HETEROSIS AND HETEROSIS RETENTION FOR REPRODUCTIVE AND MATERNAL TRAITS IN BRAHMAN x HEREFORD CROSSBRED COWS

A Thesis

by

LYDIA BOENIG

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

MASTER OF SCIENCE

December 2011

Major Subject: Animal Breeding

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Approved by:

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	David G. Riley
Committee Member,	Andy D. Herring
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ABSTRACT

Heterosis and Heterosis Retention for Reproductive and Maternal Traits in Brahman x Hereford Crossbred Cows.

(December 2011)

Lydia Boenig, B.S., Texas A&M University

Co-Chairs of Advisory Committee: Dr. James O. Sanders
Dr. David G. Riley

Calf crop born, calf crop weaned, calf birth weight, calf weaning weight, and cow weight at weaning were evaluated from 1996 to 2009 in Brahman (B) and Hereford (H) straightbred and crossbred cows (n = 1,515). The objective of these analyses was to estimate heterosis for F_1 and F_2 females for these reproductive and maternal traits. Breed groups included B, H, F_1 Hereford-sired (HB) and Brahman-sired (BH) cows (n = 114 purebreds, 55 F_1, 52 F_2). Second generation breed groups included cows sired by HB and out of HB dams (F_2HB) and BH dams (HBxBH); and cows sired by BH and out of HB dams (BHxHB) and BH dams (F_2BH). Least squares means were calculated for calf crop born, calf crop weaned, and calf birth and weaning weights, using numerous different models, where the trait was the dependent variable. Previous research and these preliminary analyses showed that the effects of year and cow age are real as is their interaction each other and with breed type. In each attempted model designed to remove these effects, different breed groups received excessive adjustments, rendering the resultant heterosis estimates inappropriate. To more clearly assess differences, presentation and visual evaluation of unadjusted means were conducted. The model for mature cow weight (cows at 6 years of age) included breed group as fixed effects and cow within breed group and year as random effects.

F_2 cows appeared to retain approximately 39% of F_1 heterosis for calf crop born and approximately 50% for calf crop weaned. HB x BH cows delivered the lightest calves at 33.9 (4.74) kg and F_2BH had the heaviest calves at birth at 36.6 (5.37) kg. BH cows weaned the heaviest calves at 240.9 (38.1) kg and F_2BH cows weaned the lightest calves at 208.4 (31.9) kg. Sire breed of calf and age of cow appear to be important factors regarding weight traits. Retained heterosis for cow weight at weaning was higher than expected at 73%. Sire breed group differences (HB vs. BH) for these traits in F_2 cows may merit further investigation.

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I am blessed to have the unconditional love and support of my family members throughout the varied endeavors of my life. My parents, Brenda and Heinrich Boenig, by offering constant encouragement and steadfast reassurance have always been the standard to which I hold myself. I cannot begin to adequately thank them.

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INTRODUCTION

Reproductive efficiency and maternal ability are two of the most important factors affecting the economy of beef production. Reproductive efficiency is a complex character consisting of a number of sub-characters (Cartwright et al., 1964). Several methods may be used to evaluate reproductive efficiency. Reproductive efficiency is usually expressed as the percentage of cows that become pregnant, calve or wean a calf in a population of cows exposed to bulls during the current year's breeding season. Maternal ability is usually measured in terms of calf survival, weaning weight and preweaning average daily gain of the calf. Greiner (2009) states that hybrid vigor, or heterosis, is expressed in crossbred animals, and crossbred animals merge the strengths of the different breeds used in the cross. Incorporating a well-designed and well executed crossbreeding system can enhance the rewards of heterosis, optimizing both reproductive efficiency and maternal ability. The most effective way by which to improve reproductive rate is to utilize heterosis for female fertility (Piper, 1982).

Most commercial beef cattle herds in the southern United States are composed of crossbred cows with a mixture of Brahman and Continental, British and possibly dairy breeding (Franke, 1980). Heterosis, or the difference in (usually superior) performance of crossbred cattle compared to the straightbred average, has the highest expression in F_1 *Bos taurus* x *Bos indicus* cattle (Dickerson, 1973). Heterosis has traditionally been explained as proportional to heterozygosity (Wright, 1922). The high costs incurred and intense management demanded by producing F_1s has led to the utilization of F_2 and subsequent generations. If heterosis is not

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proportional to heterozygosity, a substantial decrease of the crossbred advantage could be seen. Heterosis retention is important to consider in succeeding generations of composite populations as the cost of losing significant amounts of hybrid vigor may be more than a producer can sustain.

Several previous studies involving *Bos taurus* x *Bos indicus* cattle have demonstrated that large reciprocal cross differences exist in the F_1 generation, however there is a scarcity of information involving these differences and heterosis retention in reproductive traits in the F_2 generation. Therefore, the objectives of this project were to identify levels of retained heterosis in F_2 Brahman x Hereford cross cows for reproductive traits of calf crop born and calf crop weaned and maternal traits of birth weight and weaning weight. Additionally identification of F_2 heterosis levels for mature cow weight were of interest.

LITERATURE REVIEW

Historically, the single largest economic proportion of American agriculture has been beef production, and the same holds true in present times. Producers are continuously striving to maximize the efficiency of producing quality beef. The most critical of the characters that can affect the beef industry are cow reproductive efficiency and maternal ability.

Breeds

The genus *Bos* includes both wild and domesticated cattle. Several species in the *Bos* genus (such as Banteng (*Bos javanicus)*, Gaur (*Bos gaurus*), and yak (*Bos mutus*)) as well as the Bison (*Bison bison*), which some authors consider to be in the genus *Bos* as well) can interbreed with domestic cattle. The resultant crossbred female offspring generally are fertile and the males are not (J. O. Sanders, Texas A&M University, personal communication). Two subspecies of domestic cattle in the *Bos* genus are *Bos indicus* and *Bos taurus* (sometimes referred to as *Bos taurus indicus* and *Bos taurus taurus*). Crossing these two subspecies results in offspring with fertility expressed in both sexes.

Bos taurus cattle have traditionally been the typical beef species in the United States due to European influences. Limitations on performance of *Bos taurus* cattle in the sub-tropical regions are due to lack of tropical adaptation. Zebu, or *Bos indicus,* cattle are tropically adapted (Maule, 1980). *Bos indicus* cattle are typically of Indian origin and are most easily recognized by their pendulous dewlaps and large shoulder humps. Turner (1980) stated that the physiology (coat, hide, skin and hematological attributes) of Zebu cattle makes them uniquely suited to hot climates.

Crosses with Zebu cattle are prevalent in the Southern United States, at least partly, because of the genetic differences between *Bos indicus* cattle and the more traditional *Bos taurus* beef breeds. Animals that are more genetically different will produce offspring with a higher degree of heterosis when crossed than will animals that are genetically relatively similar. Brahman and Hereford purebred and crossbred cattle were involved in this study.

The Brahman Breed

The Brahman, an American Zebu breed, has contributed heavily to the beef industry in the United States for many years. The American Brahman evolved from crossing *Bos indicus* bulls from India (also imported to the United States from Brazil) on local cows in the Gulf Coast states (Franke, 1980; Sanders, 1980). Historically, two types of the American Brahman exist: the Red Brahman and the Gray Brahman. The Red Brahman is predominantly of Gir and Indu-Brasil ancestry, with some Guzerat influence (Sanders, 1980). Though some other Zebu breeds influenced Gray Brahman cattle, they are primarily a mixture of Guzerat and Nellore. Sanders (1980) also credited the Guzerat with having the most influence in the founding of the Gray Brahman. The Guzerat, or Kankrej as it is known in its native India, is still maintained as a pure breed there and in Brazil. This gray breed has unique lyre shaped horns, short faces, wide flat ears and has traditionally been a dual purpose breed; being qualified as a draught and milk animal (Maule, 1980). The Nellore breed also has its origins as a dual purpose breed in India where it is referred to as Ongole. Nellore cattle have long, narrow faces with small ears. Sanders (1980) stated that Nellore type animals were the principal Zebu cattle in the U.S. until the mid-1920's. As their maternal base, Nellore consequently contributed heavily to the Brahman breed. The influence Brahman cattle have had in the hot, humid southeastern quadrant of the country, where stresses due to climate and parasites curb the productivity of *Bos taurus* breeds (Cartwright, 1980; Franke, 1980; Turner, 1980; Herring et al., 1996), has been considerable.

The Hereford Breed

The Hereford is a *Bos taurus* beef breed whose origins are in Herefordshire, England (Oklahoma State University, 2011). Production efficiency and high yields were the driving forces in developing this breed. They are recognized as a moderate sized breed with easy fleshing ability, good muscle expression and low milking potential when used in temperate areas. Due to their origins in the temperate climate of southwestern England, Herefords are ill suited for tropical regions and associated stresses.

First imported to the United States in 1817, Herefords of that era are not credited with having much influence on today's American Herefords. Some 23 years later, America's first breeding herd was established in Albany, New York (Oklahoma State University, 2011). Huge demand for Hereford cattle began as their ability to improve beef quality when mated to Longhorn cattle of Spanish origin was recognized by producers. Their propensity to endure and adapt led to more importations of Herefords in the 1870's and 1880's. Animals in these importations influenced modern Hereford cattle considerably. In particular, the importation of the bull Anxiety 4th in 1881 led to the transformation of the Hereford breed in the United States. Herefords are easily identified by their reddish brown hair coats and distinct white pattern enveloping the face, brisket, usually white on top of the neck and withers, four white feet and tail switch.

Crossbreeding and Heterosis

Early pioneers in scientific animal breeding realized the importance of crossbreeding. Wright (1922) stated “inbreeding merely concentrates and intensifies the peculiarities of the given line, whether good, bad or indifferent.” Conversely, heterosis is widely defined as the average of the crossbred population performance compared to the average of the straightbred parental population performance. Therefore superior performance in various different characters in the crossbred animal as compared to the average of the straightbred parents’ performance is, to some extent due, to heterosis (Lush, 1945). In his discussion of the history of the theory of heterosis, Shull (1952) wrote that crossbred individuals’ superiority was known even in Darwinian times. Bruce (1910) wrote “…the crossing of two pure breeds produces a mean vigor greater than the collective mean vigor of the parent breeds.”

The expression of heterosis can be attributed to dominance and epistasis. Dominance, or the intralocus interaction of alleles, is the most commonly recognized cause of heterosis. Epistasis, or the advantageous combination of genes across loci associated with a particular trait that has arrived together in an individual of the first cross (Sheridan, 1981), is also a possible cause of heterosis. It is important to understand that epistasis, as defined by Dickerson (1952), includes all effects of a gene at one locus on the expression of genes at other loci.

“The basic objective of beef cattle cross-breeding systems is to optimize simultaneously the use of both nonadditive (heterosis) and additive (breed differences) effects of genes” (Gregory and Cundiff, 1980). Similarly, Koger (1980) stated that the objective of crucial importance to any commercial beef cattle breeding program should be to maximize the sum of the additive genetic values and heterosis levels for calf crop weaned, maternal ability, and growth potential of the calf. Two of these traits are cow traits, and one is based on the calf. Together they are economically critical to a commercial beef herd.

Cattle are raised in most habitable areas of the world; therefore, no single breed has been proven to excel in all environments in which cattle are produced. A breed's ability to thrive in its environment has tremendous impact on its performance. Selecting breeds with complementary traits to produce crossbred offspring allows for production of animals that are well suited to the environment and able to meet market demands. Stresses imposed by topography, available nutrient sources, parasites and especially climate must be taken into account in order to optimize a crossbreeding system. Various levels of heterosis have been noted to be due to environmental conditions. It has been documented by Cunningham (1982) that expression of heterosis increases as environmental stressors increase. In an Australian study, Frisch and Vercoe (1984) reported similar results: when the animals are in a harsh environment, heterosis levels are considerably higher than when the environment is milder and the superiority of the crossbreds diminishes. Koger (1973) concluded that heterosis expression seems variable within different environmental conditions.

An ideal system would include proper genotype-environment balance in addition to appropriate breed choice and application of heterosis (Frisch and O'Neill, 1998; Cundiff et al., 2000). "Crossbreeding, utilizing complementarity appears to be the most effective method by which to use selection" (Cartwright, 1970).

Willham (1970) described crossbreeding as "a management technique widely used by commercial beef producers attempting to improve production efficiency." He also stated that the utilization of heterosis permits rapid incorporation of desired genetic material in the production of market animals. Reproductive efficiency traits are critical to beef producers, however, these traits are lowly heritable (Cartwright et al., 1964). The authors also stated that large heterotic responses tend to occur in lowly heritable traits. "Heterosis is especially beneficial for traits that are difficult or time-consuming to improve through selection, such as reproductive traits, calf survival, and longevity traits" (Riley and Crockett, 2006). Selection within breeds has the potential to yield only limited increases in reproductive rates; there is ample documentation that the most prudent solution is to exploit heterosis for fertility traits (Piper, 1982).

Today, crossbred females in the Southeastern United States typically are some percentage Brahman and *Bos taurus*. These Brahman cross cattle differ from *Bos taurus* x *Bos taurus* and from *Bos indicus* x *Bos indicus* crossbred cattle in the level of heterosis. The particular cross, the proportion of Brahman present, and the proportions of other specific breeds are factors which can affect the amount of heterosis present in different Brahman cross cattle. Each of these three factors must be considered both for the dam and for her calf in order to properly account for the variation. The greater genetic divergence between Brahman and *Bos taurus* breeds increases the capacity for heterotic advantages when used in crossbreeding systems (Olson et al., 1990; 1993). Consequently, most commercial beef cattle herds in the southern United States are composed of crossbred cows with a mixture of Brahman and Continental, British and possibly dairy breeding (Franke, 1980).

When compared to *Bos taurus* x *Bos taurus* calves, Brahman cross calves have consistently displayed various advantages, including: higher calf survival rate (Franke, 1980), heavier weaning weights (Gregory et al., 1979; Franke, 1980; Cundiff et al., 2000), and improved average daily gains (Paschal et al., 1991).   Additionally, when compared to *Bos* *taurus* crossbred cows, Brahman cross cows offer higher pregnancy rates (Riley et al., 2001), higher calf crop born (Koger, 1980; McCarter et al., 1991), heavier weaning weights (Peacock et al., 1971; Franke, 1980; McCarter et al., 1991), and higher capacity for longevity (Bailey, 1991; Nuñez-Domínguez et al., 1991).

"Heterosis values reported for Brahman-European crosses generally have averaged more than three times those for crosses among European breeds" (Koger, 1980). Sanders (1994) also stated that two to three times as much hybrid vigor is routinely seen in *Bos indicus* x *Bos taurus* when compared to crosses consisting of two *Bos taurus* breeds.

Heterosis Retention

Heterosis expression is estimated to be proportional to breed heterozygosity under the dominance model (Riley and Crockett, 2006). A locus is said to be heterozygous if the two alleles at that locus are different; breed heterozygosity refers to having alleles from the two different breeds at the locus, whether the two alleles are actually different or not. Riley and Crockett (2006) wrote that the expression of heterosis is largely attributed to dominance effects at many genes. The first cross of any two breeds results in an animal that is breed heterozygous at every single locus. For instance, if a purebred Brahman is mated to a purebred Hereford, each one contributes one entire strand of DNA that is either Brahman or Hereford, respectively, to the progeny. The calves of this mating will have one Brahman allele and one Hereford allele at each locus across the whole length of their genome. Therefore, only F_1 animals are expected to express full heterosis for any given trait. Because of this, hybrid vigor is often presented in research results as a fraction of that of the F_1 generation. The F_1 female has been shown to have superior maternal characteristics and more longevity, at least partly, because of heterosis

(Cartwright et al., 1964; Franke, 1980; Turner, 1980). Koger et al. (1975) validated high levels of heterosis in *Bos indicus* x *Bos taurus* animals in a Florida study, but suggested that with respect to heterozygosity, the heterosis expression in the cows was not linear.

Based on the dominance model, only one half of the heterosis exhibited by the F_1 Brahman x British female is expected to be retained in the F_2 and subsequent generations (Riley and Crockett, 2006). This phenomenon is sometimes referred to as heterosis retention. If the assumption is made that all breeds have the same level of heterosis with each other (Sanders, personal communication), then when *n* breeds contribute equally to the cross, expected retention of initial F_1 heterozygosity after *inter se* mating within the crosses can be determined as $(n\text{-}1)/n$ (Wright, 1922; Dickerson, 1969, 1973). Dickerson (1969) further concluded that just one generation of random mating is required in order to stabilize heterozygosity.

The high levels of cow reproduction and efficiency seen in F_1 animals and the high cost of replacing these females warrant further investigation of performance of subsequent generations. According to Herring et al. (1996), the popularity of the F_1 female seems limited only by her inability to produce replacements that match her level of production.

Extensive research involving various *Bos taurus* crosses has been conducted at the R. L. Hruska U.S. Meat Animal Research Center (MARC) in Nebraska. Koch et al. (1985) described a greater reduction in heterosis than predicted by the dominance model when comparing pregnancy rate and calf survival in F_2 and F_3 Angus x Hereford cows to F_1 cows of the same breeding. This same study generated results that indicated that heterosis levels for maternal influence on birth weight and pre-weaning gain were not different than predicted by the dominance model. In a study involving three *Bos taurus* (British and Continental) composite lines (called MARC I, II, & III), traits of economic importance were evaluated (Gregory et al., 1991a; 1991b; 1999). Heterosis retained for direct and maternal effects on birth weight, weaning weight and pre-weaning average daily gain was not less than expected based on the dominance model. Similarly, retained heterosis for cow weight or condition score in the F_2 generation did not differ ($P > 0.05$) from the dominance model expectation (Gregory et al., 1992b; 1999). Furthermore, Gregory et al. (1992a) reported that age of dam was important when comparing heterosis levels. The amount of retained heterosis in F_2 and F_3 cows that produced F_3 and F_4 calves in the MARC I (75:25 ratio of continental breeds to British breeds) and MARC II (50:50 ratio of continental breeds to British breeds) composite populations did not differ ($P > 0.05$) from the amount expected based on expected heterozygosity for 200- d weight. The MARC II population retained more heterosis for 200-day weight than was predicted based on retained heterozygosity. This was also true for the overall average for 200-d weight of the three composite populations. In general, the results from this study were consistent with the hypothesis that heterosis expressed in subsequent generations is proportion to the degree of heterozygosity and can be accounted for by dominance effects of genes.

One of the composites (MARC III which was ¾ British) retained less heterosis than the dominance expectation for calf crop born, calf crop weaned and 200- d weight per heifer exposed ($P < 0.05$) (Gregory et al., 1999). In addition, Gregory et al., (1999) stated that this composite also expressed significantly less heterosis retained than expected for calf crop weaned and 200 day weight per female exposed ($P< 0.05$). This was due to fetal death loss between the time the cow was palpated pregnant and the time of parturition (Gregory et al., 1999). For all three MARC composite populations, Gregory et al. (1999) reported that the observed minus expected effects of heterosis was negative for calf crop born and weaned. In the MARC II and III populations, this difference was also negative for pregnancy rate. Of these three traits, only pregnancy rate in the MARC I cows was shown to give a positive difference when subtracting the expected amount of heterosis expressed for F_2 cows observed heterosis expressed in F_2 cows. That is, most of the estimates of heterosis for female reproductive traits in this study were less than predicted from the dominance model, in the F_2 and subsequent generations, although most were not estimated to be significantly less.

Koger et al. (1975) evaluated F_1 and backcross Brahman x Shorthorn (¾ Brahman, ¼ Shorthorn and ¾ Shorthorn ¼ Brahman) females in Florida. These cows were mated to Brahman and Shorthorn bulls. Results from this study showed that for maternal effects on weaning weight, the backcross cows outperformed the F_1 cows. Very small estimates of maternal heterosis in F_2 cows were reported by Sacco et al. (1989) in a Texas diallele involving Angus, Brahman, Hereford, Holstein, and Jersey. In the authors' discussion of weaning weight and height, they reported "a substantial loss in maternal heterosis, suggesting that epistatic recombination effects may be important, or that there is a maternal heterosis x age interaction" (Sacco et al., 1989).

These results for maternal effects on weaning weight were mirrored in a Florida study by Olson et al. (1993) who 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." Heterosis for pregnancy in the F_2 dams was reported to be less than half that reported for F_1, backcross, and three breed cross (½ Charolais ¼ Angus ¼ Brahman) dams. Average pregnancy rate for F_1 Brahman x Angus and Brahman x Charolais cows was 94.7% and 88.8%, respectively. Average pregnancy rate for F_2 Brahman x Angus and Brahman x Charolais cows was 88.9% and 87%, respectively. When compared to the parental purebred averages of Angus (92.6%), Brahman (79.2%), and Charolais (85.5%), the pregnancy rate was 7.7% higher in the F_1 cows (Brahman x Angus and Brahman x Charolais) (Sanders, 2005). Across the two breed combinations, the F_2 cows had a 3.9% higher pregnancy rate than the purebreds. That is, heterosis retained in F_2 cows was 50.6% of that in the F_1 cows; this is in close agreement with dominance model expectations (note that 34.1% of the F_1 Brahman-Angus heterosis and 72.1% of the Brahman-Charolais heterosis was estimated to be retained in the respective F_2 cows). Only Brahman sired F_1 bulls were used to produce the Brahman-Angus F_2 cows; although no record was kept of the bulls that were actually used to produce the Brahman-Charolais F_2 cows, these bulls were chosen from a group or groups that included both Brahman-sired and Charolais- sired bulls (T. A. Olson, Dept. Anim. Sci., Univ. Florida; personal communication with J. O. Sanders).

Reproductive and weight traits from *inter se* mated F_1 and F_2 ½ Brahman ½ Angus dams (BA) and ⅜ Brahman ⅝ Angus dams (⅜ B ⅝ A) from a study in Florida were reported by Hargrove et al. (1991). The F_1 BA dams had higher pregnancy rates (97.4% compared to 81.7% and 81.9% in ⅜ B ⅝ A and F_2 BA dams respectively), calf crop born (96.7% compared to 77.3% and 81%), and calf crop weaned (90.7% compared to 80.8% and 67.1%) than the ⅜ B ⅝ A dams F_2 BA. Calves out of F_1 BA dams were heavier at weaning (239.09 kg); calves out of ⅜ B ⅝ A cows weighed 218.72 kg and calves out of F_2 BA dams weighed 226.21 kg.

In Australian studies, the most substantial evidence for loss of heterosis in further interbred generations of British x Zebu has been quantified. Seifert and Kennedy (1972) reported that F_1 Africander cross, F_1 Brahman cross, and F_2 Africander cross cows weaned a significantly higher proportion of calves than did the F_2 Brahman cross cows. Seebeck (1973) also compared female fertility traits of these F_1 cows to combined F_2 and F_3 cows of *Bos taurus* cross and *Bos taurus* x *Bos indicus* breeding. He found a decrease in calf crop born of 20.5 % between the F_1 and F_2 generations of Brahman cross cows. Interestingly, there was almost no loss of heterosis for fertility in the British x Africander cross cows (Seebeck, 1973). MacKinnon et al. (1989) discussed results from subsequent analyses at the same location that suggest more heterosis loss than predicted by the dominance model for calf crop born in F_2 and later generations. Only Brahman- sired F_1 bulls were used to establish the breeding herds for these F_2 and later generations (J. E. Frisch**,** Commonwealth Scientific and Industrial Research Organization **(**CSIRO**)** Rockhampton, Queensland, personal communication with J.O. Sanders). Seifert and Kennedy (1972), Rendel (1980) and Mackinnon et al. (1989) all noted that subsequent generations of interbred Brahman crosses maintained very little heterosis.

Evaluation of early data from the current study containing crosses of Brahman, Angus and Hereford was done by Riley (2000). A breed x cow age interaction was important in all traits evaluated. The author reported higher heterosis retained than would be predicted for pregnancy rate in 2- yr.- old F_2 Angus x Brahman cows, and to a lesser degree in 2- yr.- old F_2 Hereford x Brahman cows. The author also found that less than predicted levels of heterosis were retained in F_2 cows for cow weight. Based on these results, Riley (2000) concluded that the dominance model did not adequately predict heterosis retention for reproductive and maternal traits in British x Brahman crossbred females.

In later analyses of the cows in the current study, Key (2004) reported a slightly higher percent calf crop born to Hereford (H) x Brahman (B) (sire breed listed first) dams than to BH dams. Higher calf survival rate and calf crop weaned were also attributed to HB dams. Consequently, reciprocal cross effects and breed of maternal and paternal grandsire in F_2 calves is of interest. When comparing calf crop born for the four types of reciprocal Brahman-Hereford F_2 cows, Key (2004) reported that F_2 BH (both sire and dam are sired by Brahman bulls and out of Hereford cows) cows had the lowest (69%) calf crop born and the F_2 HB (both sire and dam are sired by Hereford bulls and out of Brahman cows) had the highest of the F_2s at 98%. The other two F_2 groups, Brahman sired bulls x Hereford sired cows (BH x HB) and Hereford sired bulls x Brahman sired cows (HB x BH), had calving rates of 79% and 97%, respectively. Similar results were reported for calf crop weaned: 61% for F_2BH, 91% for F_2HB, 75% for BH x HB, and 92% for HB x BH. In a subsequent study involving the same F_2 cows, Wright (2006) similarly concluded "cows by F_1 HB sires tended to have higher reproductive efficiency than those cows by F_1 BH sires."

Key (2004) also reported that, in F_2 Brahman x Angus females, calf crop born and calf crop weaned were below the mid-parent value; that is, all of the F_1 heterosis was lost. For the same traits in Brahman x Hereford cross females, the F_2 (all combinations) cows retained much more heterosis (94% of the heterosis expressed in the F_1s, for calf crop weaned) than was predicted by the dominance model ($P < 0.001$), but there were detected reciprocal F_2 differences discussed earlier. Also, within the F_2 Brahman x Angus group (n = 90), the cows sired by Angus sired bulls (n = 89) had higher calf crop born and calf crop weaned than those sired by Brahman sired bulls (0.77 vs. 0.71 for calf crop born and 0.67 vs. 0.59 for calf crop weaned).

Regarding the same cattle, Key (2004) also evaluated maternal effects on weaning weight. When compared to purebred and F_1 averages, retained heterosis for maternal effects on weaning weight in the F_2 Brahman x Angus cows was considerably less (0.91 kg) than would have been expected using the dominance model, but was similar to expectation for Brahman x

Hereford cows (19.18 kg). Heterosis retained for the characters evaluated appeared to be overestimated by the dominance model in F_2 Brahman x Angus cows and underestimated in Brahman x Hereford cows.

Models

Evaluation of different genetic components of heterosis for a trait and evaluation of retained heterosis in the F_2 generation and beyond has been conducted by applying two categories of models. In scenarios where breed group is the effect of interest, a linear model that includes various discrete and (or) continuous variables has been used. Calculation of least squares means has been done for the various breed groups (F_1, F_2, etc.). Calculation of contrasts of breed group adjusted means has been done to estimate a given trait's heterosis and retained heterosis (Knapp et al., 1980; Gregory et al,. 1985, 1991a, 1991b, 1992a, 1992b, 1999). Koger et al. (1975) described and used a multiple regression model to estimate heterosis in Brahman x Shorthorn crossbreds. Variations on this model have been used in a number of studies (Robison et al., 1981; Koch et al., 1985; Kinghorn and Vercoe et al., 1989; Olson et al., 1990). Both of these models have been used in other studies (Roberson et al., 1986; Williams et al., 1991; Olson et al., 1993). Thorough discussions on both types of models and their contribution to beef cattle research have been presented by Koch et al. (1985) and Wyatt and Franke (1986). In most cases, these studies have found that heterosis can best be explained by the dominance model wherein heterosis is estimated to be proportional to heterozygosity using the equation $(n - 1)/n$ for this prediction where n is the number of breeds in the cross. Conversely, studies of Brahman x British cow traits conducted in Australia supplied results that suggested less heterosis expressed than was predicted by the dominance model for calf crop born in F_2 and later generations

(Seebeck, 1973; MacKinnon et al., 1989). Olson et al. (1993) reported results of expressed heterosis in excess of the dominance model prediction for Brahman x Charolais F_2 cows and that the dominance model had overestimated heterosis retention in Brahman x Angus F_2 cows.

Gregory et al. (1978) found that age and breed of dam, breed of sire, sex of calf and year had important effects on most of the analyzed traits in F_1 calves in a four breed diallele of Angus, Hereford, Red Poll, and Brown Swiss. Age of dam effects on preweaning traits has been reported to be important in other studies also (Gregory et al., 1965; Turner and McDonald, 1969). Roberson et al. (1986) reported increasing birth weights for Brahman x Hereford cross dams until age 7, after which birth weight declined gradually and weaning weight increased until dams reached 9 years of age.

Peacock et al. (1971) reported that sire breed of calf effects were significant for pregnancy rate, but essentially non-existent for calf crop weaned in Brahman-Shorthorn crosses. McCarter et al. (1991) found that breed composition of the dam affected preweaning gain, weaning weight, condition and height in the calf. Given the insufficiency of definite and non-conflicting results on heterosis retained in F_2 reciprocal cross *Bos indicus* x *Bos taurus* cows, further analyses of these types of cows under typical southeastern United States conditions are necessary.

OBJECTIVES

The objectives of this study were to:

1. Evaluate heterosis between a *Bos taurus* breed (Hereford (H)) and a *Bos indicus* breed (Brahman (B)) for cow reproductive traits and weight traits of their calves.
2. Estimate retained heterosis for these traits in the four types of reciprocal F_2 Brahman (B)-Hereford (H) crosses. These four types of cows are: F_2 HB (produced by Hereford-sired F_1 bulls mated to Hereford-sired F1 cows), F_2 BH (produced by Brahman-sired F1 bulls mated to Brahman sired F_1 cows), BH x HB (produced by Brahman-sired F_1 bulls mated to Hereford-sired F_1 cows), and HB x BH (produced by Hereford-sired F_1 bulls mated to Brahman-sired F_1 cows).

MATERIALS AND METHODS

Description of Data

Cows maintained at the Texas A&M Agrilife Research Center at McGregor in the Heterosis Retention Project were evaluated. Herds of at least 50 cows of each breed type began to be established in 1994. All calves were born to cows in multiple sire herds through natural service. Breed groups included Brahman (B), Hereford (H), F_1 Hereford-sired (HB) and Brahman-sired (BH) cows, and the four reciprocal crosses of F_2 animals. F_2 breed groups will include cows sired by HB bulls and out of HB dams (F_2HB) and out of BH dams (HB x BH); and cows sired by BH bulls and out of HB dams (BH x HB) and out of BH dams (F_2BH).

Calves were born from approximately February 15 to May 5 each year and were tagged within 12 hours of birth whenever possible. Calves were weaned at about seven months of age in October or November. At weaning, cows and calves were weighed and assigned a body condition score using the 1 to 9 scoring system (Herd and Sprott, 1986) where 1 indicates an emaciated animal and a 9 implies one that is obese. Cows were also palpated for pregnancy at this time. Additionally, heifers were vaccinated against brucellosis. Cows in this study were culled for severe injury or after their second failure to wean a calf. Females in these analyses range from two to 15 years of age.

Traits Analyzed

Calf crop born and calf crop weaned were analyzed in this study as cow reproductive traits. Calf crop born is the proportion of calves born in relation to the number of cows exposed to bulls in the most recent breeding season. Calf crop weaned was evaluated as the proportion of cows exposed during the breeding season that weaned a calf the following year. These traits were evaluated as binary traits (0 or 1) with zero indicating failure and 1 indicating success regarding the trait of interest.

Birth weight and weaning weight of the calves out of the cows in this study were also analyzed. Birth weights of the calves were taken shortly after birth, and weaning weights were measured in the fall of the year, when the calves were approximately seven months of age. At the time of weaning, cow weights were also recorded and included in this analysis.

Statistical Analysis

The variables considered in this study were analyzed using mixed linear models using the MIXED procedures of SAS (SAS Inst., Inc., Cary, NC). In one analysis, dam age was partitioned into four categories of 2-yr, 3-yr, 4-yr and 5 and older ages. In another analysis, actual cow age was nested within year.

Heterosis for each trait expressed in the six different types of crossbred cows was estimated by linear contrasts of the crossbred adjusted mean from the average of the straightbreds. Heterosis retained in the F_2 cows was evaluated as a comparison to heterosis expressed in the F_1 for that trait. For these analyses, contrasts for reciprocal crosses were evaluated between the two F_1 groups (BH and HB) and between the four F_2 groups (F_2 BH, F_2 HB, BH x HB, and HB x BH).

Cow Reproductive Traits

Least squares means were calculated for both calf crop born and calf crop weaned, where the trait was the dependent variable. Fixed effects were cow breed, cow age group and the interaction between cow breed and cow age group in the first set of analysis. Random effects for both traits were individual cow and year. The second set of analyses included actual cow age nested within year and excluded any interactions. Cow breed, cow age, cow age nested within year, sire of calf breed, calf sex and year were fixed effects and individual cow was a random effect.

In both sets of analyses, the contrasts included were employed to gain insight into specific reciprocal differences among the F_2 females and to determine heterosis retained in an uncomplicated manner. The number of observations for cow reproductive traits within each breed is presented in Table 1.

Weight Traits

The model for mature cow weight (cows at 6 years of age) included breed group as fixed effects and cow within breed group and year as random effects. Trends in averages across cow breed groups indicated that the majority of these cows reached mature weight at age 6, and number of records at ages 7 and older was very small. One analysis included fixed effects of cow age, cow breed, and the interaction of cow age, cow breed, sire of calf breed and calf sex. Fixed effects for calf weaning weight were cow age, cow breed, the interaction of cow age, sire of calf breed, weaning age of the calf, and calf sex in these analyses. Individual cow and year of calf birth were random effects for both birth weight and weaning weight. Cow breed, cow age, cow age nested within year, sire of calf breed, calf sex and year were fixed effects in another set of analyses and individual cow was a random effect. Table 2 shows the number of observations within each breed for each weight trait. Number of cows per age are shown in Table 3.

Table 1. Number of observations for reproductive traits within each cow breed

Breed[1]	Calf crop born	Calf crop weaned
B	411	408
H	306	305
BH	298	298
HB	195	195
F_2 BH	59	59
BH x HB	60	60
F_2 HB	85	82
HB x BH	101	100
Total	1515	1507

[1] Breed groups: B = Brahman, H = Hereford, HB = F_1 Hereford-sired, BH = F_1 Brahman-sired, F_2BH = cows sired by BH bulls and out of BH dams, BH x HB = cows sired by BH bulls and out of HB dams, F_2HB = cows sired by HB bulls and out of HB dams, HB x BH= cows sired by HB bulls and out of BH dams

Table 2. Number of observations for calf and cow weight traits within each cow breed.[1, 2]

	Calf birth weight	Calf weaning weight	Cow weight
B	290	263	382
H	247	223	276
BH	262	238	286
HB	176	166	190
F_2 BH	39	35	51
BH x HB	43	40	49
F_2 HB	77	73	78
HB x BH	94	90	98
Total	1228	1128	1410

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first

Table 3. Number of cows per age.[1,2]

Breed	Age														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
B	64	62	58	54	47	42	34	25	14	6	4	1			411
H	50	47	44	38	32	28	24	17	4	8	3	1			306
BH	34	34	34	33	33	25	22	20	18	15	11	10	7	2	298
HB	21	20	18	18	17	17	16	15	13	11	9	8	7	5	195
F_2BH	14	13	11	6	4	3	3	2	1	1	1				59
BHxHB	12	12	9	8	8	6	4	1							60
F_2HB	13	12	12	11	11	10	7	5	4						85
HBxBH	13	12	13	12	11	10	8	8	8	2	2	2			101
Total	221	212	199	180	163	141	118	93	72	43	30	22	14	7	1515

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first

RESULTS AND DISCUSSION

Calf Crop Born

Numerous models were implemented in order to explain heterosis and heterosis retained in the cows of the current study, however, these attempts were inconclusive. Previous research and these preliminary analyses showed that the effects of year and cow age are real as is their interaction each other and with breed type. In each attempted model designed to remove these effects, different breed groups received excessive adjustments, rendering the resultant heterosis estimates inappropriate. To more clearly assess differences, presentation and visual evaluation of unadjusted means were conducted. Italicized numbers represent fewer than 3 observations for that particular interaction.

Calf crop born means are given in Table 4. Purebred B females had the lowest calf crop born as heifers, which was expected due to later onset of puberty that is characteristic of B cattle. These cows had a cyclical pattern of calf crop born percentages: low then high then low again until age 6 when a more steady production rate began. BH heifers also produced a small calf crop, as did several groups as 3 year olds. A common occurrence in Brahman and Brahman crossed cattle is the oscillation between getting bred and subsequently calving at 2 years of age, not getting bred at 3 and then stabilizing as four year olds (Koger et al., 1962; Riley et al., 2005). One possible explanation is that the stress of parturition and lactation on a 2- yr.- old Brahman or Brahman cross cow compounded with her own growth and maturation adversely affects reproductive ability to calve again as a three year old. Note that HB- sired F_2 heifers outperformed heifers of every other breed group by a substantial margin. Calf crop born percentages remained high for these cows across all ages. BH- sired F_2 cows were consistently among the lowest performers until age 6. By 10 years of age, only one BH- sired F_2 cow was still in the herd, and none were left after she was culled at age 12. F_1 cows recovered after a low calving percentage as heifers and were still producing at age 15.

Table 5 presents means for calf crop born by cow breed and birth year of the calf. H cows produced consistently small calf crops from the time they were introduced (1998) until 2003 when higher percentages were produced. 2008 was the last year any calves were produced by BH- sired F_2 cows, though they calved first in 1999. All other groups were still producing in 2009, the youngest of which were 13 years of age. Table 6 includes means for calf crop born by cow age and year of calving. Very low percentages were produced in 1997, and 2002 showed a decline in percentages across all ages. Inconsistencies between tables may be due to the small number of observations for certain ages/ breed groups or years.

Calf crop born by cow breed and heterosis estimates are given in Table 7. This table and subsequent equivalent tables were constructed as linear combinations of unadjusted means. The scenario presented by these data necessitated this unconventional presentation of means which were not statistically tested for difference from 0, nor were standard errors determined for them. Cows sired by HB bulls had the highest percentage of calf crop born. Those sired by BH bulls had lower calving percentages than all other breed groups including purebreds. F_1 cows expressed a 13.6% advantage over the purebred mean, using these unadjusted means. While it appears that F_2 cows only retain 39% of F_1 heterosis, it seems that the lack of heterosis in BH- sired F_2 cows is responsible for this low level of retention. Based on these estimates, HB- sired F_2 cows seem to express as much and possibly more heterosis than the F_1 cows.

Values determined in this study using unadjusted means seem to indicate slightly less heterosis was retained in F_2 cows than would be expected based on heterozygosity (39 vs. 50%); however, all of the apparent heterosis was due to HB-sired F_2 cows. Though the following comparisons between current study and previous studies where adjusted means were feasible are not ideal, basic trends and interpretations might be gleaned in making them. The retained heterosis found in this study is less than that found by Seebeck (1973) for Africander cross cows but greater than F_2 Brahman cross cows in the same study. Results from this study follow the same trend as those reported by Cartwright et al. (1964), with crossbreds having a marked advantage over purebreds with respect to calving percentage. However, differences in breed combinations did not permit exact comparisons between the current study and that by Cartwright et al. Cartwright et al. suggested the observed heterosis was largely due to the genetics of the cow, rather than of the calf. Peacock and Koger (1980) estimated heterotic effects associated with crossbred (F_1) cows to be somewhat lower than that of the current study: 8.7% for A x B crosses and 9.2% for B x C crosses ($P < 0.01$) compared to 13.6% found in these calculations for F_1 cows.

Table 4. Unadjusted means and standard deviations for calf crop born by cow breed and age at calving.[1,2,3]

	Age					
Breed	2	3	4	5	6	7
B	0.19 (0.41)	0.77 (0.48)	0.60 (0.50)	0.87 (0.34)	0.85 (0.44)	0.88 (0.31)
H	0.80 (0.42)	0.57 (0.51)	0.66 (0.54)	0.82 (0.41)	0.91 (0.38)	0.93 (0.33)
BH	0.41 (0.52)	0.82 (0.45)	1.00 (0.00)	0.90 (0.32)	0.88 (0.31)	1.00 (0.00)
HB	0.76 (0.42)	0.55 (0.52)	0.94 (0.21)	1.00 (0.00)	1.00 (0.00)	0.94 (0.24)
F_2BH	0.43 (0.57)	0.69 (0.56)	0.55 (0.52)	0.67 (0.5)	1.00 (0.00)	1.00 (0.00)
BH x HB	0.58 (0.55)	0.33 (0.57)	0.89 (0.35)	1.00 (0.00)	0.88 (0.45)	0.67 (0.54)
F_2HB	0.85 (0.45)	0.75 (0.54)	0.92 (0.37)	1.00 (0.00)	0.91 (0.39)	1.00 (0.00)
HB x BH	0.92 (0.32)	0.75 (0.53)	0.92 (0.32)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction.

Table 4 continued.

Breed	Age							
	8	9	10	11	12	13	14	15
B	0.85 (0.4	0.96 (0.2	0.86 (0.4	0.66 (0.5	1.00 (0.00)	*1.00 (0.00)*	-	-
H	0.92 (0.3	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	*1.00 (0.00)*	-	-
BH	1.00 (0.00)	1.00 (0.00)	0.94 (0.2	1.00 (0.00)	0.91 (0.3	1.00 (0.00)	1.00 (0.00)	*1.00 (0.00)*
HB	0.94 (0.3	1.00 (0.00)	0.92 (0.3	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
F_2BH	1.00 (0.00)	*1.00 (0.00)*	*1.00 (0.00)*	*1.00 (0.00)*	*1.00 (0.00)*	-	-	-
BH x HB	1.00 (0.00)	*1.00 (0.00)*	-	-	-	-	-	-
F_2HB	0.86 (0.4	1.00 (0.00)	1.00 (0.00)	-	-	-	-	-
HB x BH	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	*1.00 (0.00)*	*1.00 (0.00)*	*1.00 (0.00)*	-	-

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction.

Table 5. Unadjusted means and standard deviations for calf crop born by cow breed and calving year.[1, 2, 3]

	Year						
Breed	1996	1997	1998	1999	2000	2001	2002
B	-	-	0.45 (0.51)	0.74 (0.46)	0.59 (0.51)	0.80 (0.46)	0.37 (0.50)
H	-	-	0.56 (0.50)	0.79 (0.44)	0.79 (0.45)	0.71 (0.55)	0.56 (0.51)
BH	0.75 (0.44)	0.67 (0.54)	0.52 (0.53)	0.91 (0.38)	1.00 (0.00)	1.00 (0.00)	0.87 (0.32)
HB	0.79 (0.43)	0.50 (0.55)	0.89 (0.34)	1.00 (0.00)	1.00 (0.00)	0.94 (0.25)	0.94 (0.28)
F_2BH	-	-	-	0.4 (0.55)	0.77 (0.48)	0.42 (0.59)	0.71 (0.57)
BH x HB	-	-	-	0.5 (0.74)	0.58 (0.58)	0.36 (0.58)	0.89 (0.39)
F_2HB	-	-	0.33 (0.64)	1.00 (0.00)	0.60 (0.54)	1.00 (0.00)	0.82 (0.42)
HB x BH	-	-	0.75 (0.53)	1.00 (0.00)	0.50 (0.51)	1.00 (0.00)	1.00 (0.00)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 5 continued.

Breed	Year 2003	2004	2005	2006	2007	2008	2009
B	0.80 (0.43)	0.72 (0.51)	0.87 (0.38)	0.81 (0.47)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
H	0.85 (0.41)	1.00 (0.00)	0.88 (0.34)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
BH	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	0.93 (0.34)	0.92 (0.31)	1.00 (0.00)	1.00 (0.00)
HB	1.00 (0.00)	0.92 (0.36)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
F_2BH	0.80 (0.47)	1.00 (0.00)	1.00 (0.00)	*1.00 (0.00)*	*1.00 (0.00)*	*1.00 (0.00)*	-
BH x HB	1.00 (0.00)	0.88 (0.45)	0.67 (0.54)	-	-	-	-
F_2HB	1.00 (0.00)	1.00 (0.00)	0.78 (0.48)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
HB x BH	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 6. Unadjusted means and standard deviations for calf crop born by cow age and calving year.[1, 2, 3]

	Year						
Age	1996	1997	1998	1999	2000	2001	2002
2	0.77 (0.43)	0.15 (0.47)	0.23 (0.47)	0.71 (0.51)	0.61 (0.57)	0.71 (0.56)	0.10 (0.39)
3		0.56 (0.54)	0.85 (0.48)	0.93 (0.34)	0.60 (0.55)	0.57 (0.56)	0.63 (0.50)
4			0.97 (0.25)	0.69 (0.58)	0.93 (0.37)	0.81 (0.44)	0.43 (0.51)
5				0.91 (0.31)	0.83 (0.40)	0.97 (0.21)	0.66 (0.57)
6					1.00 (0.00)	0.82 (0.48)	0.79 (0.48)
7						0.97 (0.18)	0.9 (0.37)
8							0.96 (0.26)
9							
10							
11							
12							
13							
14							
15							

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 6 continued.

	Year						
Age	2003	2004	2005	2006	2007	2008	2009
2	*0.50 (0.75)*	-	-	-	-	-	-
3	0.78 (0.46)	*0.50 (0.75)*	1.00 (0.00)	-	-	-	-
4	0.78 (0.46)	0.75 (0.51)	*0.50 (0.71)*	0.67 (0.62)	-	-	-
5	0.94 (0.25)	1.00 (0.00)	1.00 (0.00)	*1.00 (0.00)*	1.00 (0.00)	-	-
6	0.88 (0.31)	0.93 (0.30)	0.89 (0.31)	1.00 (0.00)	*1.00 (0.00)*	*1.00 (0.00)*	-
7	0.96 (0.24)	0.84 (0.41)	0.88 (0.37)	0.94 (0.27)	1.00 (0.00)	*1.00 (0.00)*	1.00 (0.00)
8	0.80 (0.47)	0.95 (0.23)	0.75 (0.45)	0.95 (0.28)	1.00 (0.00)	1.00 (0.00)	*1.00 (0.00)*
9	1.00 (0.00)	0.88 (0.46)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
10		0.96 (0.24)	0.72 (0.57)	0.93 (0.39)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
11			1.00 (0.00)	0.33 (0.61	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
12				0	0	1.00 (0.00)	1.00 (0.00)
13					1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
14						1.00 (0.00)	1.00 (0.00)
15							1.00 (0.00)

[1]H= Hereford, B= Brahman

[2]Crossbred animals are referenced with the sire breed listed first

[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 7. Calf crop born means and standard deviations by cow breed and associated heterosis estimates.[1, 2]

Breed	Mean (SD)	Heterosis	Heterosis
B	71.2 (45.3)		
H	80.7 (39.5)		
BH	88.3 (32.2)		
HB	90.8 ±29.0)	13.6%	
F_2BH	67.8 (47.1)		
BH x HB	71.7 (45.4)		-6.2%
F_2HB	90.6 (29.3)	5.3%	
HB x BH	95.0 (21.9)		16.85%

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first

Calf Crop Weaned

As with calf crop born, cow breed, cow age, and year and the interaction between them had highly significant effects on calf crop weaned in the models that were attempted. As a result of small numbers of observations, each attempted model adjusted one or more breed group severely, and no single model adequately explained these data. Unadjusted means are presented here for visual evaluation of differences between breeds, ages and years.

Table 8 presents calf crop weaned means by cow breed and cow age at weaning. Calf crop weaned is directly influenced by calf crop born, and many trends are similar in both traits. Brahman heifers weaned the lowest percentage of calves, again due to their failure to conceive because of later maturity. As with calving percentages, BH heifers and F_2BH heifers had extremely low weaning percentages. F_2BH heifers, though they did not have many calves to begin with, only weaned 65% of those they did have. In a previous study, survival to weaning for third generation (out of F_2BH cows) BH calves was found to be 91.9% (Sacco et al., 1991). Survival to weaning percentages tend to be higher than calf crop weaned percentages because it is based on percent of calves born that survive until weaning, not percentage of calves weaned per cow exposed.

Heifers sired by HB bulls had extremely high calf crop weaned percentages and weaned about 98% of the calves born to them. As 6 year olds, BH cows weaned a surprisingly low percentage of calves (48% compared to 88% calf crop born). BH- sired F_2 cows weaned consistently lower percentages of calves than did HB-sired F_2 cows. HB- sired F_2 cows weaned the highest percentage of calves at most ages.

Table 9 contains means for calf crop weaned by cow breed and year at weaning. F_1 cows weaned consistently high percentages of calves after 1998, with the exception of BH performing at a decreased level in 2002 and HB weaning a reduced percentage of calves in 2004. BH-sired F_2 cows weaned very low percentages of calves until 2002, when they performed well. In 2003 F_2BH cows weaned very few calves. The following years showed improvement, however, very few cows remained in these breed groups past 2006. With the exception of 1998 (the first year for their oldest group) and 2000, HB- sired F_2 cows weaned high percentages of calves for the duration of the study. Calf crop weaned means and standard deviations by cow age and weaning year are presented in Table 10. As expected, heifers weaned the lowest percentage of calves across all years, with only 7% in 1997 (almost all of the two year old heifers in 1997 were Brahman; the Brahman heifers may not have been exposed.) Several breed groups had 100% calf crop weaned.

Table 11 presents calf crop weaned means by breed and heterosis estimates for F_1 and F_2 cows. As in Table 7, these unadjusted means were not tested for statistical difference from 0, nor were standard errors determined for these means. F_2BH cows weaned the smallest percentage of calves across all breeds. HB x BH cows weaned the largest percentage of calves. Heterosis estimates were determined as linear combinations of unadjusted means. Based on the calculations done from these simple means, it appears that as a group, F_2 crossbred Brahman x Hereford cows retain 50% of F_1 heterosis. However, performance seems to be affected by sire breed of the F_2 cows. Using these simple means, BH-sired F_2 calves express no advantage for calf crop weaned over the purebred average. Conversely, it appears from these data that HB-sired F_2 cows may express a larger advantage over the purebred mean than F_1 cows.

In Florida, the adjusted crossbred (F_1, including the reciprocal Charolais-Angus F_1 cows) mean among Brahman, Angus and Charolais was 72.7 ± 1.8 (Peacock et al. 1977) compared to the current study's F_1 unadjusted mean of 82.8% calf crop born. Peacock (1980) reported weaning rate percentages of 87 ± 2.7 and 84 ± 2.9 for Angus/ Brahman crosses and Charolais x Brahman crosses (these numbers include the reciprocal crosses). These numbers are slightly higher than what was found in the current study. Sanders et al. (2005) also reported higher weaning rate percentages for Grey and Red Brahman sires of 83.3 and 86.0, respectively. As a group, F_2 cows retained approximately 50% of the heterosis expressed in the F_1 generation, precisely what would be expected based on heterozygosity. This is lower than the 94% retained heterosis in F_2 Brahman x Hereford cross females reported by Key (2004), at an earlier stage of the current study; however, Key also noted large reciprocal differences in the F_2 breed combinations. Cartwright et al. (1964) also reported large heterotic effects (approximately 12%) for calf crop weaned by BH females but did not report on subsequent generations.

Table 8. Unadjusted means and standard deviations for calf crop weaned by cow breed and cow age at weaning.[1, 2, 3]

	Age					
Breed	2	3	4	5	6	7
B	0.14 (0.47)	0.68 (0.50)	0.5 (0.51)	0.81 (0.48)	0.79 (0.46)	0.88 (0.30)
H	0.7 (0.54)	0.51 (0.51)	0.61 (0.55)	0.79 (0.44)	0.88 (0.32)	0.86 (0.49)
BH	0.35 (0.59)	0.79 (0.46)	0.94 (0.24)	0.85 (0.40)	0.49 (0.41)	0.88 (0.37)
HB	0.71 (0.56)	0.5 (0.58)	0.94 (0.21)	1.00 (0.00)	1.00 (0.00)	0.82 (0.42)
F_2BH	0.28 (0.54)	0.62 (0.50)	0.55 (0.57)	0.5 (0.51)	0.75 (0.50)	1.00 (0.00)
BH x HB	0.58 (0.51)	0.25 (0.58)	0.89 (0.31)	1.00 (0.00)	0.75 (0.54)	0.67 (0.54)
F_2HB	0.83 (0.43)	0.67 (0.54)	0.92 (0.36)	1.00 (0.00)	0.90 (0.39)	1.00 (0.00)
HB x BH	0.91 (0.37)	0.75 (0.50)	0.77 (0.47)	1.00 (0.00)	1.00 (0.00)	0.80 (0.48)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 8 continued.

Breed	Age							
	8	9	10	11	12	13	14	15
B	0.79 (0.46)	0.84 (0.42)	0.86 (0.41)	0.67 (0.54)	0.75 (0.58)	*1.00 (0.00)*	-	-
H	0.75 (0.45)	1.00 (0.00)	0.77 (0.48)	1.00 (0.00)	1.00 (0.00)	*1.00 (0.00)*	-	-
BH	0.82 (0.41)	1.00 (0.00)	0.89 (0.31)	0.87 (0.40)	0.91 (0.34)	0.80 (0.47)	0.86 (0.42)	*1.00 (0.00)*
HB	0.94 (0.34)	0.87 (0.40)	0.69 (0.54)	0.91 (0.31)	1.00 (0.00)	0.88 (0.44)	1.00 (0.00)	1.00 (0.00)
F_2BH	1.00 (0.00)	1.00 (0.00)	*1.00 (0.00)*	*1.00 (0.00)*	*1.00 (0.00)*	-	-	-
BH x HB	0.75 (0.54)	*1.00 (0.00)*	-	-	-	-	-	-
F_2HB	0.86 (0.47)	0.80 (0.41)	1.00 (0.00)	-	-	-	-	-
HB x BH	0.88 (0.46)	1.00 (0.00)	1.00 (0.00)	*1.00 (0.00)*	*1.00 (0.00)*	*1.00 (0.00)*	-	-

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 9. Unadjusted means and standard deviations for calf crop weaned by cow breed and weaning year.[1, 2, 3]

	Year						
Breed	1996	1997	1998	1999	2000	2001	2002
B	-	-	0.40 (0.51)	0.48 (0.50)	0.47 (0.50)	0.76 (0.48)	0.37 (0.54)
H	-	-	0.56 (0.54)	0.67 (0.51)	0.73 (0.52)	0.65 (0.55)	0.53 (0.55)
BH	0.69 (0.58)	0.56 (0.54)	0.53 (0.57)	0.91 (0.30)	0.91 (0.34)	0.91 (0.36)	0.68 (0.51)
HB	0.74 (0.54)	0.50 (0.57)	0.90 (0.34)	0.95 (0.33	1.00 (0.00)	0.88 (0.33)	0.94 (0.29)
F_2BH	-	-	-	0.20 (0.44)	0.69 (0.50)	0.42 (0.52)	0.71 (0.54)
BH x HB	-	-	-	*0.5 (0.71)*	0.50 (0.53)	0.36 (0.58)	0.89 (0.32)
F_2HB	-	-	0.33 (0.64)	1.00 (0.00)	0.60 (0.54)	1.00 (0.00)	0.73 (0.52)
HB x BH	-	-	0.75 (0.51)	1.00 (0.00)	0.50 (0.51)	1.00 (0.00)	1.00 (0.00)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 9 continued.

Breed	Year						
	2003	2004	2005	2006	2007	2008	2009
B	0.76 (0.45)	0.48 (0.56)	0.86 (0.40)	0.88 (0.39)	1.00 (0.00)	0.95 (0.28)	1.00 (0.00)
H	0.76 (0.44)	0.96 (0.27)	0.80 (0.43)	0.89 (0.38)	1.00 (0.00)	0.75 (0.54)	1.00 (0.00)
BH	0.91 (0.31)	0.95 (0.28)	0.95 (0.22)	0.93 (0.34)	0.69 (0.50)	0.89 (0.37)	1.00 (0.00)
HB	0.81 (0.40)	0.69 (0.84)	0.91 (0.38)	1.00 (0.00)	0.88 (0.41)	1.00 (0.00)	1.00 (0.00)
F_2BH	0.40 (0.52)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	*1.00 (0.00)*	*1.00 (0.00)*	*1.00 (0.00)*
BH x HB	1.00 (0.00)	0.75 (0.52)	0.50 (0.51)	1.00 (0.00)	1.00 (0.00)	0	*1.00 (0.00)*
F_2HB	1.00 (0.00)	1.00 (0.00)	0.66 (0.50)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
HB x BH	0.83 (0.44)	0.80 (0.41)	1.00 (0.00)	1.00 (0.00)	0.83 (0.44)	1.00 (0.00)	1.00 (0.00)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 10. Unadjusted means and standard deviations for calf crop weaned by cow age and weaning year.[1, 2, 3]

	Year						
Age	1996	1997	1998	1999	2000	2001	2002
2	0.71 (0.56)	0.07 (0.38)	0.23 (0.41)	0.54 (0.54)	0.59 (0.51)	0.63 (0.52)	0.10 (0.36)
3		0.52 (0.54)	0.76 (0.44)	0.81 (0.44)	0.48 (0.54)	0.57 (0.57)	0.58 (0.54)
4			0.97 (0.29)	0.62 (0.50)	0.81 (0.48)	0.78 (0.43)	0.40 (0.52)
5				0.91 (0.30)	0.82 (0.47)	0.89 (0.34)	0.66 (0.50)
6					0.97 (0.29)	0.73 (0.51)	0.74 (0.44)
7						0.91 (0.32)	0.90 (0.38)
8							0.83 (0.41)
9							
10							
11							
12							
13							
14							

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 10 continued.

Age	Year						
	2003	2004	2005	2006	2007	2008	2009
2	*0.5 (0.74)*	0	-	-	-	-	-
3	0.78 (0.53)	*0.5 (0.79)*	0.75 (0.51)	-	-	-	-
4	0.65 (0.58)	0.63 (0.51)	*0.50 (0.74)*	0.66 (0.67)	-	-	-
5	0.88 (0.37)	0.89 (0.30)	1.00 (0.00)	*1.00 (0.00)*	1.00 (0.00)	-	-
6	0.84 (0.42)	0.80 (0.48)	0.89 (0.36)	1.00 (0.00)	*1.00 (0.00)*	1.00 (0.00)	1.00 (0.00)
7	0.78 (0.43)	0.68 (0.54)	0.88 (0.35)	1.00 (0.00)	1.00 (0.00)	*1.00 (0.00)*	1.00 (0.00)
8	0.70 (0.57)	0.84 (0.46)	0.6 (0.50)	0.89 (0.34)	0.92 (0.34)	1.00 (0.00)	*1.00 (0.00)*
9	0.92 (0.31)	0.50 (0.57)	0.94 (0.25)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
10		0.79 (0.46)	0.71 (0.43)	0.93 ±0.36)	1.00 (0.00)	0.67 (0.50)	1.00 (0.00)
11			0.90 (0.31)	0.33 (0.33)	0.88 (0.41)	1.00 (0.00)	1.00 (0.00)
12				1.00 (0.00)	*1.00 (0.00)*	0.83 (0.49)	1.00 (0.00)
13					0.82 (0.40)	*1.00 (0.00)*	*1.00 (0.00)*
14						*1.00 (0.00)*	*1.00 (0.00)*
15							*1.00 (0.00)*

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 11. Calf crop weaned means and standard deviations by cow breed and associated heterosis estimates.[1, 2,]

Breed	Mean (SD)	Heterosis	Heterosis
B	69.1 (47.9)		
H	73.8 (44.0)		
BH	80.5 (39.7)	13.7%	
HB	85.1 (35.7)		
F_2BH	59.3 (49.5)		-6.1%
BH x HB	66.7 (47.5)	6.8%	
F_2HB	87.8 (32.9)		19.8%
HB x BH	90.0 (30.2)		

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first

Calf Birth Weight

Preliminary analyses of calf birth weight showed interactions between calf sex, breed composition of the dam, and sire breed of the calf to be important. Additionally, analyses of cow age and breed, the interaction of cow age and cow breed, sire of calf breed and calf sex were conducted. Another model was attempted, in which cow breed, her age, cow breed nested within year, sire of calf breed, sex and year were included as fixed effects in the final model. Results of these models and other attempted models resulted in excessive adjustments. Sire breed of the calf is partially confounded with year, as is dam breed. It was determined that no single model adequately explained these data. Unadjusted means and standard deviations are presented for visual assessment and comparison.

Table 12 presents means for calf birth weight by cow breed and age at calving. H and BH x HB cows had the lightest calves as heifers. The heaviest calves born to heifers were out of F_2HB females. Calves born to BH x HB cows as heifers were among the lightest, however each subsequent year an average of 2.4 kg was added to their calves' birth weight until age 7. Calves born to H cows follow a similar trend; during lifetime production, a difference of 11.7 kg was seen in birth weights between calves born to H heifers and those born to 9 year old H cows. In contrast, calves born to F_2HB cows increased less than 6 kg over a lifetime of production. Lower increases in calf birth weight over time in HB-sired cows may be because 75% of HB-sired F_2 cows' genetic material on the X chromosome is of Brahman origin, and calf weight suppression is characteristic of Brahman females (Riley et al., 2007). Other breeds had increases in calf birth weight that fell somewhere between that of HB x BH and F_2HB cows.

Calf birth weight means by cow breed and calving year are presented in Table 13. The lightest calves across all breeds and ages were born to H cows in 1998 (when the only H females were two year olds). The heaviest calves were born in 2002 to F_2BH cows. Across all years, BH cows had heavier calves than HB calves, although some years the difference is negligible. Also, BH- sired females produced consistently heavier calves, on average, than did their HB- sired counterparts. Table 14 presents calf birth weight means by cow age and year. The lightest calves were born to 2 year old heifers in 2002 and the heaviest to 9 year old cows in 2007. Cows that were 2 years of age in 1998 had some of the most consistently high birth weights until they were 11 in 2008. Cows that were 2 years of age in 2001 had consistently low birth weights until the last two years of the project.

Calf birth weight means by sire breed, dam breed and sex are presented in Table 15. Only H cows were bred to Wagyu bulls, and only during the first years of the study. The large reciprocal sex differences expected to occur between B-sired and H-sired F_1 calves are not clear from these data. This is probably because of sampling error associated with small groups of cows. In general, bull calves were no more than 7 kg heavier than females of the same mating. Some exceptions where the female calves were heavier existed in HB sires on HB dams and in Wagyu sires on H dams.

Table 16 presents calf birth weight means by cow breed. The lightest calves were born to HB x BH cows, and the heaviest calves were out of F_2BH cows. A large reciprocal difference was seen between the F_1 groups, with B sired females having heavier calves than H sired females. In the F_2 groups, BH - sired cows had heavier calves at birth than did HB – sired cows. In the current study as in the one reported on by Roberson et al. (1986), calves born to H dams were, on average, heavier than those born to Brahman dams.

Table 12. Unadjusted means and standard deviations for calf birth weight by cow breed and age.[1, 2, 3]

Breed	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
B	31.64 (4.53)	32.69 (4.32)	34.50 (3.51)	33.79 (4.50)	34.97 (5.08)	34.44 (5.59)
H	28.59 (5.74)	32.99 (4.39)	34.73 (4.06)	37.60 (4.85)	39.10 (4.94)	38.72 (4.55)
BH	30.06 (3.61)	35.29 (3.91)	36.03 (5.11)	37.5 (3.33)	36.96 (4.70)	39.09 (4.44)
HB	29.57 (4.82)	33.22 (4.44)	35.03 (5.86)	36.81 (2.58)	34.49 (4.45)	38.52 (7.72)
F_2BH	35.00 (2.30)	34.09 (2.47)	38.5 (6.73)	37.72 (3.16)	39.32 (12.22)	37.88 (2.94)
BH x HB	28.96 (6.88)	33.41 (4.84)	37.61 (3.54)	37.73 (5.92)	38.96 (7.54)	40.22 (5.33)
F_2HB	31.73 (1.90)	34.95 (5.73)	35.3 (3.77)	35.62 (4.47)	35.27 (5.72)	36.09 (3.68)
HB x BH	30.29 (3.67)	31.61 (5.60)	32.1 (6.41)	34.39 (3.70)	36.53 (2.57)	36.45 (4.26)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 12 continued.

Breed	Age							
	8	9	10	11	12	13	14	15
B	34.11 (4.92)	33.48 (4.76)	33.11 (4.32)	35.23 (5.22)	32.16 (1.64)	*35.00 (0.00)*	-	-
H	36.81 (5.15)	40.29 (4.92)	33.89 (4.64)	36.71 (7.41)	32.12 (5.54)	*38.18 (0.00)*	-	-
BH	36.42 (7.39)	39.81 (6.94)	39.24 (9.18)	36.06 (4.40)	38.82 (5.48)	35.65 (6.62)	29.96 (5.01)	*25.91 (4.52)*
HB	35.51 (7.34)	33.63 (6.29)	35.30 (5.92)	37.56 (6.19)	35.05 (4.13)	36.25 (4.01)	30.90 (5.35)	29.45 (2.71)
F_2BH	36.36 (3.21)	37.27 (5.10)	*39.09 (0.00)*	*40.91 (0.00)*	*27.27 (0.00)*	-	-	-
BH x HB	39.09 (3.90)	*30.00 (0.00)*	-	-	-	-	-	-
F_2HB	37.27 (3.57)	31.09 (7.55)	29.32 (2.85)	-	-	-	-	-
HB x BH	36.49 (2.86)	33.40 (3.51)	35.11 (2.97)	*36.82 (7.12)*	*35.23 (1.67)*	*26.82 (1.92)*	-	-

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 13. Unadjusted means and standard deviations for calf birth weight by cow breed and year.[1, 2, 3]

Breed	Year 1996	1997	1998	1999	2000	2001	2002
B	-	-	30.61 (5.35)	36.42 (2.70)	34.29 (4.75)	33.23 (3.74)	35.17 (6.21)
H	-	-	26.91 (4.74)	34.35 (2.81)	28.95 (6.71)	33.32 (2.78)	35.79 (5.38)
BH	30.23 (3.94)	33.64 (4.72)	35.80 (6.52)	37.18 (2.45)	35.76 (3.28)	37.44 (3.82)	36.41± 6.83)
HB	29.99 (4.71)	31.72 (3.13)	34.3 (6.49)	37.03 (2.67)	34.65 (4.49)	37.21 (5.23)	36.1 (7.03)
F_2BH	-	-	-	34.09 (2.29)	34.44 (2.52)	35.81 (3.98)	41.09 (5.15)
BH x HB	-	-	-	*38.18 (0.00)*	27.40 (5.55)	37.7 (4.54)	37.04 (2.84)
F_2HB	-	-	*33.64 (0.00)*	33.99 (3.91)	33.93 (2.64)	33.10 (2.66)	33.03 (6.44)
HB x BH	-	-	30.6 (1.11)	32.67 (3.24)	32.95 (5.45)	33.79 (4.40)	31.8 (5.71)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 13 continued.

Breed	Year						
	2003	2004	2005	2006	2007	2008	2009
B	33.78 (5.37)	31.62 (3.87)	33.98 (4.94)	34.50 (3.85)	34.67 (4.15)	33.86 (4.57)	34.54 (4.74)
H	39.59 (4.83)	39.49 (4.84)	37.33 (4.21)	36.74 (3.94)	42.37 (5.26)	33.35 (4.72)	33.97 (5.21)
BH	38.05 (4.90)	38.08 (6.36)	39.76 (7.55)	38.78 (9.24)	37.60 (5.65)	31.21 (7.94)	29.09 (4.58)
HB	35.28 (8.91)	35.30 (5.62)	37.56 (6.11)	35.05 (4.18)	36.25 (4.06)	30.9 (5.43)	29.45 (2.79)
F_2BH	36.82 (12.05)	39.09 (4.50)	36.66 (3.76)	37.88 (3.79)	*39.09 (0.00)*	*40.91 (0.00)*	*27.27 (0.00)*
BH x HB	37.5 (5.92)	39.61 (7.93)	40.91 (4.94)	37.57 (2.93)	-	-	*30.00 (0.00)*
F_2HB	36.28 (3.81)	36.66 (3.41)	34.02 (8.20)	35.58 (4.22)	36.36 (4.18)	33.64 (5.71)	31.45 (5.64)
HB x BH	33.33 (6.94)	36.54 (4.35)	34.77 (3.19)	36.50 (2.14)	37.45 (3.74)	33.33 (3.80)	31.49 (3.90)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 14. Unadjusted means and standard deviations for calf birth weight by cow age and year.[1, 2, 3]

Age	Year						
	1996	1997	1998	1999	2000	2001	2002
2	30.1 (4.39)	*29.09 (1.31)*	28.36 (4.36)	33.22 (2.68)	26.09 (5.54)	31.96 (3.91)	*22.73 (0.00)*
3		33.21 (4.22)	30.25 (4.85)	36.51 (2.83)	32.37 (4.52)	32.91 (2.97)	31.76 (6.65)
4			35.82 (6.10)	37.27 (2.28)	35.35 (3.55)	34.32 (3.86)	37.27 (5.46)
5				37.15 (2.59)	34.54 (5.38)	35.79 (3.52)	34.72 (5.20)
6					35.42 (3.87)	34.14 (3.30)	36.73 (5.47)
7						37.63 (4.41)	40.3 (3.81)
8							34.81 (6.93)
9							
10							
11							
12							
13							
14							
15							

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 14 continued.

	Year						
Age	2003	2004	2005	2006	2007	2008	2009
2	*31.82 (0.00)*	-	-	-	-	-	-
3	32.34 (2.34)	*36.36 (0.00)*	32.27 (3.42)	-	-	-	-
4	32.48 (5.61)	33.18 (4.01)	*32.73 (0.00)*	34.54 (1.31)	-	-	-
5	38.15 (4.79)	33.73 (5.35)	35.34 (4.83)	*38.18 (0.00)*	34.85 (2.94)	-	-
6	38.06 (6.32)	38.18 (6.02)	34.26 (5.58)	36.59 (4.55)	*41.82 (0.00)*	38.49 (5.82)	-
7	38.14 (7.91)	36.53 (5.51)	37.99 (4.10)	35.00 (3.56)	34.66 (5.11)	28.18 (0.00)	35.15 (5.03)
8	34.92 (7.08)	38.08 (6.18)	35.45 (6.41)	37.32 (3.70)	34.77 (3.48)	34.66 (3.15)	*32.28 (3.84)*
9	34.76 (5.56)	31.81 (2.49)	38.23 (8.78)	35.00 (3.98)	42.08 (4.66)	32.42 (4.41)	36.25 (5.43)
10		36.09 (5.77)	38.36 (2.82)	38.12 (9.89)	35.76 (4.45)	32.91 (5.18)	30.91 (3.14)
11			36.34 (5.63)	*35.45 (0.00)*	40.34± 5.10)	34.4 (4.89)	35.09 (5.42)
12				35.51 (3.71)	-	36.82 (6.64)	30.30 (2.60)
13					36.55 (5.40)	*30.91 (0.00)*	31.73 (5.18)
14						29.72 (5.22)	*32.73 (0.00)*
15							28.44 (3.47)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 15. Unadjusted means and standard deviations for calf birth weight by sire breed, dam breed and sex.

	Sire Breed							
	Angus		B		H		BH	
Sex	F	M	F	M	F	M	F	M
Dam Breed								
B	33.85 (4.93)	34.09 (4.15)	31.86 (4.44)	34.90 (4.23)	34.47 (5.12)	33.31 (4.75)		
H	33.39 (6.80)	36.72 (6.12)	39.09 (4.41)	39.99 (4.78)	34.72 (4.82)	37.49 (5.12)		
BH	28.52 (4.31)	35.75 (7.61)					31.90 (3.42)	36.7 (6.41)
HB	28.99 (3.95)	34.24 (3.48)					33.86 (5.93)	33.22 (5.23)
F_2BH	34.09 (9.61)							
BH x HB	*30.00 (0.00)*							
F_2HB	*33.46 (4.27)*	30.39 (2.84)						*33.64 (0.00)*
HB x BH	32.59 (4.71)	31.14 (4.03)					*30.00 (0.00)*	30.91 (1.31)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 15 continued.

	Sire Breed							
	HB		Nellore/ Angus		¾ Angus 1/4 Nellore		Wagyu	
Sex	F	M	F	M	F	M	F	M
Dam Breed								
B								
H							*29.09 (5.17)*	25.45 (4.74)
BH	31.45 (4.76)	36.2 (4.31)	37.04 (5.58)	37.75 (5.82)				
HB	35.2 (4.42)	32.50 (5.14)	35.61 (5.80)	36.02 (6.11)				
F_2BH			34.94 (3.72)	37.88 (5.96)	*36.82 (0.64)*			
BHxHB			36.18 (4.71)	40.06 (5.41)	23.19 (0.62)	29.55 (6.43)		
F_2HB			35.12 (5.48)	35.14 (4.18)				
HBxBH			34.59 (4.44)	34.38 (5.14)				

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 16. Calf birth weight means and standard deviations by cow breed.[1, 2]

Breed	Mean (SD
B	33.9 (4.64)
H	35.4 (6.11)
BH	36.5 (5.95)
HB	34.7 (5.82)
F_2BH	36.6 (5.37)
BH x HB	36.3 (6.50)
F_2HB	34.5 (4.71)
HB x BH	33.9 (4.74)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first

Calf Weaning Weight

The same models were attempted to describe calf weaning weight as were tried for calf birth weight. Similarly, none adequately explained the many facets of multi- generational crossbred *Bos indicus x Bos taurus* cattle produced over 14 years, as evidenced by severe adjustments to some breed group means. Unadjusted means are presented for assessment of differences between breed types, ages and years.

Table 17 shows calf weaning weight means by cow breed and cow age at weaning. Hereford cows, as heifers, weaned the lightest calves across all ages and breeds. As five year olds, H cows weaned notably heavier calves than in the previous three years (in which they weaned the lightest calves across all breeds); this is probably due to the breed of sire used (*Bos indicus*) interaction. Wagyu (*Bos taurus*) sires were used on Hereford heifers in 1997 (for the 1998 calves). Calves born to BH x HB two year old cows were the next lightest, but, as 3 year olds, these cows weaned the second heaviest calves of all 3 year olds. The heaviest calves were weaned by BH cows at 14 years of age. Only 8 kg lighter, F_2HB cows also weaned heavy calves at 9 years of age. The largest increase in weaning weight over time was found in F_2HB cows.

Calf weaning weight means for cow breed-year interaction are presented in Table 18. Hereford cows weaned the lightest calves across ages and breeds as heifers. BH cows weaned the heaviest calves across all years and breeds in 2008 at 297.13 (41.92) kg. There are very few (6) years in which more than two records for F_2BH cows existed. Table 19 presents calf weaning weight means by cow age and year. In general, the very low weights for calves born to 2 year old heifers reflect only 1 or 2 records. Five year old cows in 2001 weaned a very light set of calves, however, the following year their calves were in the middle of the range of weights.

Cows that were 8 years of age in 2002 weaned the heaviest calves across all ages and years. This same group of cows posted the heaviest weights for all ages in year 2008 as 14 year olds.

Calf weaning weight means are shown by sire breed, dam breed and sex in Table 20. In general, males tended to be heavier than females of the same breed composition. One exception of note was in males born to H females by B bulls. They were approximately 35 kg lighter at weaning than their female counterparts; both groups were small and had large standard deviations. Males sired by Nellore/Angus bulls were at least 11 kg heavier than the females of the same breeding and as much as 28 kg heavier.

Table 21 presents calf weaning weight means by cow breed. Hereford cows weaned the lightest calves on average, and BH cows the heaviest, with a difference of approximately 47 kg between them. The reciprocal difference among F_1 cows appeared to be present in weaning weight as it was in birth weight analyses. These results appear similar to those found by Peacock et al. (1978); however that study presented adjusted means. For F_2 groups, the reciprocal differences were present, but the direction was opposite of that found in calf birth weight. Calves weaned by HB-sired F_2 cows seem to weigh more than those out of BH-sired cows, when considered within type of maternal grand dam.

Table 17. Unadjusted means and standard deviations for calf weaning weight by cow breed and age.[1, 2, 3]

Breed	Age					
	2	3	4	5	6	7
B	181.67 (33.52)	207.41 (32.76)	206.61 (31.20)	223.06 (34.44)	234.70 (36.41)	242.54 (38.65)
H	145.37 (19.51)	147.63 (18.97)	176.10 (27.15)	207.62 (27.38)	222.20 (25.20)	215.85 (20.16)
BH	184.58 (31.15)	227.85 (30.82)	227.26 (22.16)	245.93 (17.63)	246.50 (24.54)	246.86 (22.83)
HB	187.80 (18.14)	195.00 (0.29)	230.71 (20.56)	236.72 (16.50)	236.23 (32.22)	246.43 (23.10)
F_2BH	185.23 (27.98)	201.9 (20.92)	218.71 (28.97)	248.03 (27.46)	218.33 (40.23)	159.24 (29.11)
BH x HB	169.93 (30.86)	212.12 (25.03)	229.71 (33.74)	244.77 (29.96)	232.50 (31.95)	246.14 (32.17)
F_2HB	207.10 (21.58)	209.10 (29.24)	234.63 (27.54)	231.07 (23.19)	233.74 (15.02)	225.75 (14.95)
HB x BH	185.21 (18.11)	195.91 (33.15)	212.54 (25.70)	212.54 (18.22)	246.19 (19.96)	223.98 (23.10)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 17 continued.

Breed	Age							
	8	9	10	11	12	13	14	15
B	236.31 (33.56)	232.97 (27.94)	222.19 (37.54)	254.78 (12.32)	226.21 (21.84)	*194.55 (0.00)*	-	-
H	225.03 (25.68)	227.91 (22.27)	223.86 (16.52)	206.19 (37.28)	179.70 (33.60)	*164.09 (0.00)*	240.86 (43.21)	238.4 (22.54)
BH	252.50 (32.16)	250.35 (29.99)	234.88 (35.97)	260.54 (31.98)	258.80 (32.63)	248.50 (24.32)	292.00 (39.96)	*213.5 (30.41)*
HB	267.27 (31.14)	264.6 (26.22)	210.60 (30.47)	233.50 (46.66)	242.56 (16.78)	263.29 (38.91)	-	-
F_2BH	215.61 (21.65)	220.05 (15.53)	*221.82 (0.00)*	*245.45 (0.00)*	*195.45 (0.00)*	-	-	-
BHxHB	236.67 (5.58)	*229.09 (0.00)*	-	-	-	-	-	-
F_2HB	253.26 (17.42)	280.34 (10.72)	234.66 (11.36)	-	-	-	-	-
HBxBH	234.55 (37.55)	237.04 (28.53)	235.91 (18.41)	224.32 (20.89)	231.37 (4.55)	207.96 (28.60)	-	-

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 18. Unadjusted means and standard deviations for calf weaning weight by cow breed and year.[1, 2, 3]

	1996	1997	1998	1999	2000	2001	2002
B	-	-	196.70 (31.35)	203.07 (31.72)	189.17 (17.41)	207.08 (32.02)	235.79 (40.01)
H	-	-	143.81 (10.86)	150.45 (18.43)	150.56 (26.11)	155.88 (21.44)	212.21 (26.01)
BH	190.00 (26.01)	201.00 (33.72)	226.77 (24.74)	238.90 (21.41)	230.48 (22.75)	244.00 (17.91)	266.47 (24.25)
HB	187.14 (18.62)	191.88 (41.74)	228.41 (21.90)	234.72 (15.82)	233.94 (30.63)	247.00 (22.54)	267.75 (30.19)
F_2BH	-	-	-	*209.09 (5.14)*	191.56 (25.78)	208.82 (24.09)	245.18 (21.48)
BHxHB	-	-	-	*167.27 (0.00)*	170.37 (33.61)	227.27 (36.52)	232.27 (37.91)
F_2HB	-	-	*189.09 (0.00)*	197.45 (38.35)	198.18 (9.68)	214.67 (17.13)	226.76 (12.60)
HBxBH	-	-	178.00 (10.62)	195.12 (20.57)	193.29 (31.24)	202.65 (23.50)	217.31 (37.07)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 18 continued.

Breed	Year						
	2003	2004	2005	2006	2007	2008	2009
B	230.08 (36.64)	207.62 (30.61)	231.93 (36.5	252.70 (34.73)	243.74 (26.85)	239.25 (30.57)	222.81 (24.74)
H	214.65 (19.47)	230.23 (25.35)	208.34 (19.12)	225.56 (18.91)	241.52 (19.71)	212.07 (13.64)	182.67 (28.38)
BH	253.94 (21.71)	229.00 (34.34)	256.55 (28.4)	244.92 (26.84)	263.22 (34.32)	297.13 (41.92)	225.75 (32.72)
HB	264.61 (26.25)	210.55 (30.45)	233.50 (46.61)	242.55 (16.79)	263.28 (38.95)	240.86 (43.12)	238.4 (22.53)
F$_2$BH	*195.22 (5.43)*	187.57 (70.52)	197.12 (20.41)	225.03 (13.45)	*221.82 (0.00)*	*245.45 (0.00)*	*195.45 (0.00)*
BHxHB	241.18 (24.55)	234.62 (34.73)	235.76 (29.96)	236.67 (5.52)	-	-	*229.09 (0.00)*
F$_2$HB	246.81 (18.01)	230.70 (26.21)	234.09 (15.20)	226.97 (15.71)	252.38 (22.26)	280.34 (10.83)	238.27 (12.78)
HBxBH	235.82 (24.56)	212.10 (25.55)	230.4 (26.73)	236.56 (15.95)	247.09 (28.23)	240.07 (28.81)	224.35 (19.23)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 19. Unadjusted means and standard deviations for calf weaning weight by cow age and year.[1, 2, 3]

	Year						
Age	1996	1997	1998	1999	2000	2001	2002
2	188.40 (21.74)	*125.00 (0.00)*	164.06 (23.82)	172.10 (30.32)	148.89 (25.33)	190.24 (30.18)	*218.64 (0.00)*
3		200.67 (33.52)	196.86 (33.61)	214.05 (41.25)	179.83 (26.45)	179.36 (43.19)	208.18 (37.81)
4			230.41 (19.66)	206.73 (30.78)	201.03 (33.92)	195.15 (36.91)	218.92 (25.69)
5				236.47 (16.29)	202.73 (17.81)	124.51 (35.43)	226.56(29.58)
6					234.32 (25.47)	210.75 (25.72)	246.26 (29.82)
7						240.63 (20.47)	255.51 (38.51)
8							276.20 (28.93)
9							
10							
11							
12							
13							
14							
15							

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 19 continued.

	Year						
Age	2003	2004	2005	2006	2007	2008	2009
2	*207.73 (0.00)*	-	-	-	-	-	-
3	215.39 (32.94)	*189.09 (0.00)*	234.85 (24.41)	-	-	-	-
4	231.94 (32.63)	200.18 (28.51)	*242.73 (0.00)*	219.77 (4.87)	-	-	-
5	231.33 (23.75)	210.91 (34.52)	238.92 (27.52)	*277.27 (0.00)*	248.33 (38.34)	-	-
6	226.10 (31.75)	231.74 (25.43)	227.16 (27.11)	268.81 (28.52)	*232.73 (0.00)*	252.73 (38.12)	-
7	244.62 (34.18)	213.36 (40.49)	218.45 (31.18)	224.90 (26.01)	252.73 (23.12)	*232.73 (0.00)*	230.45 (32.31)
8	223.3 (34.12)	232.16 (28.22)	219.19 (37.69)	233.61 (20.15)	244.39 (29.93)	240.85 (36.80)	*252.73 (0.00)*
9	256.42 (25.40)	207.25 (15.15)	240.45 (37.05)	231.77 (28.44)	237.54 (16.37)	249.96 (33.72)	235.68 (5.22)
10		221.21 (34.74)	214.98 (42.41)	247.35 (23.96)	230.83 (18.68)	216.21 (12.75)	220.91 (24.55)
11			244.5 (37.66)	*204.0 (0.00)*	273.68 (29.91)	224.02 (25.95)	195.18 (29.28)
12				244.82 (17.61)	-	262.44 (45.29)	195.45 (29.33)
13					256.84 (32.90)	*225.00 (0.00)*	208.31 (40.0
14						269.08 (101.91)	*209.00 (0.00)*
15							231.29 (25.31)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 20. Unadjusted means and standard deviations of calf weaning weight by sire breed, dam breed and sex.[1, 2, 3]

	Sire Breed							
	A		B		H		BH	
Sex	F	M	F	M	F	M	F	M
Breed								
B	227.20 (30.84)	239.78 (38.62)	187.67 (24.94)	207.32 (24.87)	227.53 (33.24)	243.19 (29.94)		
H	186.95 (40.97)	209.96 (37.11)	192.35 (44.42)	157.42 (30.81)	192.21 (38.52)	198.71 (37.22)		
BH	280.29 (32.01)	259.11 (34.83)					206.27 (40.21)	224.88 (20.23)
HB	235.78 (38.72)	252.11 (17.69)					213.50 (38.61)	221.45 (27.14)
F_2BH	*220.45 (35.43)*							
BHxHB	*229.09 (0.00)*							
F_2HB	238.27 (35.28)	236.06 (26.52)						*189.09 (0.00)*
HBxBH	215.78 (30.24)	226.41 (28.98)					*166.36 (0.00)*	184.54 (2.66)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 20 continued.

	HB		Nellore/ Angus		¾ A ¼ N		Wagyu	
Sex	F	M	F	M	F	M	F	M
Breed								
B								
H							*146.81 (12.23)*	141.82 (12.01)
BH	196.79 (33.34)	228.50 (22.78)	238.01 (28.51)	252.19 (26.32)				
HB	215.27 (29.53)	211.16 (30.62)	238.11 (36.44)	251.11 (32.18)				
F_2BH			196.11 (27.42)	221.20 (29.55)	*161.37 (26.43)*			
BHxHB			220.46 (29.45)	248.05 (27.34)	144.09 (40.52)	183.54 (25.55)		
F_2HB			223.29 (28.76)	234.17 (20.23)				
HBxBH			210.94 (27.12)	230.73 (29.91)				

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first
[3]Italicized numbers represent fewer than 3 observations for that particular interaction

Table 21. Calf weaning weight means and standard deviations by cow breed.[1, 2]

Breed	Mean (SD
B	224.1 (36.6)
H	193.8 (39.7)
BH	240.9 (38.1)
HB	234.9 (36.4)
F_2BH	208.4 (31.9)
BH x HB	223.5 (38.2)
F_2HB	230.2 (26.8)
HB x BH	219.2 (30.2)

[1]H= Hereford, B= Brahman
[2]Crossbred animals are referenced with the sire breed listed first

Cow Weight at Weaning

Cows were weighed in the fall of each year when the calves were weaned. Cow weight was evaluated at 6 years of age because younger cows had not yet matured, and numbers of observations for cows over 6 years of age were not sufficient. The effect of lactation status on cow weight appeared important and attempts to model the trait appropriately were made. Due to the small number (n = 9) of dry cows at 6 years of age (4 breed groups had no observations), modeling this effect was not possible.

Least squares means and standard errors for cow weight (kg) are presented in Table 22. H cows were the lightest (529.21 ± 16.95 kg) ($P < 0.0001$) and F_2BH were the heaviest (612.76 ± 31.90) ($P < 0.0001$). There were large differences within F_2 breed groups that cannot be attributed to sire breed of the cow alone as BH x HB cows had similar weights to HB x BH cows (544.18 ± 27.74 kg and 539.41 ± 21.25 kg, respectively). F_2HB cows were heavier than those two groups and lighter than the F_2BH cows at 573.82 ± 23.02 ($P < 0.0001$).

Estimates of heterosis, reciprocal differences and selected differences for cow weight at 6 years of age are given in Table 23. Significant heterosis was detected in F_1 and F_2 cows. Cows sired by BH bulls were also significantly heavier than the mid-parent average. No other differences were significant in this analysis. It appears that F_2 cows retained 73% of F_1 expressed heterosis. This does not appear consistent with the dominance model prediction. This is inconsistent with findings from an earlier study of these cattle by Riley (2000) who found less than predicted levels of heterosis retained for cow weight, however those cows were all young at that time and had not yet matured.

Table 22. Cow weight at 6 years of age by cow breed.

Breed	LSM (SE
B	535.90 (13.79) [a]
H	529.21 (16.95) [a]
BH	584.92 (18.43) [b]
HB	575.94 (23.26) [b]
F_2BH	612.76 (31.90) [c]
BH x HB	544.18 (27.74) [a,b]
F_2HB	573.82 (23.02) [b]
HB x BH	539.41 (21.25) [a]

[a,b,c] Means that do not share a superscript are different

Table 23. Estimates of heterosis, reciprocal differences and selected differences for cow weight at 6 years of age (N = 157) weight in Brahman-Hereford F_1 and F_2 cows.[1]

L	Estimate (SE)
F_1 heterosis	47.88 (18.77)*
F_2 heterosis	34.99 (13.75)*
HB-sired F_2 – BH-sired F_2	-21.85 (25.05)
HB sired F_2 – MP	24.06 (16.57)
BH sired F_2 – MP	45.92 (20.43)*
HB F_1 – BH F_1	-22.76 (11.97)†
F_1 – F_2	12.89 (21.32)

[1] MP = Midparent value (average of the two straightbreds)
† P< 0.10
* P< 0.05

SUMMARY

Reproductive Traits

Within the F_2 group, there were reciprocal differences for both calf crop born and calf crop weaned. The HB-sired females had higher means for calf crop born and calf crop weaned than did the BH-sired females. For both traits, HB-sired females outperformed the F_1 groups as well.

According to the dominance model, F_1 cows would be expected to express maximum heterosis, and F_2 females would be expected to retain half the observed F_1 heterosis. When evaluated across all ages, F_1 cows expressed substantial heterosis for calf crop born and calf crop weaned. No heterosis was expressed in the BH- sired F_2 cows for calf crop born or calf crop weaned. HB sired F_2 cows appeared to express heterosis at higher levels than F_1 cows for both reproductive traits. When evaluating F_2 cows as a group, it appears that approximately equal levels of heterosis was expressed and retained for crop born and calf crop weaned as was predicted by the dominance model; however, when these cows are evaluated by type of F_1 sire, HB-sired cows appeared to express more heterosis than the F_1s, while the BH-sired cows were not shown to be superior to the mid-parent average.

Based on these observations, the most profitable choice for producers using Brahman x Hereford crossbred F_2 females may be to consider the type of sires of these females. When deciding on replacement females to keep, F_2 females that were sired by HB bulls seem to be the most effective choice.

Birth and Weaning Weight

Analyses of birth and weaning weight by cow breed and age group showed BH x HB heifers to produce the lightest calves at birth and at weaning at 28.96 (6.88) kg and 169.93 (30.86) kg, respectively. These cows' calves increased in birth weight each subsequent year; by 7 yr. of age, these cows had increased the average birth weight of their calves by 11.3 kg. Conversely, calves born to mature (8 yr. old) F_2HB cows differed much less from birth weight from calves born to F_2HB heifers (only 5.5 kg heavier). Weaning weights of calves born to F_2HB heifers were the heaviest of all weaning weights in heifers.

Cow Weight at Weaning

Heterosis for cow weight at six years of age was estimated using linear contrasts of least squares means. F_1 cows expressed heterosis for cow weight ($P < 0.05$) as did F_2 cows ($P < 0.05$). Of the crossbred cows, F_2 BH cows were the heaviest at 612.76 ± 31.90 kg, and HB x BH cows were the lightest (539.41 ± 21.25 kg). Cows sired by BH bulls were significantly heavier than the mid-parent average ($P < 0.05$) and those sired by HB bulls were not.

CONCLUSIONS

The results of this study suggest that heterosis retained in F_2 Brahman x Hereford cross females is dependent on the type (reciprocal cross) of sire. For certain traits and breed groups, the dominance model predictions were very similar to the observed results; predictions for other traits and groups were very different from the observed results. Across all traits and breeds, it appears that HB-sired F_2 cows have a better probability of consistently producing and weaning a calf while maintaining a lower mature weight than BH-sired F_2 cows.

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