaning weight ($P < 0.05$). *Bos taurus*-sired dams (ANAN and ANNA) had unexpected results with heifer calves weighing about the same as bull calves at weaning.

Sire type in F_2 calves was the sole influential effect for percent male at birth and weaning with NA bulls averaging 17% more males for both. Additionally, F_2 calves with NA sires, AN dams, and calves that were NAAN or NANA breed types had more males ($P \leq 0.05$) than the expected sex ratio. No effects analyzed in calves from the F_2 cows were found to be important sources of variation in frequency of males at birth and weaning. However, calves from F_2 dams appeared to follow a reverse trend where those with NA-sired dams or those out of NANA cows had more females ($P \leq 0.05$) than 50%. One possible explanation for these results is that they could be caused by imprinted sex-linked gene(s). Further research is needed to conclude if these differences in sex ratio are unique to the types of cattle analyzed in this study as well as determine the mechanisms behind these sex biases.

Breed type effects were not influential for any of the female reproductive traits analyzed in the F_2 cows. Calf crop born and calf crop weaned were relatively low for all F_2 breed types with calf crop born ranging from 76.1% to 80.7% and calf crop weaned ranging from 70.7% to 74.2%. This is dissimilar to Boenig's (2011) results where F_2 HB-sired cows outperformed F_2 BH-sired cows for calf crop born (92.8% vs. 69.8%) and calf crop weaned (88.9% vs. 63.0%). Cow age nested within cow birth year accounted for variation ($P < 0.001$) in first calving period among the F_2 dams with 2 yr old heifers born in 2013 having the highest occurrence of calving in the first 21 d at 45.5%. For cumulative calves, first calving period nested within F_2 animal birth year was the sole influential effect ($P < 0.05$). Calving in the first calving period did not appear to be advantageous as many of the cows in this study first calved in the second 21 d period, regardless of age at first calf. Additionally, no distinct patterns were observed among different parity, calving period, and age combinations for cumulative calves.

Dissimilarities in breed type significance in this study compared to previous studies, may be partially due to differences in ages evaluated. For example, Boenig (2011) used F_2 cows aged 2 yr to 15 yr and Bohac (2015) used F_2 cows aged 2 yr to 16 yr. Only cows aged 2 yr to 4 yr were included for analysis in this study due to the disproportionate number of records associated with cow birth year (e.g., cows born in 2015 had fewer records than those born in 2010). Further research is needed to evaluate whether breed type effects are influential in mature reciprocal F_2 Nellore-Angus cows (cows aged 5 yr or older).

Additionally, differences between *Bos indicus* breeds used in each study could cause variation in results. Past studies have mostly used Brahman for the *Bos indicus* breed in their *Bos taurus*-*Bos indicus* F_1 and F_2 reciprocal crosses whereas this study used Nellore. While Nellore and Brahman are comparable, deviations in breed characteristics may lead to unsimilar outcomes. Breed type effects were influential for some of the traits analyzed in F_2 NA crosses, but none were as drastic as what was observed in Bohac's (2011) study. Additional research on reciprocal F_2 crosses is required to determine if the large differences in calf performance traits, female reproductive traits, and abnormally high hybrid vigor, as seen by Bohac (2011), are a novelty for F_2 *Bos taurus*-Brahman crosses or if these can occur in other F_2 *Bos taurus-Bos indicus* crosses. Research involving subsequential generations (F_3 and later) would also be beneficial to determine if these reciprocal differences, first observed in the F_1s, can persist in later generations.

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