# HETEROSIS FOR REPRODUCTIVE AND MATERNAL TRAITS IN FIRST AND SECOND GENERATION RECIPROCAL BRAHMAN-ANGUS CROSSES

A Thesis

by

JENNIFER KAY BOHAC

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| Chair of Committee, | James O. Sanders |
| Co-Chair of Committee, | David G. Riley |
| Committee Members, | Andy D. Herring |
| | Larry A. Redmon |
| Head of Department, | H. Russell Cross |

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# ABSTRACT

Calf crop born, calf crop weaned, calf birth weight, calf weaning weight, and calf preweaning average daily gain (ADG) were evaluated from 1997 to 2009 in Brahman (B) and Angus (A) straightbred and crossbred cows (n = 194). The objective was to estimate heterosis for $F_1$ and to compare between two groups of $F_2$ females for these reproductive traits. Breed groups included A, B, $F_1$ Brahman-sired (BA; a pair of letters designate the cow's sire breed and dam breed, respectively) cows (n = 92 purebreds, 53 $F_1$, 49 $F_2$). $F_2$ breed groups included cows sired by AB and out of BA dams (ABBA) and cows sired by BA and out of BA dams (BABA). Data from 2-yr-old females were analyzed separately from cows ages 3-yr-old and older. As 2-yr-olds, Brahman had the lowest calf crop born (0.36 ± 0.07; $P < 0.01$) and a lower calf crop weaned than every breed group except BABA (0.26 ± 0.08; $P < 0.01$). Also as 2-yr-olds, BABA had a lower calf crop born ($P < 0.05$) than BA and ABBA (0.92 ± 0.05 and 0.88 ± 0.08, respectively). As 3-yr-olds and older, BABA had heavier calves (38.74 ± 0.86; $P < 0.05$) than Brahman, BA, and ABBA, while Brahman had calves with the lightest ($P < 0.001$) birth weight. As 3-yr-olds, ABBA had the lowest ($P < 0.02$) calf crop born and weaned (0.28 ± 0.07 and 0.22 ± 0.08, respectively). As 5 to 10-yr-olds, BA weaned heavier calves than Angus, Brahman, and BABA ($P < 0.01$), and as 10-yr-old and older, ABBA weaned heavier calves than Angus, Brahman, and BABA ($P < 0.02$). Results suggest that low means of $F_2$ cows sired by Brahman-sired $F_1$ bulls may be responsible for earlier reports that heterosis for reproductive traits was totally lost in that generation. That group (BABA) was represented by a small number of cows for much of the data in later years, because of culling for reproduction, and means for that group may not be representative of the true group performance (i.e., their reproductive performance, as reported in this

document, may be inflated). The low performance of BABA as 2-yr-olds and early exit of most of those cows from the project may indicate superior fertility of ABBA $F_2$ cows.

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# INTRODUCTION

Among domesticated cattle, there are two subspecies: *Bos indicus* and *Bos taurus.* *Bos indicus* breeds, such as the Brahman, are known to be parasite resistant and adapted to hot, humid climates. The *Bos indicus* breeds that have been important in the western hemisphere have large mature size but do not produce as high meat quality as *Bos taurus* breeds. In the United States the subspecies *Bos taurus* is often considered as two main categories based on origin: British and Continental European. British *Bos taurus* breeds are popular because carcasses often have high marbling relative to other breeds and they generally are considered to milk well as mothers. Originating from Great Britain, these breeds are often crossed to *Bos indicus* breeds, particularly Brahman, resulting in animals that are well-adapted to conditions in the southern USA and that express high levels of heterosis (crossbred superiority over the parental average) for many traits. Crossbreeding is important in the Texas beef cattle industry in blending the hot climate adapted traits of the Brahman breed with the carcass and mothering traits of the Angus breed, for example.

Reproductive success and maternal ability are two very important traits in the beef cattle industry. Reproductive efficiency and calf survival are of great economic value (Dearborn et al., 1973). Reproductive efficiency is a complex character consisting of a number of traits (Cartwright et al., 1964). Reproductive efficiency is often expressed as the percent of cows that become pregnant, calve, or wean a calf within a population of cows that were exposed to a bull or artificially inseminated during a breeding season. Maternal ability is often measured in terms of calf survival and calf weaning weight. Reproductive traits have low heritabilities (Dechow et al., 2001); heterosis is often effective for trait improvement when heritability is low (Cartwright et al., 1964). Crossbreeding often improves maternal ability as well as reproductive traits. Numerous studies have reported that crossbreeding Brahman with a British breed, such as the Angus, increases survival of calves, reproductive performance, and milking ability (Gregory et al., 1965; Gaines et al., 1966; Wiltbank et al., 1967; Cundiff et al., 1974a,b; Rohrer et al., 1988; Núñez- Domínguez et al., 1991).

Heterosis, or hybrid vigor, is defined as the increased performance of crossbred animals over the purebred base of the breeds that comprise the crossbred animal (Jones, 1917; Crow, 1948). Many commercial beef cattle enterprises in the southern United States utilize Brahman crossbreds as the female line due to the combination of their heat tolerance and hardiness coupled with British or Continental *Bos taurus* breeds' carcass traits and mothering abilities. These breeding strategies take advantage of heterosis in the cows as well as the calves they produce. Heterosis is often assumed to be due to dominance at many loci and therefore heterosis expression is predicted to be proportional to heterozygosity. If hybrid vigor is due to dominance effects, $F_1$ females are expected to express maximal heterosis while the $F_2$ females are expected to retain half of the heterosis observed in the $F_1$ generation. Heterosis usually has its highest expression in the $F_1$ generation because succeeding generations do not retain as much heterozygosity, and thus heterosis, as the initial cross from purebred parents. Heterosis retention is an important issue for producers to consider in non-$F_1$ crossbred cattle, as the loss of heterosis in performance may also mean a loss in their profit. In more recent studies, the heterosis retention of the $F_2$ generation of *Bos indicus-Bos taurus* has been researched (Sanders et al., 2005), and the cows studied in this thesis are a subset of that group of cows. Sanders et al. reported that Australian research (Seifert and Kennedy, 1972; Seebeck, 1973) indicated that *Bos indicus-Bos taurus* crosses have a massive loss of heterosis from the $F_1$ to the $F_2$ generations for calf crop born.

Previous studies have shown a large reciprocal cross birth weight differences in the $F_1$ generation of *Bos taurus-Bos indicus* crosses (Cartwright et al., 1964). Results of Boenig (2011) suggest that cow reproduction differs in a similar way. Brahman-sired $F_1$ cows and $F_2$ cows sired by Brahman-sired $F_1$ bulls had lower unadjusted means for calf crop born and calf crop weaned than Hereford-sired $F_1$ cows and $F_2$ cows sired by Hereford-sired $F_1$ bulls (Boenig, 2011). Additional knowledge of $F_1$ and $F_2$ cow performance could either confirm or refute the Australian results and either would be important to know for breeding programs comprising of *Bos taurus-Bos indicus* cattle.

## LITERATURE REVIEW

### *The Brahman Breed*

The American Brahman is a composite that resulted from Indian and Brazilian Zebu (*Bos indicus)* bulls that were used on *Bos taurus* females in the United States in the early 1900's (Sanders, 1980; Franke, 1980). The Red Brahman was developed from the Gir, Guzerat, and Nellore breeds while the Gray Brahman was developed primarily from the Guzerat and the Nellore (Sanders, 1980), and probably with some influence from the Krishna Valley breed (J. O. Sanders, personal communication). Brahman cattle are popular as both purebreds and for crossbreeding across the southern United States due to their heat and parasite tolerance and/or resistance (Cartwright, 1980; Franke, 1980; Turner, 1980; Herring et al., 1996).

### *The Angus Breed*

The Aberdeen-Angus, as it was originally known but is more commonly known as the Angus, originates from the counties of Angus and Aberdeen in Scotland where animals of this breed are naturally polled and generally have excellent marbling capabilities. Their marbling is used as an industry standard and has led to branded beef programs such as Certified Angus Beef. Angus, being a British *Bos taurus* breed, have a reputation to make excellent mothers, with notably good udders and high milking ability for a beef breed. Angus come in black and red, though they are registered in separate associations and are commonly distinguished by referring to the recessive color type as Red Angus and the black colored Angus as simply "Angus." The Angus has the most numerous annual registrations and is used almost everywhere in the United States today.

***Heterosis***

Heterosis is the higher performance of crossbred cattle compared to the average of their purebred parental breeds (Lush, 1945; Dickerson, 1973). Historically, Shull (1914) defined hybrid vigor, now also called heterosis, as the vigor as a result of the union of dissimilar gametes. The concept can be traced back to the time of Darwin (1896, as cited by Boenig, 2011), though Shull (1952) claimed to have used it first in 1911 when referring to corn. Hayes (1952) also worked with corn and noted that dominance or partial dominance appeared to be important in heterosis. Bruce (1910) proposed that heterozygosity across loci was associated with heterosis. Shull (1952) and Hays (1952) supported this idea with their work with corn and Wright (1922) supported this idea in his research with guinea pigs when he explained heterosis as being proportional to the amount of heterozygosity.

The cause of heterosis is usually attributed to dominance across many loci. Dominance is the interaction of alleles within a locus. Another potential cause of heterosis is epistasis which is the interaction between loci. Dickerson (1952) defined epistasis to include all effects of a gene at one locus on the expression of genes at other loci. Forms of epistasis that could cause the superior performance in $F_1$ offspring include combinations of genes that have become fixed over time (Lush, 1946; Dickerson, 1969) or the desirable gene combinations that are brought together in the $F_1$ individual (Sheridan, 1981). Even though epistatic combinations are expected to be present in the $F_1$ generation, some of these combinations could be disrupted by recombination or mutation events in meiosis (Sheridan, 1981).

### *Heterosis Retention*

Riley and Crockett (2006) wrote that heterosis expression is estimated to be proportional to breed heterozygosity under the dominance model. A locus is heterozygous if the two alleles at that locus are different and breed heterozygosity is having alleles from two different breeds, whether the alleles are different or not. The first cross ($F_1$) of two breeds gives an animal that is breed heterozygous at each locus. For example, if a purebred Angus is bred to a purebred Brahman, each parent contributes one entire strand of DNA from the Angus and Brahman, respectively, to the progeny. The progeny will then have one allele of Angus origin and one allele of Brahman origin at every single autosomal locus across its entire genome. For this reason, only $F_1$ animals are expected to express full heterosis for each trait. Therefore, hybrid vigor is often presented as a fraction of the amount the $F_1$ generation is expected to possess. The Brahman-*Bos taurus* $F_1$ female has proved to be very productive and valuable in commercial beef cattle operations. They have been shown to have superior maternal traits and greater longevity due to heterosis (Cartwright et al., 1964; Franke, 1980; Turner, 1980).

If $F_1$ animals are intermated or backcrossed with a parent breed, the proportion of the $F_1$ heterosis expressed is called retained heterosis. If heterosis is correctly predicted by the dominance model, non-$F_1$ crossbred animals would be expected to express a fraction of the $F_1$ heterosis that is proportional to the proportion of loci that are heterozygous (Wright, 1922; Dickerson, 1969, 1973). According to Dickerson (1969), only one generation of random mating is necessary to stabilize heterozygosity after *inter se* matings.

The retention of heterosis is especially important to consider in non-$F_1$ crossbred females because heterosis for reproductive efficiency and maternal traits are very critical for beef cattle producers. The high levels of reproduction and efficiency seen in $F_1$ cows and the current high cost of replacing females merits further research into the performance of subsequent generations. The popularity of the $F_1$ female in commercial beef cattle production systems only seems limited by her inability to produce a replacement that matches her performance (Herring et al., 1996). Piper (1982) reported that the most effective means of increasing reproductive rate is by utilizing heterosis for female fertility. This heterosis can be maximized in $F_1$ *Bos indicus-Bos taurus* females whose expressed heterosis exceeds that of $F_1$ *Bos taurus-Bos taurus* females (Cartwright et al., 1964; Koger 1973; Koger et al., 1975; Gregory et al., 1978; Gregory and Cundiff, 1980).

In a study evaluating $F_1$, $F_2$, and $F_3$ Hereford x Angus cows, calf survival and pregnancy rate heterosis had a greater reduction in the $F_2$ and $F_3$ generations compared to the $F_1$ than the dominance model predicted (Koch et al., 1985).Yet the same study showed maternal influence on birth weight and pre-weaning gain heterosis did not differ from the dominance model prediction. Gregory et al. studied MARC I, II, and III composites and evaluated economically important traits (1991a, 1991b, 1999). Direct and maternal heterosis retained for birth weight, weaning weight, and pre-weaning average daily gain was not less than predicted by the dominance model. Additionally, Gregory et al. reported that cow age was important when comparing heterosis levels (1992).

The objective of any commercial beef cattle breeding program should be to maximize the additive genetic values and heterosis levels for maternal ability, calf crop weaned, and growth potential of a calf (Koger, 1980). Likewise, Gregory and Cundiff (1980) stated that the objective of beef cattle crossbreeding systems should be to optimize both non-additive and additive effects of genes, meaning to optimize heterosis and breed differences. This is especially important in the subtropical region of the southern United States where the extreme hot temperatures and humidity can be very harsh on straight *Bos taurus* cattle. Cunningham (1982) reported that heterosis expression increases as environmental stresses increases. Similarly, Frisch and Vercoe (1984) found similar results in a study in Australia: when the animals are in a tough environment, heterosis levels are considerably higher compared to a milder environment in which the superiority of the crossbreds diminishes. In order for cattle to be better adapted to the climate of the southern United States, *Bos taurus* cattle are commonly crossbred with *Bos indicus* cattle, primarily the Brahman.

***Heterosis in Cow Reproductive and Maternal Traits***

As reported from the results of various studies, Brahman-crossbred calves have advantages such as higher calf survival rate, heavier weaning weights, and improved average daily gains compared to crosses between different *Bos taurus* breeds (Gregory et al., 1979; Franke, 1980; Paschal et al., 1991; Cundiff et al., 2000). Also, Brahman-cross cows have been reported to have higher pregnancy rates, higher calving rate, better longevity, and wean heavier calves than *Bos taurus* crossed cows (Peacock et al., 1971; Franke, 1980; Koger, 1980; Bailey, 1991; McCarter et al., 1991; Núñez-Dominguez et al., 1991; Riley et al., 2001).

It is well documented that $F_1$ *Bos taurus-Bos indicus* crossbred calves sired by *Bos indicus* bulls tend to weigh about 6.8 to 9 kg heavier at birth than those sired by *Bos taurus* bulls, and *Bos indicus* sired $F_1$ bull calves weigh 5.4 to 7.25 kg more than heifer calves (Cartwright et al., 1964; Roberson et al., 1986). Obeidat (2013) reported the same findings in $F_1$ Nellore-Angus crosses:  Nellore sired $F_1$ calves were heavier at birth than Angus sired $F_1$ calves.

Further studies have shown that the particular breed of the sire and dam can determine major differences in birth weight and weaning weight of *Bos taurus-Bos indicus* crossed calves. Obeidat (2013) reported that while the youngest and oldest cows tended to wean lighter calves, calves from Nellore sires and Angus dams were heavier at weaning than calves from Angus sires and Nellore dams. Boenig (2011) reported that $F_1$ Brahman-Hereford cows had calves with heavier birth weights if the cows were by Brahman sires and out of Hereford dams. The reciprocal crosses did not result in heavier birth weights than straightbred Brahman, while straightbred Hereford calves had the lightest birthweight of all as 2-yr-olds.

Obeidat (2013) also found that bull calves tended to have heavier birth weights than heifer calves across all crosses except the Angus-sired $F_1$ calves. This tendency of bull calves weighing more than heifer calves at birth can be found in purebred matings as well as $F_1$ and further crossbred generations. Amen et al. (2007) found that, in embryo transfer calves, the more *Bos indicus* was in the sire breed in crosses of an $F_1$ Brahman-Angus backcrossed to either a purebred Brahman or purebred Angus, the heavier the resulting calf was at birth than the respective reciprocal cross. In these backcrossed calves a large difference was also noted between sexes, where bull calves weighed 4.9 kg more than heifer calves when their sire had more *Bos indicus* than the dam.

Knapp et al. (1980) reported the results of a study from 1965 to 1967, where heterosis in calf growth traits from first-calf beef crossbred dams (Hereford, Angus and Charolais composite) or first-calf beef-dairy crossbred dams (Hereford, Angus, Charolais and Brown Swiss composite) was evaluated. Those researchers found that the dams with dairy influence milked more and thus had calves with higher preweaning ADG, birth weight, and 205-day weaning weight.

Boenig (2011) reported that $F_1$ Brahman-Hereford and purebred Brahman cows had low percent calf crop born at 2 yr of age. This may be due to the Brahman breed's late maturity. Many of the cows in this study were unable to calve a second time until they were 4 years old and finished growing. This not only influenced the purebred Brahman cows' calf crop born but also the $F_1$ and $F_2$ Brahman-Hereford calf crop born. When $F_1$ crosses between *Bos indicus* breeds were made, the crossbred Boran-Ankole and Boran-Zebu animals had higher calf crop born percentages than their purebred counterparts (Gregory et al., 1985). Sanders (1994) indicated that *Bos indicus-Bos taurus* crosses consistently have two to three times as much heterosis as *Bos taurus-Bos taurus* crosses.

Boenig (2011) found that crossbred Brahman-Hereford $F_1$ cows weaned heavier calves than straightbred Herefords. Sanders et al. (2005) stated that these $F_1$ cows weaned calves that were on average 48.5 lbs heavier than straightbred Brahman and straightbred Hereford. In a separate study performed in Australia, Arthur et al. (1994) also reported that $F_1$ Brahman-Hereford cows weaned heavier calves than both straightbred Brahman and Hereford.

Koger et al. (1975) found that Brahman-backcrossed cows outperformed $F_1$ Brahman-Shorthorn cows for maternal effects on weaning weight. Sacco et al. (1989) reported a loss in heterosis in $F_2$ cows in a diallele study including Angus, Jersey, Holstein, Brahman, and Hereford due to epistatic recombination effects or a maternal heterosis x age interaction. Similarly, Olson et al. (1993) stated "a loss in productivity for the $F_2$ dams was also observed for weaning weight because they weaned $F_3$ calves that were almost identical in weight to purebred calves from purebred dams." In that work, $F_2$ heterosis for pregnancy rate was half that found in the $F_1$, backcross, and three breed cross consisting of ½ Charolais ¼ Brahman ¼ Angus.

Much of the information about heterosis retention in *Bos indicus-Bos taurus* crosses has been obtained from studies conducted in Queensland, Australia which is in a subtropical climate. A study of half *Bos indicus* blood, consisting of either Brahman or Afrikander, and half *Bos taurus* blood, consisting of either Hereford or Shorthorn, at the Belmont Station in Queensland, Australia, found a drastic loss of heterosis for the Brahman crosses (Seebeck, 1973). $F_2$ and $F_3$ Brahman crossbreds had a calf crop born of 60.7%, compared to that of 81.2% for $F_1$ Brahman cows. This severe loss of heterosis was not observed in the Afrikander or British crossbred groups. Likewise, Seifert and Kennedy (1972) reported that $F_2$ Brahman crossed cows had a significantly lower calf crop weaned than $F_1$ Brahman cross, $F_2$ Afrikander cross and $F_1$ Afrikander cross cows. In a later report from this study, MacKinnon et al. (1989) reported results from groups of $F_1$, $F_2$, and $F_n$ ($F_3$ and greater) cows of the following groups: ½ Afrikander, ¼ Hereford ¼ Shorthorn, ½ Brahman ¼ Hereford ¼ Shorthorn, and ¼ Afrikander ¼ Brahman ¼ Hereford ¼ Shorthorn. Heterosis in the Afrikander crossbreds for calf crop born was 19.1%, 13.3%, and 11.2% for the $F_1$, $F_2$, and $F_n$ generations, respectively. The $F_n$ represents the $F_3$ and further generations. In the Brahman half-blood cows, heterosis levels were 16.4%, –5.2%, and 1.6% for the $F_1$, $F_2$, and $F_n$ generations. The difference in the Brahman cross $F_2$ and $F_n$ generations was attributed to year x breed interactions resulting from above average years during which the $F_2$ group was evaluated. Heterosis levels in the crossbred ¼ Afrikander ¼ Brahman ¼ Hereford ¼ Shorthorn composites were 5% for the first cross and 4.8% for the $F_2$ and $F_3$ cows combined.

# OBJECTIVES

The objectives of this study were: (1) to estimate heterosis for maternal traits of calf birth weight, preweaning average daily gain, and calf weaning weight and reproductive traits of calf crop born and calf crop weaned, (2) to compare heterosis of the $F_1$ generation to that of the $F_2$ generation for these traits, and (3) where possible, to compare the reciprocal cross females among the $F_2$ generation cows for these traits.

## MATERIALS AND METHODS

### *Description of Data*

The data used in this study are part of a larger study conducted at the Texas A&M AgriLife Research Center at McGregor, Texas, and Texas A&M AgriLife facilities near College Station. That study consisted of 14 different breed groups of purebreds and *Bos indicus-Bos taurus* $F_1$ and $F_2$ crossbreds including the breeds Nellore, Angus, Brahman, and Hereford (Sanders et. al, 2005). All calves were born to cows in multiple-sire, natural mating herds. The present study is limited to these breed groups of cows: straightbred Angus (A), straightbred Brahman (B), $F_1$ BA (throughout, a pair of letters designate the cow's sire breed and dam breed, in that order), $F_2$ ABBA (throughout, four letters indicate a cow that had $F_1$ parents, and represent breed group as two pairs of letters, in this case AB bulls bred to BA cows), and $F_2$ BABA.

The numbers of cows and the number of records per breed group are shown in Table 1. The BA and AB bulls used to produce the $F_2$ generation females were produced at the Texas A&M AgriLife Research Centers at McGregor and Overton, Texas, respectively. Cows were exposed to fertile bulls for a breeding period of approximately two months beginning in May of each year, first as yearlings and annually thereafter. The breeds of bulls that were bred to cows each year varied by year (Table 2).

Table 1. Number of cows and records per breed group[1]

| Cow breed | N cows | Calf crop born | Calf crop weaned | Calf birth wt | Calf weaning wt | Calf preweaning ADG |
|---|---|---|---|---|---|---|
| A | 51 | 352 | 352 | 260 | 237 | 237 |
| B | 41 | 168 | 166 | 111 | 102 | 102 |
| BA | 53 | 432 | 431 | 397 | 367 | 367 |
| ABBA | 24 | 170 | 167 | 146 | 137 | 137 |
| BABA | 25 | 112 | 110 | 94 | 84 | 84 |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

Table 2. Sire breeds used with each cow breed by cow birth year and year of breeding[1,2,3]

| Cow breed | Cow birth year | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1997 | | A | A | A, C | A | A | A | A | A | A, N |
| | 1998 | | | A | A | A | A | A | A | A | A, N |
| | 1999 | | | | A | A | A | A | A | A | A, N |
| B | 1997 | | B | B | B, H | B, H | B, H | B | A | A | A |
| | 1998 | | | B | B, H | B, H | H | B | A | A | A |
| | 1999 | | | | A | H | H | B, H | A | A | A |
| BA $F_1$ | 1997 | | BA | BA | 1N3A | 1B3A | 1B3A | NA | NA | NA | NA |
| | 1998 | | | A | 1N3A | 1B3A | 1B3A | NA | NA | NA | NA |
| $F_2$ ABBA | 1998 | | | A | 1N3A | 1B3A | 1B3A | NA | NA | NA | NA |
| | 1999 | | | | A | 1B3A | 1B3A | NA | NA | NA | NA |
| $F_2$ BABA | 1997 | | BA | BA | 1N3A | 1B3A | 1B3A | NA | NA | NA | NA |
| | 1998 | | | A | 1N3A | 1B3A | 1B3A | NA | NA | NA | NA |
| | 1999 | | | | A | 1B3A | 1B3A | NA | NA | NA | NA |

[1]H = Hereford, B = Brahman; A = Angus; N = Nellore; C = Charolais

[2]Crossbred groups are referenced with the sire breed listed first in a pair. Four letters indicate breed groups in which the cows had $F_1$ parents, and represent breed group as two pairs of letters.

[3]1N3A= ¼ Nellore ¾ Angus; 1B3A= ¼ Brahman ¾ Angus

Table 2 continued.

| Cow breed | Cow birth year | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|
| A | 1997 | A, N | A | A | A, N | | | | |
| | 1998 | A, N | A | A | A | | | | |
| | 1999 | A, N | | | | | | | |
| B | 1997 | A | A | | | | | | |
| | 1998 | | | | | | | | |
| | 1999 | A | A | | | | | | |
| BA $F_1$ | 1997 | A | A | A | A | | | | |
| | 1998 | A | A | A | A | | | | |
| $F_2$ ABBA | 1998 | A | A | A | A | A | A | A | A |
| | 1999 | A | A | A | A | A | A | A | |
| $F_2$ BABA | 1997 | A | A | | | | | | |
| | 1998 | | | | | | | | |
| | 1999 | A | A | A | A | A | A | A | A |

[1]H = Hereford, B = Brahman; A = Angus; N = Nellore; C = Charolais

[2]Crossbred groups are referenced with the sire breed listed first in a pair. Four letters indicate breed groups in which the cows had $F_1$ parents, and represent breed group as two pairs of letters.

[3]1N3A= ¼ Nellore ¾ Angus; 1B3A= ¼ Brahman ¾ Angus

Calves were born from February to May each year and birth weight was recorded as soon as possible after birth. Calves were weaned in October, except in 2010 in which some calves were weaned in June, and in 2011 in which calves were weaned in August due to severe drought. Cows in this study were culled due to debilitating injury or after their second failure to successfully wean a calf, except for purebred Brahman cows, who were not culled until their second failure to successfully wean a calf after they were 3 yr old. Females in these analyses ranged from 2 to 16 yr old.

***Traits Analyzed***

Cow reproduction traits that were evaluated are calf crop born and calf crop weaned. Calf crop born and calf crop weaned are the proportion of cows that gave birth and weaned calves, respectively, of the cows that were exposed to bulls the previous breeding season. These two traits were evaluated as binary traits with 1 indicating a success and 0 indicating a failure.

Calf birth weight, preweaning ADG, and calf weaning weight were evaluated as though they were traits of the cow. Preweaning ADG was calculated by subtracting the weaning date from the birth date of the calves to get their age in days, then dividing by the difference in their weights at those two times.

***Statistical Analysis***

Data were analyzed using mixed linear models with SAS (SAS Inst., Inc., Cary, NC) where appropriate. A significant p-value of 0.05 was used in all analyses.

***Age.*** Data were analyzed in two separate groups based upon age. Records of 2-yr-olds were analyzed separately from records of cows 3-yr-old and older. Data were analyzed separately because in some years Brahman heifers were exposed to bulls at one year of age and in some years Brahman heifers were exposed to bulls for the first time at 2 yr of age. Records of 2-yr-old heifers were analyzed using a mixed model including cow breed and year. The rest of the data were further subdivided into age groups of 3, 4, 5 to 10, and greater than 10 yr old.

Data from 2010 and later were excluded from analyses because there were no Brahman cows remaining for comparison. By 2010, all of the cows in this project were in the greater than 10-yr-old group. These data were analyzed using mixed linear models including breed of cow, year, and age groups (3- (n = 166), 4- (n = 152), 5- to 10- years old (n = 561), and older than 10 years (n = 139)) nested within year. All breed groups had every age group represented in the remaining analyzed data. The numbers of cows by age-year combination are presented in Table 3. As illustrated, after 2009, there were no more Brahman cows left in the project. There were 13 total BABA cows used that were born in 1997. In 1999, only 6 calved as 2-yr-olds. But by 2000, all 13 calved for their first or second time.

For all traits two analyses were performed, consisting of records of 2-yr-old cows and 3-yr-old cows and older. Two year old data consists of records from all cows 2 years after their birth year (n = 172). The other data set contains the remaining records of cows 3 years after their birth year and each year afterward until 2010 (n = 1018) further divided into their age groups.

***Weight traits.*** As evidenced in Table 2, the effect of sire breed of calf was in large part confounded with year and cow breed. Sire of calf breed was modeled as a linear regression on proportion of *Bos indicus* in sires. Mixed model analysis included the cow's birth year nested within year, sex of the calf, and cow breed. Trait values were regressed on the amount (percentage) of *Bos indicus* in the sire of the calf and this regression was investigated across and unique to cow breed groups. The maternal granddam and cow were modeled as random variables.

***Heterosis.*** Linear contrasts of breed group means were used to estimate genetic effects for all traits in both data sets. Heterosis for each trait was estimated as the difference of straightbred means from the average of the crossbred group means: BA – ½(A + B). The difference between the $F_2$ groups was estimated: ABBA – BABA. These represent the difference in having $F_2$ cows with Brahman sired $F_1$ sires or Angus sired $F_1$ sires. A difference between the average of the straightbreds and the $F_2$ groups was estimated as [½(ABBA + BABA) – ½(A + B)]. Lastly, the difference between the $F_1$s and the $F_2$s was estimated as BA – ½ (ABBA + BABA).

Table 3. Numbers of cows by birth year and year of record[1]

| | | Year | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cow Breed | Birth Year | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
| A | 1997 | 17 | 17 | 17 | 16 | 15 | 14 | 12 | 10 | 10 | 6 | 4 | 2 | 2 | | | |
| | 1998 | | 17 | 14 | 12 | 12 | 10 | 6 | 6 | 5 | 4 | 2 | 2 | 1 | | | |
| | 1999 | | | 17 | 11 | 10 | 8 | 6 | 6 | 5 | 5 | | | | | | |
| B | 1997 | 8 | 8 | 8 | 8 | 6 | 5 | 4 | 2 | 2 | 2 | 2 | | | | | |
| | 1998 | | 10 | 9 | 9 | 8 | 7 | 4 | 2 | 1 | | | | | | | |
| | 1999 | | | 10 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | | | | | |
| BA | 1997 | 25 | 26 | 26 | 25 | 19 | 16 | 16 | 14 | 12 | 11 | 10 | 8 | 7 | | | |
| | 1998 | | 26 | 23 | 21 | 19 | 18 | 18 | 18 | 17 | 17 | 17 | 14 | 12 | | | |
| ABBA | 1998 | | 18 | 18 | 15 | 10 | 10 | 10 | 9 | 9 | 9 | 9 | 6 | 6 | 2 | 2 | 2 |
| | 1999 | | | 6 | 6 | 6 | 6 | 5 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| BABA | 1997 | 13 | 13 | 12 | 5 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | | | | | |
| | 1998 | | 5 | 5 | 3 | 3 | 3 | 2 | 2 | 1 | | | | | | | |
| | 1999 | | | 7 | 6 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 1 |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

## RESULTS AND DISCUSSION

### *Calf Crop Born*

The numbers of cows per breed are listed in Table 1. Unadjusted means for each breed across all ages are presented in Table 4. Unadjusted means for cow breed and cow age are given in Table 5. Unadjusted means are presented for comparison to the adjusted.

***Records of 2-yr-old cows.*** The final model included only cow breed ($P < 0.001$), maybe because year of record and cow breed explained in large part the same variation (Table 3). Calf crop born of BA cows was greater ($P = 0.04$) than Angus, Brahman, and BABA. Brahman had a lower calf crop born ($P < 0.001$) than all other groups (Table 6), which ranged from 0.64 ± 0.08 for BABA to 0.92 ± 0.05 for BA. Brahman females reach puberty later than *Bos taurus* breeds of cattle (Franke, 1980) and this is mostly likely the reason Brahman females had the lowest calf crop born at this young age.

***Records of older cows.*** Preliminary model attempts were made that would best parameterize the differences in cow age and year. The final model included the interaction of cow breed with age group ($P < 0.001$) and cow age group within year ($P < 0.001$). Cow age group-year means were generally higher for later years and older cow ages (Table 7).

An interaction of cow breed and age is often detected in analyses of cow reproductive data, especially as an oscillation between success and failure at young ages (Koger et al., 1962; Riley et al., 2005). Such an oscillation in low and high calf crop born can be seen in Table 8 in Brahman and ABBA 3- and 4-yr-old means, and especially when 2-yr-old means are considered (Table 5). As 3-yr-olds, ABBA had the lowest calf crop born (0.28 ± 0.07; $P < 0.001$), but had a higher calf crop born than Brahman, BA, and BABA as 4-yr-olds ($P < 0.05$). Angus had a higher calf crop born than ABBA and BABA ($P < 0.02$) as 3-yr-olds, and the difference between Brahman and Angus approached significance ($P$ = 0.08). As 4-yr-olds, the difference between ABBA (0.99 ± 0.07) and Angus (0.83 ± 0.05) approached significance ($P$ = 0.08). Brahman had the lowest calf crop born of all breed groups ($P$ < 0.001) as 4-yr-olds. $F_1$s should express maximum heterosis and not surprisingly BA had the numerically highest unadjusted calf crop born across all ages (Table 4), but breed group adjusted means were mostly uniformly high for ages 5 to 10, and 10 and older. Brahman calf crop born in the 5 to 10 age category (Table 8) was lower ($P$ < 0.01) than BA and ABBA. Calf crop born means for ABBA cows were lower than BABA as 3-yr-olds, but higher than BABA as 4-yr-olds ($P$ < 0.05). Although in many cases differences for calf crop born between the $F_2$ groups were not detected, in later years, BABA was represented by such a small number of cows that their means may not be representative of the true group means. The high calf crop born of the $F_2$ groups were not consistent with the low performance of *Bos indicus-Bos taurus* $F_2$ cows reported in Australia (Siefert and Kennedy, 1972; Seebeck, 1973) and results in Florida (Olson et al., 1993).

Heterosis for calf crop born was detected ($P < 0.01$) only for the $F_1$ group (Table 9). Although heterosis for calf crop born was not detected in the $F_2$ groups, examination of means and differences between $F_1$ and $F_2$ cows did not appear to support the total loss of heterosis in the $F_2$ generation previously reported (Seifert and Kennedy, 1972; Seebeck, 1973; Olson et al., 1993). Olson et al. (1993) found that the combination of Brahman-Charolais resulted in more heterosis retained in the $F_2$ than in the Brahman-Angus $F_2$. In that study, the Brahman-Angus $F_2$ cows were all sired by Brahman-sired $F_1$ bulls; for the Brahman-Charolais $F_2$ cows, both Brahman-sired and Charolais-sired $F_1$ bulls had been available to be used, but no records have survived of how many of the two types of sires were used to produce the $F_2$ cows (J. O. Sanders, personal communication, based on personal communication with T. A. Olson).

Table 4. Unadjusted means (SD) for calf crop born and calf crop weaned by cow breed[1]

| Cow breed | Calf crop born | Calf crop weaned |
|---|---|---|
| A | 0.87 (0.34) | 0.79 (0.41) |
| B | 0.76 (0.47) | 0.68 (0.49) |
| BA | 0.92 (0.27) | 0.87 (0.34) |
| ABBA | 0.87 (0.34) | 0.81 (0.39) |
| BABA | 0.80 (0.40) | 0.69 (0.46) |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

Table 5. Unadjusted means (SD) for calf crop born by cow age group (yr) and cow breed group at calving[1]

| Cow age group | A | B | BA | ABBA | BABA |
|---|---|---|---|---|---|
| 2 | 0.76 (0.43) | 0.36 (0.49) | 0.92 (0.27) | 0.88 (0.34) | 0.64 (0.49) |
| 3 | 0.86 (0.35) | 0.70 (0.47) | 0.80 (0.41) | 0.29 (0.46) | 0.67 (0.48) |
| 4 | 0.85 (0.37) | 0.46 (0.51) | 0.77 (0.43) | 0.86 (0.36) | 0.84 (0.37) |
| 5 to 10 | 0.91 (0.29) | 0.83 (0.38) | 0.96 (0.20) | 1.00 (0.00) | 0.91 (0.28) |
| Older than 10 | 0.89 (0.39) | 1.00 (0.00) | 0.99 (0.00) | 1.00 (0.00) | 1.00 (0.00) |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

Table 6. Means ± SE for calf crop born and calf crop weaned by cow breed group for 2-yr-olds[1]

| Cow breed group | Calf crop born | Calf crop weaned |
|---|---|---|
| A | $0.76 \pm 0.05^{bc}$ | $0.57 \pm 0.06^{bc}$ |
| B | $0.36 \pm 0.07^{d}$ | $0.26 \pm 0.08^{d}$ |
| BA | $0.92 \pm 0.05^{a}$ | $0.83 \pm 0.07^{a}$ |
| ABBA | $0.88 \pm 0.08^{ab}$ | $0.80 \pm 0.10^{ab}$ |
| BABA | $0.64 \pm 0.08^{c}$ | $0.44 \pm 0.09^{cd}$ |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

[a,b,c,d]Means within traits (columns) that do not share a superscript differ ($P < 0.05$).

Table 7. Means ± SE for calf crop born by cow age group (yr) and year for 3-yr-olds and older

| | Cow age group | | | |
|---|---|---|---|---|
| Year | 3 | 4 | 5 to 10 | Older than 10 |
| 2000 | 0.78 ± 0.04[a] | | | |
| 2001 | 0.68 ± 0.04[ay] | 0.87 ± 0.04[ax] | | |
| 2002 | 0.56 ± 0.06[by] | 0.57 ± 0.04[by] | 0.72 ± 0.04[bx] | |
| 2003 | | 0.84 ± 0.06[acx] | 0.94 ± 0.03[ax] | |
| 2004 | | | 0.90 ± 0.03[a] | |
| 2005 | | | 0.92 ± 0.03[a] | |
| 2006 | | | 0.92 ± 0.04[a] | |
| 2007 | | | 0.96 ± 0.04[a] | |
| 2008 | | | 0.96 ± 0.05[ax] | 0.87 ± 0.07[ax] |
| 2009 | | | 1.04 ± 0.12[ax] | 0.97 ± 0.05[ax] |

[a,b,c]Means within age groups (columns) that do not share a superscript differ ($P < 0.05$).
[x,y]Means within years (rows) that do not share a superscript differ ($P < 0.05$).

Table 8. Means ± SE for calf crop born by cow breed group and age group (yr) for 3-yr-olds and older[1]

| | Cow breed | | | | |
|---|---|---|---|---|---|
| Cow age group | A | B | BA | ABBA | BABA |
| 3 | $0.84 \pm 0.05^{ax}$ | $0.71 \pm 0.06^{bxy}$ | $0.74 \pm 0.05^{bxy}$ | $0.28 \pm 0.07^{bz}$ | $0.65 \pm 0.06^{by}$ |
| 4 | $0.83 \pm 0.05^{axy}$ | $0.47 \pm 0.06^{cz}$ | $0.79 \pm 0.05^{by}$ | $0.99 \pm 0.07^{ax}$ | $0.78 \pm 0.07^{ay}$ |
| 5 to 10 | $0.92 \pm 0.03^{axy}$ | $0.84 \pm 0.04^{ay}$ | $0.97 \pm 0.03^{ax}$ | $0.99 \pm 0.04^{ax}$ | $0.92 \pm 0.05^{axy}$ |
| Older than 10 | $0.83 \pm 0.09^{ax}$ | $1.00 \pm 0.15^{ax}$ | $0.98 \pm 0.05^{ax}$ | $0.96 \pm 0.11^{ax}$ | $1.00 \pm 0.22^{abx}$ |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

[a,b,c]Means within breed groups (columns) that do not share a superscript differ ($P < 0.05$).

[x,y,z]Means within age groups (rows) that do not share a superscript differ ($P < 0.05$).

Table 9. Heterosis estimates ± SE for calf crop born and calf crop weaned and estimates of the differences between $F_1$ and $F_2$ means for 3-yr-olds and older[1]

| Cow breed | Calf crop born | Calf crop weaned |
|---|---|---|
| $F_1$ heterosis | 0.08 ± 0.02** | 0.08 ± 0.03** |
| $F_2$ heterosis | 0.03 ± 0.03 | 0.03 ± 0.03 |
| $F_1 – F_2$ | 0.05 ± 0.03 | 0.05 ± 0.03 |

** *P* < 0.01

[1]Estimates lacking the superscript asterisk do not differ from 0 (*P* < 0.05).

### ***Calf Crop Weaned***

Unadjusted means for cow breed and cow age are given in Table 10.

***Records of 2 year olds.*** Cow breed was the only effect in the final model ($P < 0.001$). Brahman weaned the lowest proportion of calves ($P < 0.01$) of all breed groups (Table 6), which ranged from 0.26 ± 0.08 to 0.83 ± 0.07 (BA). Angus had lower calf crop weaned than BA ($P = 0.002$) and ABBA had a higher calf crop weaned than BABA ($P = 0.02$).

***Records of older cows.*** The final model included the interaction of cow breed with age group ($P < 0.0001$) and cow age group within year ($P < 0.001$).

The adjusted means for calf crop weaned by cow breed for 3-yr-olds and older are given in Table 11. Since calf crop weaned is directly influenced by percent calf crop born, means and differences had similar patterns in both traits. As 3-yr-olds, ABBA had the lowest calf crop weaned ($P < 0.02$). Although Angus and BA had higher calf crops weaned than BABA ($P < 0.01$), the difference between Brahman and BABA approached significance ($P = 0.08$). As 4-yr-old cows, ABBA had higher calf crop weaned than Brahman and BA ($P < 0.05$), but did not differ significantly from Angus and BABA. In the peak of their productive lives, from age 5 to 10 yr, Brahman had a lower calf crop weaned than ABBA and BA ($P < 0.01$) but did not differ from Angus or BABA ($P > 0.12$). There were no breed group differences detected ($P > 0.63$) in cows older than 10 yr. Other than the large difference as 3-yr-olds ($P < 0.05$), the $F_2$ groups did not differ significantly for calf crop weaned. As evidenced in Table 3, there were more ABBA cows left in the herd than BABA cows at the end of this study. The means presented here do not represent performance of the entire herd, just of the few that were remaining as older cows. Boenig (2011) reported higher unadjusted means for $F_2$ cows sired by *Bos taurus* (Hereford)-sired $F_1$ cows than $F_2$ cows sired by Brahman-sired $F_1$ cows.

As cows matured, generally their calf crop weaned increased (Table 12). Culling cows who failed to reproduce probably leaves only the most fertile (reproductively successful) cows in the older age categories. Younger cows are probably subject to more nutritional stress than older cows because they themselves are still growing, and this likely affects reproductive success of the group.

Heterosis for calf crop weaned was only significant ($P < 0.01$) for the $F_1$ breed group (Table 9). As was the case for calf crop born, examination of the means and differences between the $F_1$ and $F_2$ cows might suggest that the heterosis lost in the $F_2$ generation in this study was not as large as previously reported by others (Seifert and Kennedy, 1972; Olson et al., 1993; Boenig, 2011). Heterosis retained could be a consequence of how the cross was made (Boenig, 2011), as all of the results reported by Seifert and Kennedy (1972) and at least half of the results reported by Olson et al. (1993) were using records of $F_2$ cows sired by Brahman-sired $F_1$ bulls.

Table 10. Unadjusted means (SD) for calf crop weaned by cow breed group and cow age group (yr)[1]

| Cow age group | A | B | BA | ABBA | BABA |
|---|---|---|---|---|---|
| 2 | 0.56 (0.50) | 0.25 (0.44) | 0.84 (0.37) | 0.75 (0.44) | 0.44 (0.51) |
| 3 | 0.81 (0.40) | 0.67 (0.48) | 0.80 (0.41) | 0.25 (0.44) | 0.50 (0.51) |
| 4 | 0.79 (0.41) | 0.42 (0.50) | 0.68 (0.47) | 0.81 (0.40) | 0.84 (0.37) |
| 5 to 10 | 0.84 (0.37) | 0.76 (0.43) | 0.90 (0.29) | 0.97 (0.16) | 0.83 (0.38) |
| Older than 10 | 0.89 (0.29) | 1.00 (0.00) | 0.94 (0.27) | 1.00 (0.00) | 1.00 (0.00) |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

Table 11. Means ± SE for calf crop weaned by cow breed group and age group (yr) for 3-yr-olds and older[1]

| | Cow breed | | | | |
|---|---|---|---|---|---|
| Cow age group | A | B | BA | ABBA | BABA |
| 3 | 0.80 ± 0.06$^{ax}$ | 0.67 ± 0.07$^{axy}$ | 0.74 ± 0.06$^{ax}$ | 0.22 ± 0.08$^{az}$ | 0.49 ± 0.07$^{ay}$ |
| 4 | 0.78 ± 0.06$^{axy}$ | 0.43 ± 0.07$^{bz}$ | 0.72 ± 0.06$^{ay}$ | 0.97 ± 0.08$^{bx}$ | 0.77 ± 0.08$^{bxy}$ |
| 5 to 10 | 0.83 ± 0.03$^{ayz}$ | 0.75 ± 0.04$^{az}$ | 0.89 ± 0.03$^{bxy}$ | 0.94 ± 0.05$^{bx}$ | 0.83 ± 0.05$^{bxyz}$ |
| Older than 10 | 0.92 ± 0.10$^{ax}$ | 1.00 ± 0.18$^{ax}$ | 0.91 ± 0.06$^{bx}$ | 0.97 ± 0.13$^{bx}$ | 1.00 ± 0.25$^{bx}$ |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

[a,b]Means within breed groups (columns) that do not share a superscript differ ($P < 0.05$).

[x,y,z]Means within age groups (rows) that do not share a superscript differ ($P < 0.05$).

Table 12. Means ± SE for calf crop weaned by cow age group (yr) and year for 3-yr-olds and older

| | Cow age groups | | | |
|---|---|---|---|---|
| Year | 3 | 4 | 5 to 10 | Older than 10 |
| 2000 | 0.71 ± 0.05[ab] | | | |
| 2001 | 0.66 ± 0.05[ay] | 0.84 ± 0.05[ax] | | |
| 2002 | 0.50 ± 0.06[by] | 0.47 ± 0.05[by] | 0.65 ± 0.05[cx] | |
| 2003 | | 0.84 ± 0.07[ax] | 0.89 ± 0.04[abx] | |
| 2004 | | | 0.79 ± 0.04[b] | |
| 2005 | | | 0.88 ± 0.04[ab] | |
| 2006 | | | 0.89 ± 0.04[ab] | |
| 2007 | | | 0.91 ± 0.04[a] | |
| 2008 | | | 0.95 ± 0.06[ax] | 0.87 ± 0.08[ax] |
| 2009 | | | 0.76 ± 0.14[abcx] | 0.92 ± 0.06[ax] |

[a,b,c]Means within age groups (columns) that do not share a superscript differ ($P < 0.05$).
[x,y]Means within years (rows) that do not share a superscript differ ($P < 0.05$).

### ***Weight Traits***

***Birth weight.*** *Records of 2-yr-olds.* Cow breed, amount of *Bos indicus* in the sire within cow breed, and cow birth year nested within year were not kept in the final birth weight model ($P > 0.19$). The final model included cow birth year ($P < 0.001$) and sex of the calf ($P < 0.02$). Table 13 presents birth weight means by cow birth year. Females born in 1998 had the lightest calves at birth ($P < 0.001$) while females born in 1997 did not differ from the 1999 born females ($P = 0.36$). As 2-yr-olds, Brahman had the heaviest calves while ABBA had the lightest calves (unadjusted means are shown in Table 14). Male calves weighed more than female calves (32.80 ± 0.62, and 30.21 ± 0.55, respectively, $P = 0.003$).

*Records of older cows.* Interactions were not significant; most notably the 3-way interaction of calf sire breed, cow breed, and sex of the calf that is often important in birth weight of *Bos indicus* crossbreds (parameterized as amount of *Bos indicus* in the sire as a covariate nested within combinations of sex of the calf and cow breed; $P = 0.33$). The final model consisted of cow birth year within year ($P = 0.004$), amount of *Bos indicus* in the sire within cow breed ($P < 0.001$), sex of the calf ($P < 0.001$), and cow breed ($P = 0.01$).

From 3-yr-old and older, BABA had heavier calves ($P < 0.05$) than Brahman, BA, and ABBA, while Brahman cows had calves with the lightest ($P < 0.001$) birth weight which ranged from 36.47 ± 0.76 to 38.74 ± 0.86 (Table 15). All breed groups had the heaviest calves from ages 5- to 10-yr-old and as cows matured older than 10-yr-old their calf birth weight means were somewhat lower (Table 14). Boenig (2011) reported that Hereford cows had the lightest (not statistically tested) calves and $F_2$ HBHB cows had the heaviest calves at birth. Olson et al. (1993) reported that $F_2$ cows, consisting of ⅜ ⅝ fractions of Brahman, Angus, and/or Charolais, had calves whose weight at birth was less than the birth weight of calves out of purebred cows. Gregory et al. (1991a) reported that retained heterosis was generally consistent with dominance model expectation in $F_2$ and $F_3$ generations of *Bos taurus* composites for birth weight.

Birth weight means by sex of calf are presented in Table 16. Not surprisingly, bull calves weighed more than heifer calves ($P < 0.001$). Calving year-cow birth year means generally indicated that in later project years (and therefore, correspondingly older cows) calves were heavier at birth (Table 17).

Table 13. Calf weight and ADG means ± SE (kg) by birth year of 2-yr-olds

| Cow birth year | Birth weight | Weaning weight | Preweaning ADG |
|---|---|---|---|
| 1997 | 34.10 ± 0.68[a] | 199.15 ± 4.54[a] | 0.74 ± 0.02[a] |
| 1998 | 26.75 ± 0.62[b] | 189.13 ± 4.29[ab] | 0.69 ± 0.02[b] |
| 1999 | 33.04 ± 0.89[a] | 177.20 ± 6.34[b] | 0.67 ± 0.03[ab] |

[a,b]Means within traits (columns) that do not share a superscript differ ($P < 0.05$).

Table 14. Unadjusted means (SD) for birth weight (kg) by cow age group (yr) and cow breed group[1]

| Cow age group | A | B | BA | ABBA | BABA |
|---|---|---|---|---|---|
| 2 | 31.36 (5.73) | 32.73 (3.64) | 30.73 (5.92) | 28.08 (4.45) | 31.33 (6.97) |
| 3 | 33.77 (4.50) | 32.30 (4.27) | 36.16 (3.93) | 36.29 (5.29) | 38.67 (6.29) |
| 4 | 36.64 (5.56) | 32.88 (4.06) | 36.38 (4.11) | 36.61 (4.59) | 38.22 (4.38) |
| 5 to 10 | 37.45 (5.76) | 32.73 (4.53) | 38.25 (5.82) | 37.47 (5.46) | 39.54 (5.91) |
| Older than 10 | 34.55 (5.31) | 32.39 (4.69) | 34.96 (5.66) | 34.06 (4.32) | 39.59 (5.32) |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

Table 15. Calf birth weight ± SE (kg) by cow breed group for 3-yr-olds and older[1]

| Cow breed group | Birth weight |
|---|---|
| A | $38.18 \pm 0.56^{ab}$ |
| B | $32.64 \pm 0.65^{d}$ |
| BA | $36.49 \pm 0.50^{c}$ |
| ABBA | $36.47 \pm 0.76^{bc}$ |
| BABA | $38.74 \pm 0.86^{a}$ |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

[a,b,c,d]Means within traits (columns) that do not share a superscript differ ($P < 0.05$).

Table 16. Calf weight and ADG means ± SE (kg) by sex of calf for 3-yr-olds and older

| Sex of calf | Birth weight | Weaning weight | Preweaning ADG |
|---|---|---|---|
| F | 35.49 ± 0.36[b] | 218.44 ± 2.19[b] | 0.85 ± 0.01[b] |
| M | 37.52 ± 0.34[a] | 234.13 ± 2.12[a] | 0.92 ± 0.01[a] |

[a,b]Means within traits (columns) that do not share a superscript differ (*P* < 0.05).

Table 17. Calf birth weight means ± SE (kg) by calving year and cow birth year for 3-yr-olds and older

| | Cow birth year | | |
|---|---|---|---|
| Year | 1997 | 1998 | 1999 |
| 2000 | 35.29 ± 0.82 | | |
| 2001 | 35.92 ± 0.70 | 35.93 ± 0.75 | |
| 2002 | 36.56 ± 0.83 | 36.84 ± 0.89 | 35.29 ± 1.20 |
| 2003 | 38.91 ± 0.82 | 38.05 ± 0.74 | 38.03 ± 1.04 |
| 2004 | 39.07 ± 0.96$^{x}$ | 38.76 ± 0.85$^{xy}$ | 36.25 ± 1.14$^{y}$ |
| 2005 | 38.17 ± 1.01 | 36.99 ± 0.89 | 37.18 ± 1.14 |
| 2006 | 37.00 ± 1.08 | 36.18 ± 0.94 | 35.20 ± 1.32 |
| 2007 | 37.15 ± 1.08 | 37.05 ± 0.97 | 36.56 ± 1.36 |
| 2008 | 35.10 ± 1.28 | 34.65 ± 1.11 | 35.50 ± 1.43 |
| 2009 | 36.19 ± 1.28 | 36.47 ± 1.13 | 34.33 ± 2.04 |

$^{x,y}$Where superscripts are present, means within years (rows) that do not share a superscript differ ($P < 0.05$).

The proportion of *Bos indicus* in sires of calves for birth weight (expressed as a fraction between zero and one) was not important as a linear covariate unique to cow breed-calf sex combinations ($P = 0.33$); however this covariate was significant when nested within cow breed groups ($P < 0.001$). The regression coefficient for Angus was 10.26 ± 1.52 kg ($P < 0.001$). The $F_1$ and ABBA cows had similar regression coefficients of 5.24 ± 2.40 ($P < 0.03$) and 5.13 ± 2.79 ($P < 0.07$), respectively. Coefficients for Brahman (–1.47 ± 1.18) and BABA (4.08 ± 3.78) cows did not differ from 0 ($P > 0.20$).

***Weaning weight.*** Unadjusted means are presented in Table 18 for assessment and comparison results from analyses.

*Records of 2-yr-old cows.* Cow breed ($P < 0.001$) and the amount of *Bos indicus* in the sire ($P = 0.03$) were kept in the final model. Sex of calves did not explain substantial weaning weight variation ($P = 0.39$).

Cows born in 1997 weaned heavier calves as 2-yr-olds than cows born in 1999 ($P < 0.01$) but cows born in 1998 did not differ ($P < 0.20$) (Table 13). Table 19 contains weaning weight means by cow breed. BA weaned the heaviest calves ($P < 0.02$). The difference between ABBA and Brahman approached significance ($P = 0.06$).

The regression coefficient estimate of weaning weight on the amount of *Bos indicus* in the sire was detected across breed groups ($P = 0.01$). This estimate (29.28 ± 11.81) indicated a strong association of heavy weaning weight for calves sired by bulls with high proportions of *Bos indicus*. As 2-yr-olds, Angus females had Angus-sired calves, $F_1$ and $F_2$ females had BA-sired and Angus-sired calves, and Brahman females had Brahman-sired and Angus-sired calves; however, only 2 straightbred calves were weaned and 5 Angus-sired calves were weaned by 2-yr-old Brahman females (Table 2).

*Records of older cows.* The amount of *Bos indicus* in the sire nested within cow breed group-calf sex combinations did not differ from 0 ($P = 0.30$). The interaction of cow breed and cow age groups detected for other traits was important ($P = 0.002$). The final model included this interaction, sex of the calf ($P = 0.001$), year ($P < 0.001$), cow breed ($P < 0.001$), the age of the calf at weaning ($P < 0.001$) and the amount of *Bos indicus* in the sire nested within cow breed ($P = 0.002$).

In general, as cows matured, their calves weighed more at weaning (Table 20). As 3-yr-olds, Angus weaned lighter calves than Brahman, BA, and BABA ($P = 0.04$; Table 21). As 4-yr-olds, BA weaned heavier calves than BABA ($P = 0.04$), although the difference between Angus and BA approached significance ($P = 0.07$). As 5 to 10-yr-olds, BA weaned heavier calves than Angus, Brahman, and BABA ($P < 0.01$), and as 10-yr-old and older, ABBA weaned heavier calves than Angus, Brahman, and BABA ($P < 0.02$).

As expected, male calves had heavier weaning weights than female calves ($P < 0.001$; Table 16).

The covariate for amount of *Bos indicus* in the sire nested within cow breed was significant ($P < 0.001$). The regression coefficient for Brahman was $-33.50 \pm 7.58$ ($P < 0.001$), indicating a strong negative association of calf weaning weight and proportion of *Bos indicus* in their sires. Regression coefficients for other cow breed groups did not differ from 0 ($P > 0.32$).

Table 18. Unadjusted means (SD) for weaning weight (kg) by cow age group (yr) and cow breed group[1]

| Cow age group | A | B | BA | ABBA | BABA |
|---|---|---|---|---|---|
| 2 | 172.88 (26.33) | 172.66 (32.51) | 210.18 (26.70) | 184.08 (22.80) | 183.50 (24.71) |
| 3 | 184.03 (35.08) | 208.50 (33.80) | 195.61 (31.09) | 188.54 (24.82) | 212.28 (33.49) |
| 4 | 213.39 (34.34) | 214.40 (33.75) | 213.58 (20.54) | 237.02 (31.53) | 203.97 (31.58) |
| 5 to 10 | 221.53 (32.55) | 224.21 (37.25) | 255.29 (30.72) | 241.96 (33.69) | 231.70 (25.21) |
| Older than 10 | 192.94 (37.32) | 230.80 (20.04) | 233.90 (28.06) | 215.36 (24.83) | 225.37 (4.49) |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

Table 19. Means ± SE for weaning weight (kg) and preweaning ADG (kg/day) by cow breed group for 2-yr-olds

| Cow breed | Weaning weight | Preweaning ADG |
|---|---|---|
| A | $191.86 \pm 8.88^{b}$ | $0.61 \pm 0.02^{c}$ |
| B | $178.53 \pm 10.05^{b}$ | $0.70 \pm 0.04^{bc}$ |
| BA | $223.38 \pm 8.30^{a}$ | $0.79 \pm 0.02^{a}$ |
| ABBA | $203.07 \pm 9.68^{b}$ | $0.69 \pm 0.02^{bc}$ |
| BABA | $197.46 \pm 10.59^{b}$ | $0.67 \pm 0.03^{bc}$ |

$^{a,b,c}$Means within traits (columns) that do not share a superscript differ ($P < 0.05$).

Table 20. Means ± SE for weaning weight (kg) by calving year and cow birth year for 3-yr-olds and older

| | Cow birth year | | |
|---|---|---|---|
| Year | 1997 | 1998 | 1999 |
| 2000 | 206.99 ± 4.96 | | |
| 2001 | 206.99 ± 4.96$^{x}$ | 178.81 ± 4.43$^{y}$ | |
| 2002 | 236.82 ± 5.09 | 227. 83 ± 5.49 | 223.24 ± 7.40 |
| 2003 | 253.11 ± 4.96$^{x}$ | 254.08 ± 4.44$^{x}$ | 233.47 ± 6.07$^{y}$ |
| 2004 | 237.19 ± 5.91$^{x}$ | 235.78 ± 5.22$^{x}$ | 217.81 ± 7.16$^{y}$ |
| 2005 | 235.80 ± 6.01 | 229.95 ± 5.40 | 232.10 ± 6.67 |
| 2006 | 224.40 ± 6.33 | 223.51 ± 5.66 | 219.15 ± 7.70 |
| 2007 | 234.44 ± 6.64$^{xy}$ | 246.91 ± 5.83$^{x}$ | 228.76 ± 7.95$^{y}$ |
| 2008 | 241.81 ± 7.23$^{xy}$ | 255.14 ± 6.45$^{x}$ | 232.80 ± 8.34$^{y}$ |
| 2009 | 231.40 ± 7.41 | 235.08 ± 6.81 | 209.42 ± 12.78 |

$^{x,y}$Where superscripts are present, means within years (rows) that do not share a superscript differ ($P < 0.05$).

Table 21. Weaning weight means ± SE (kg) by cow age group (yr) and cow breed group for 3-yr-olds and older[1]

| | Cow breed group | | | | |
|---|---|---|---|---|---|
| Cow age group | A | B | BA | ABBA | BABA |
| 3 | 189.82 ± 6.76[cy] | 221.02 ± 7.87[ax] | 208.21 ± 7.27[cx] | 204.21 ± 12.24[cxy] | 212.30 ± 10.96[ax] |
| 4 | 215.10 ± 6.15[abxy] | 211.61 ± 9.23[axy] | 229.25 ± 6.57[bx] | 227.24 ± 7.42[bcxy] | 211.07 ± 8.01[ay] |
| 5 to 10 | 218.07 ± 3.90[az] | 222.11 ± 4.75[az] | 249.27 ± 3.64[ax] | 241.53 ± 5.15[abxy] | 227.77 ± 7.37[ayz] |
| Older than 10 | 192.61 ± 10.23[bcy] | 209.30 ± 15.39[ay] | 260.09 ± 7.64[ax] | 264.02 ± 11.86[ax] | 207.40 ± 21.46[ay] |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

[a,b,c]Means within breed group (columns) that do not share a superscript differ ($P$ < 0.05).

[x,y,z]Means within age group (rows) that do not share a superscript differ ($P$ < 0.05).

***Preweaning ADG.*** Unadjusted means are presented for comparison and to illustrate the differences among breed and age groups in Table 22.

*Records of 2-yr-old cows.* The final model included cow birth year ($P = 0.02$) and cow breed group ($P < 0.001$). The amount of *Bos indicus* in the sire approached significance ($P < 0.06$). Sex of the calf was not significant ($P = 0.4$).

Calves raised by BA cows gained the most per day before weaning ($P < 0.04$) (Table 19). Preweaning ADG by birth year for 2-yr-olds are shown in Table 13. Calves raised by cows born in 1997 had a higher preweaning ADG ($P < 0.01$) than calves raised by cows born in 1998, but calves raised by cows born in 1999 did not differ from the preweaning ADG of calves raised by cows born in 1998 ($P = 0.09$) or 1997 ($P = 0.66$).

The amount of *Bos indicus* in the sire did not explain substantial variation when modeled within ($P = 0.11$) or across ($P = 0.19$) cow breeds.

*Records of older cows.* The covariate of the amount of *Bos indicus* in the sire within cow breed-sex of calf combinations was not significant ($P = 0.73$). The final model included year ($P < 0.001$), sex of calf ($P < 0.001$), cow breed ($P < 0.001$), the interaction of cow breed group with cow age group ($P < 0.001$) and the amount of *Bos indicus* in the sire nested within cow breed ($P = 0.02$).

Preweaning ADG by sex of calf for 3-yr-olds and older are presented in Table 16. Male calves had larger preweaning ADG than female calves ($P < 0.001$). This is consistent with results reported by Obeidat (2013). Calves had the highest ADG when they were out of cows in their peak of production ages (Table 22). This is also consistent with the findings of Obeidat that calves out of intermediate aged cows were the heaviest at weaning (2013).

In general, calves out of cows of intermediate ages gained more than calves out of 2- and 3-yr-old cows (Table 23). As 3-yr-olds, the calves raised by Angus cows had the lowest ADG ($P < 0.03$). Calves raised by 4-yr-old BA cows gained more per day ($P < 0.03$) than calves raised by Angus and BABA cows. Once the BA cows were 5-yr-old and older, their calves gained more per day than calves raised by Angus, Brahman, and BABA cows ($P < 0.02$). Calves raised by BA cows older than 10 yr gained more per day than calves raised by Angus and Brahman cows ($P < 0.02$). These results are consistent with those reported by Obeidat (2013) in which calves out of $F_1$ Nellore-Angus cows had larger ADG than calves born to straightbred cows and in many cases ⅜ Nellore ⅝ Angus cows.

Regression coefficients for amount of *Bos indicus* in the sire by each cow breed for cows 3-yr-old and older ($P < 0.001$) for ABBA and BABA were 0.11 ± 0.04 kg/day and 0.12 ± 0.05 kg/day, respectively ($P < 0.02$). These indicated positive correspondence of amount of *Bos indicus* in the sire of the calf with preweaning ADG in calves raised by $F_2$ cows. The $F_1$ had the largest regression coefficient ($P < 0.001$) of 0.18 ± 0.03 kg/day. Regression coefficients for Angus and Brahman cows did not differ from 0 ($P > 0.29$).

Table 22. Unadjusted means (SD) for preweaning ADG (kg/day) by cow age group (yr) and cow breed group[1]

| Cow age group | A | B | BA | ABBA | BABA |
|---|---|---|---|---|---|
| 2 | 0.61 (0.12) | 0.72 (0.12) | 0.79 (0.08) | 0.67 (0.07) | 0.68 (0.09) |
| 3 | 0.65 (0.15) | 0.79 (0.11) | 0.73 (0.11) | 0.74 (0.21) | 0.79 (0.13) |
| 4 | 0.80 (0.16) | 0.81 (0.10) | 0.81 (0.09) | 0.92 (0.09) | 0.77 (0.13) |
| 5 to 10 | 0.85 (0.12) | 0.89 (0.14) | 1.00 (0.11) | 0.95 (0.12) | 0.93 (0.09) |
| Older than 10 | 0.79 (0.15) | 0.94 (0.09) | 1.01 (0.11) | 0.95 (0.11) | 0.96 (0.05) |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

Table 23. Means ± SE for preweaning ADG (kg/day) by calving year and cow birth year for 3-yr-olds and older

| | Cow birth year | | |
|---|---|---|---|
| Year | 1997 | 1998 | 1999 |
| 2000 | 0.73 ± 0.02 | | |
| 2001 | 0.74 ± 0.02$^{x}$ | 0.68 ± 0.02$^{y}$ | |
| 2002 | 0.94 ± 0.02 | 0.90 ± 0.02 | 0.90 ± 0.03 |
| 2003 | 0.98 ± 0.02$^{x}$ | 0.98 ± 0.02$^{x}$ | 0.92 ± 0.02$^{y}$ |
| 2004 | 0.91 ± 0.02 | 0.90 ± 0.02 | 0.85 ± 0.03 |
| 2005 | 0.99 ± 0.02 | 0.94 ± 0.02 | 0.95 ± 0.02 |
| 2006 | 0.89 ± 0.02 | 0.89 ± 0.02 | 0.85 ± 0.03 |
| 2007 | 0.91 ± 0.02 | 0.93 ± 0.02 | 0.90 ± 0.03 |
| 2008 | 0.96 ± 0.03$^{x}$ | 1.02 ± 0.02$^{xy}$ | 0.91 ± 0.03$^{x}$ |
| 2009 | 0.92 ± 0.03$^{x}$ | 0.94 ± 0.02$^{xy}$ | 0.81 ± 0.05$^{y}$ |

$^{x,y}$Where superscripts are present, means within years (rows) that do not share a superscript differ ($P < 0.05$).

Table 24. Preweaning ADG means ± SE (kg/day) by cow age group (yr) and cow breed group for 3-yr-olds and older[1]

| | Cow breed group | | | | |
|---|---|---|---|---|---|
| Cow age group | A | B | BA | ABBA | BABA |
| 3 | 0.73 ± 0.3[by] | 0.88 ± 0.03[ax] | 0.86 ± 0.03[bx] | 0.84 ± 0.04[bcx] | 0.86 ± 0.04[abx] |
| 4 | 0.83 ± 0.02[ay] | 0.85 ± 0.03[axy] | 0.90 ± 0.02[bx] | 0.86 ± 0.03[cxy] | 0.83 ± 0.03[by] |
| 5 to 10 | 0.83 ± 0.01[ay] | 0.87 ± 0.02[ay] | 0.95 ± 0.01[ax] | 0.93 ± 0.02[abx] | 0.88 ± 0.03[aby] |
| Older than 10 | 0.73 ± 0.04[bz] | 0.86 ± 0.05[ay] | 0.99 ± 0.03[ax] | 0.96 ± 0.04[axy] | 0.99 ± 0.06[axy] |

[1]A = Angus; B = Brahman; BA = B-sired $F_1$; ABBA = $F_2$ from AB x BA parents; BABA = $F_2$ from BA x BA parents.

[a,b,c]Means within breed group (columns) that do not share a superscript differ ($P < 0.05$).

[x,y,z]Means within age group (rows) that do not share a superscript differ ($P < 0.05$).

# SUMMARY

Calf crop born, calf crop weaned, calf birth weight, calf weaning weight, and calf preweaning average daily gain (ADG) were evaluated from 1997 to 2009 in Brahman (B) and Angus (A) straightbred and crossbred cows (n = 194). The objective was to estimate heterosis for $F_1$ and $F_2$ females for these reproductive and maternal traits. Breed groups included A, B, $F_1$ Brahman-sired (BA; a pair of letters designate the cow's sire breed and dam breed, respectively) cows (n = 92 purebreds, 53 $F_1$, 49 $F_2$). $F_2$ breed groups included cows sired by AB bulls and out of BA dams (ABBA) and cows sired by BA bulls and out of BA dams (BABA).

Data from 2-yr-old females were analyzed separately from cows ages 3-yr-old and older. Final models for 2-yr-old records included cow breed ($P < 0.001$) for calf crop born and calf crop weaned. As 2-yr-olds, Brahman had the lowest calf crop born and weaned (0.36 ± 0.07; 0.26 ± 0.08; respectively, $P < 0.01$), and BABA had a lower ($P < 0.05$) calf crop born (0.64 ± 0.08) than BA (0.92 ± 0.05) and ABBA (0.88 ± 0.08). Heterosis was not detected for 2-yr-olds.

Final models for 3-yr-olds and older included the interaction of cow breed group with cow age group and cow age group within year ($P < 0.001$). As 3-yr-olds, ABBA had the lowest ($P < 0.02$) calf crop born and weaned (0.28 ± 0.07 and 0.22 ± 0.08, respectively) while Brahman had the lowest calf crop born as 4-yr-olds (0.47 ± 0.06; $P < 0.02$). As 5- to 10-yr-olds, Brahman had lower ($P < 0.01$) calf crop born (0.84 ± 0.04) than BA (0.97 ± 0.03) and ABBA (0.99 ± 0.04). $F_1$ heterosis was 0.08 ± 0.02 and 0.08 ± 0.03 for calf crop born and weaned ($P < 0.01$).

The final model for 2-yr-old birth weight consisted of cow birth year (*P* < 0.001) and sex of the calf (*P* = 0.02). Females born in 1998 had the lightest calves at birth as 2 yr olds (*P* < 0.001). The final model for 2-yr-old weaning weight included cow breed (*P* < 0.001) and the amount of *Bos indicus* in the sire (*P* < 0.03). As 2-yr-olds, BA weaned the heaviest calves (*P* < 0.02). A regression coefficient was found to be 29.28 ± 11.81 in the 2-yr-old data using the amount of *Bos indicus* in the sire as a linear covariate across all cow breed groups (*P* = 0.01). The final model for preweaning ADG for 2-yr-olds included cow birth year (*P* = 0.02) and cow breed group (*P* < 0.001). Calves raised by BA cows gained the most per day before weaning (*P* < 0.04).

The final model for 3-yr-olds and older for birth weight included cow birth year within year, amount of *Bos indicus* in the sire within cow breed, sex of the calf, and cow breed (*P* < 0.01). BABA had heavier calves (*P* < 0.05) than Brahman, BA, and ABBA, while Brahman had calves with the lightest (*P* < 0.001) birth weight. The regression coefficient for the amount of *Bos indicus* in calf sires for Angus was 10.26 ± 1.52 kg (*P* < 0.001). The $F_1$ and ABBA cows had similar regression coefficients of 5.24 ± 2.40 (*P* < 0.03) and 5.13 ± 2.79 (*P* < 0.07), respectively.

The final model for 3-yr-old weaning weight consisted of the interaction of cow breed and cow age group, sex of the calf, year, cow breed, cow age group, the interaction of cow breed with cow age group and the amount of *Bos indicus* in the sire nested within cow breed (*P* < 0.003). As 3-yr-olds, Angus weaned lighter calves than Brahman, BA, and BABA (*P* = 0.04). As 4-yr-olds, BA weaned heavier calves than BABA (*P* = 0.04), and the difference between Angus and BA approached significance (*P* = 0.07). As 5 to 10-yr-olds, BA weaned heavier calves than Angus, Brahman, and BABA (*P* < 0.01), and as 10-yr-old and older, ABBA weaned heavier calves than Angus, Brahman, and BABA ($P < 0.02$). For the 3-yr-olds and older, a regression coefficient (kg weaning weight per unit of Brahman in the sire) was found for Brahman cows (–33.50 ± 7.58; $P < 0.001$).

The final model for preweaning ADG for 3-yr-olds and older included year, sex of calf, cow breed, the interaction of cow breed group with cow age group, and the amount of *Bos indicus* in the sire nested within cow breed ($P < 0.02$). As 3-yr-olds, the calves raised by Angus cows had the lowest ADG ($P < 0.03$). Calves raised by 4-yr-old BA cows gained more per day ($P < 0.03$) than calves raised by Angus and BABA cows. Once the BA cows were 5-yr-old and older, their calves gained more per day than calves raised by Angus, Brahman, and BABA cows ($P < 0.02$). Calves raised by BA cows older than 10 yr gained more per day than calves raised by Angus and Brahman cows of this age group ($P < 0.02$). Regression coefficients for amount of *Bos indicus* in the sire by each cow breed for cows 3-yr-old and older ($P < 0.001$) for ABBA, BABA, and $F_1$ were 0.11 ± 0.04, 0.12 ± 0.05, and 0.18 ± 0.03 kg/day, respectively ($P < 0.02$). Results of this study suggest that there is not a total loss of heterosis in the $F_2$ generation from the $F_1$ generation. Although significant differences for calf crop born and calf crop weaned between the $F_2$ groups were not detected for cows of all ages, BABA were represented by a few very good cows for much of the data from latter years, and may not be representative of the true group means. The low performance of BABA as 2-yr-olds and rapid exit of most cows from the project, appear to indicate superior fertility of ABBA $F_2$ cows. *Bos indicus*-influenced females oscillated between reproductive success and failure for the first few years of life.

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