HETEROSIS AND HETEROSIS RETENTION FOR REPRODUCTIVE AND MATERNAL TRAITS IN BRAHMAN - BRITISH CROSSBRED COWS

A Dissertation

by

KELLI LOREN KEY

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

DOCTOR OF PHILOSOPHY

December 2004

Major Subject: Animal Breeding

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Approved as to style and content by:

James O. Sanders (Chair of Committee)	David Adelson (Member)
Clare Gill (Member)	P. Fred Dahm (Member)
	John McNeill (Head of Department)

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ABSTRACT

Heterosis and Heterosis Retention for Reproductive and Maternal Traits in Brahman - British Crossbred Cows. (December 2004)

Kelli Loren Key, B.S., Texas A&M University

Chair of Advisory Committee: Dr. James O. Sanders

Reproductive, maternal, and weight traits were analyzed for Angus (A), Brahman (B), and Hereford (H) straightbred cows; F_1 and F_2 BA and BH cows; and 3/8 B 5/8 A first (Bn) and second (Bn_2) generation cows in Central Texas. Heterosis was estimated for calf crop born (CCB), calf crop weaned (CCW), and cow weight at palpation (PW) by linear contrasts within cow breed groups. F_1 BA cows expressed heterosis ($P<0.01$) for CCB (0.10) and CCW (0.11), while F_2 BA cows expressed negative heterosis ($P<0.10$) for CCB (-0.06) and CCW (-0.07). F_1 BH cows expressed heterosis ($P<0.001$) for CCB (0.15) and CCW (0.16), and F_2 BH cows retained F_1 heterosis ($P<0.001$) for CCB (0.13) and CCW (0.15). Bn_2 cows expressed heterosis ($P<0.01$) for CCB (0.14), but Bn cows did not express heterosis ($P>0.10$) for CCB or CCW. Only the F_1 BA (22.9 kg) and F_2 BH (42.1 kg) groups expressed heterosis ($P<0.10$) for PW. Bn_2 cows (-65.7 kg) expressed negative heterosis ($P<0.01$) for PW. Heterosis for calf survival (CS), birth weight (BW), and weaning weight (WW) was estimated by linear contrasts within calf breed groups for B- and H-influenced calves. F_1 BH (0.11) and F_2 BH (0.14) calves expressed heterosis ($P<0.01$) for CS. None of the groups expressed heterosis ($P>0.10$) for BW, but B-sired F_1 BH calves were 5.5 kg heavier ($P<0.01$) than H-sired F_1 calves at

birth. F_1 BH (22.4 kg) and F_2 BH (26.2 kg) calves expressed heterosis (P<0.001) for WW, and H-sired F_1 BH calves were 20.7 kg heavier (P<0.10) than B-sired F_1 calves at weaning.

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INTRODUCTION

Two of the most critical elements of a successful beef cattle operation are cow reproductive efficiency and maternal ability. Reproductive efficiency is a complex character composed of a number of sub characters (Cartwright et al., 1964) that can be assessed using several methods. It may be described as the number of females that become pregnant, produce a calf, or wean a calf each year as compared to the number of cows exposed to a bull through natural service or artificial insemination during the breeding season. Reproductive rate can be increased most effectively by utilizing heterosis for female fertility (Piper, 1982), and this is one of the reasons why the use of crossbred cows has become increasingly important to beef producers. A cow's maternal ability affects the performance of her calf and includes both milk production and the desire to protect and nurture a calf. It is typically quantified by evaluating the calf's weaning weight or average daily gain from birth to weaning.

Many present day beef cattle operations rely on the use of crossbreeding to enhance herd performance. In the Gulf Coast region of the United States, the majority of the beef cows are *Bos indicus* x *Bos taurus* crossbreds. While the highest levels of heterosis, or the superior performance of crossbred cattle over the straightbred average for a particular trait, are seen in F_1 *Bos indicus* x *Bos taurus* cattle, many of the crossbreeding systems in the Gulf Coast region utilize cows that are not F_1s, including F_2 and composite breed females as well as those produced by rotational crossbreeding

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This dissertation follows the style and format of the Journal of Animal Science.

systems. These non-F_1 crossbred females are used in many cases because of the expense of maintaining straightbred herds to produce F_1 replacements. The retention of heterosis in non-F_1 cows is an important issue for producers to consider, as any significant loss of heterosis may be more than a producer can afford. Heterosis has been traditionally described as being proportional to heterozygosity (Wright, 1922). If this is true, much of the advantage of crossbreeding for reproductive and maternal performance would be expected to be lost after the F_1 generation. If heterosis is not proportional to heterozygosity, even more of the crossbred advantage may be lost. While studies have indicated that heterosis is retained in *inter se* mated *Bos taurus* composites (Gregory et al., 1991a-b, 1992a-c, 1999), there is a scarcity of information concerning the retention of heterosis for reproductive and maternal traits in F_2 and later generations of *Bos indicus* x *Bos taurus* crossbred females.

LITERATURE REVIEW

Brahman Cattle

Brahman is a *Bos indicus* breed of cattle that was developed in the United States from cattle imported from Brazil and India (Sanders, 1980). This breed has been used extensively throughout the Southeastern United States because of its adaptability to the heat and humidity and resistance to pests and diseases (Franke, 1980). While these are desirable characteristics for efficient beef production, Brahman cows have been shown to have lower calving, calf survival of purebred calves, and weaning rates as compared to contemporary *Bos taurus* breeds. These and other undesirable characteristics make crossbreeding of the Brahman with *Bos taurus* breeds to take advantage of breed complementarity and heterosis a more desirable option than using purebred Brahmans in commercial production.

Heterosis

Heterosis is an effect of outbreeding that was defined by Lush (1945) as "superiority of the outbred animals over the average of their parents in individual merit." The concept of heterosis can be traced back to the time of Darwin (1896). Shull (1952) claimed to have first used the term heterosis in 1911 to describe the phenomenon in corn. Hayes (1952), who also worked with corn, noted that dominance or partial dominance appeared to be important to heterosis. Bruce (1910) proposed the idea that heterosis is associated with heterozygosity across many loci; this idea was supported by research in corn by Shull and Hayes and in guinea pigs by Wright (1922).

The cause for heterosis is typically described as dominance, or the interaction of alleles within a locus. An alternate cause for heterosis is epistasis, which was defined by Dickerson (1952) as all effects of a gene in one set of alleles on the expression of genes in other sets of alleles. Dickerson stated that epistasis is "universal," as gene expression is dependent on and (or) modified by gene effects in other sets of alleles within an organism. Forms of epistasis that could cause the superior performance in F_1 offspring include the combinations of genes that have become fixed over time in different breeds (Lush, 1946; Dickerson, 1969) or the desirable gene combinations that are brought together in the F_1 individual (Sheridan, 1981). While these epistatic combinations could be present in the F_1 generation, some of these combinations would be expected to be disrupted by recombination events in meiosis.

Heterosis is typically higher in traits that are lowly heritable (Cartwright et al., 1964), including reproductive efficiency traits in cattle. Utilizing heterosis for female fertility is the most effective means of increasing reproductive rate (Piper, 1982), and this is one of the reasons why the use of crossbred cows has become increasingly popular in the United States. This heterosis can be maximized in F_1 *Bos indicus* x *Bos taurus* females, who exceed F_1 *Bos taurus* x *Bos taurus* cows in expressed heterosis (Cartwright et al., 1964; Koger 1973; Koger et al., 1975; Gregory et al., 1978; Gregory and Cundiff, 1980).

Heterosis for Cow Efficiency Traits

In studies involving British crosses, estimates of heterosis for pregnancy rate have ranged from 3.0% to 8.9% (Cundiff et al., 1974a; Spelbring et al., 1977b; Koch et al., 1985). In British x Continental crosses, estimates have ranged from 5.0% to 21.3% (Olson et al., 1985, 1993; Newman et al., 1993). Estimates in *Bos indicus* x *Bos taurus* crosses have ranged from 7.6% to 25.0% (Olson et al., 1990, 1993). Heterosis estimates for *Bos indicus* x *Bos taurus* crosses may be heavily influenced by low performance of the *Bos indicus* parent, resulting in wide ranges among these estimates.

Estimates of heterosis for calf crop born in British crosses across the United States have generally been small, ranging from nearly zero to almost 7.0% (Cundiff et al., 1974a, 1992; Spelbring et al., 1977b; Neville et al., 1984a; Dearborn et al., 1987). Reports of heterosis for calf crop born in British x Continental crosses have ranged from 8.0% to 8.7% (Peacock and Koger, 1980; Kress et al., 1992; Newman et al., 1993). *Bos indicus* x *Bos taurus* crosses have been shown to expresses higher degrees of heterosis for calf crop born, ranging from 8.7% to almost 25% (Cartwright et al., 1964; Turner et al., 1968; Peacock and Koger, 1980; Neville et al., 1984a; Olson et al., 1990).

Estimates of heterosis for calf crop weaned in British crossbred cows ranged from a low of 4.6% to a high of 11.5% (Cundiff et al., 1974a, 1992; Spelbring et al., 1977b; Neville et al., 1984a). In British x Continental crosses, heterosis estimates have ranged from -3.0% to 13.0% (Gregory et al., 1978; Peacock and Koger, 1980; Olson et al., 1985; Dearborn et al., 1987; Kress et al., 1990, 1992; Newman et al., 1993). Heterosis for calf crop weaned in *Bos indicus* x *Bos taurus* crosses has been estimated to be from 6.9% to 20% (Cartwright et al., 1964; Koger et al., 1975; Peacock and Koger, 1980; Neville et al., 1984a; Olson et al., 1990; Winder et al., 1992).

Numerous studies have found maternal heterosis to have a very small effect on birth weight of calves out of crossbred cows (Cartwright et al., 1964; McDonald and Turner, 1972; Cundiff et al., 1974b; Alenda et al., 1980; Dillard et al., 1980; Olson et al., 1985, 1990, 1993; Kress et al., 1990, 1992). An estimate of maternal heterosis for birth weight of calves out of linecrossed Hereford cows of 1.7 kg was reported by MacNeil et al. (1989). It is well documented that F_1 *Bos indicus* x *Bos taurus* crossbred calves sired by *Bos indicus* bulls tend to be heavier at birth than those sired by *Bos taurus* bulls, and very large differences are typically seen between *Bos indicus*-sired F_1 bulls and heifers (Cartwright et al., 1964; Roberson et al., 1986).

In British cross cows, maternal heterosis estimates for weaning weight have ranged from 3.2 kg to 8.4 kg (Cundiff et al., 1974b, 1992; Spelbring et al., 1977a; Alenda et al., 1980; Neville et al., 1984a; Dearborn et al., 1987). A much higher estimate of maternal heterosis for weaning weight of 28.7 kg was reported from a study involving Angus x Hereford F_1 heifers (Hohenboken and Weber, 1989). In British x Continental crossbred cows, estimates of maternal heterosis have ranged from 6.8 kg to 16 kg (Alenda et al., 1980; Dillard et al., 1980; Knapp et al., 1980; Olson et al., 1985; Kress et al., 1990). Maternal heterosis estimates for weaning weight in *Bos indicus* x *Bos taurus* cows have exceeded 18.0 kg (McDonald and Turner, 1972; Roberson et al., 1986; Wyatt and Franke, 1986; Olson et al., 1993; Arthur et al., 1994).

Heterosis Retention

When parents of two different breeds are mated together, the resulting F_1 offspring will have one allele from each parent breed at each locus across the genome.

This F_1 offspring is said to express full heterosis for a trait of interest. When F_1 individuals are inter-mated or backcrossed to one of their parental breeds, the proportion of the F_1 heterosis expressed in the resulting offspring can be described as retained heterosis. The retention of heterosis in non-F_1 crossbred cows is an important consideration due to the importance of heterosis for reproductive efficiency and maternal traits in females. If the dominance model correctly predicts heterosis, non-F_1 crossbred females would be expected to express a fraction of F_1 heterosis that is directly proportional to their fraction of heterozygous loci (Wright, 1922; Dickerson, 1969, 1972). The fraction of F_1 heterosis expressed is typically referred to as retained heterosis. When F_1s and other crosses are *inter se* mated, one generation of random mating is expected to stabilize heterozygosity (Dickerson, 1969).

The potential role of epistasis in heterosis and the effect it could have on the amount of heterosis that is present and maintained in various types of crosses in advanced generations of *inter se* matings has been discussed in detail by Dickerson (1969, 1972), Kinghorn (1980), Sheridan (1981), and Hill (1982). Dickerson (1969) described epistasis as one of the causes for individual heterosis. In 1972, Dickerson advised that rotational crossbreeding systems would be superior to composite breeds for traits where epistasis combinations were important and would be disrupted by recombination during meiosis. However, in the situation where epistatic effects do not significantly contribute to the superiority of a crossbred, composite breeds would be preferable.

Kinghorn (1980) proposed that epistatic loss due to recombination could be estimated using a model that included additive effects, dominance effects, additive x additive, additive x dominance, and dominance x dominance interactions. Two different forms of epistasis, parental and F_1, which could contribute to heterosis, were described by Sheridan (1981). Parental epistasis results from "different homozygous epistatic gene combinations present in the parental lines being passed across to the crossbred in a manner analogous to the dominance model." F_1 epistasis refers to favorable gene combinations that are brought together in the F_1 individual. Sheridan described a parental epistasis model involving two to three loci whose F_2 performance expectation is much lower than that predicted by the dominance model (Cunningham, 1982). Hill (1982) postulated that additive x additive and dominance x dominance interactions could be the cause for deviations in F_2 performance from that predicted by the dominance model. However, Koch et al. (1985) and Cunningham (1982) suggest that Hill's model has limited usefulness.

Koch et al. (1985) and Kinghorn and Vercoe (1989) evaluated these different models. Kinghorn and Vercoe proposed that models that use only dominance effects or those that include dominance and epistatic effects may be sufficient. Kress et al. (1986) suggested that the dominance model should be evaluated first in crossbreeding studies because of the ease with which it predicts performance in multiple crossbreeding systems.

Heterosis Retention for Reproductive and Maternal Traits

The majority of the research involving retention of heterosis in crossbred *Bos taurus* cows produced from *inter se* matings has been conducted by the R. L. Hruska U. S. Meat Animal Research Center (MARC) in Clay Center, Nebraska. In a study comparing Angus x Hereford F_2 and F_3 cow performance to that of F_1 cows, Koch et al. (1985) found a greater than expected reduction in heterosis for pregnancy rate and survival. Heterosis levels for maternal effects on birth weight and pre-weaning gain did not differ significantly from those predicted by the dominance model.

Researchers at MARC developed three composite lines of cattle from British and Continental breeds. The populations were designated MARC I (¼ Braunvieh ¼ Charolais ¼ Limousin 1/8 Angus 1/8 Hereford), MARC II (¼ Gelbvieh ¼ Simmental ¼ Angus and ¼ Hereford), and MARC III (¼ Red Poll ¼ Pinzgauer ¼ Angus ¼ Hereford). Retained heterosis for traits of economic importance was evaluated after several generations of *inter se* matings within these populations. Retained combined direct and maternal heterosis for birth weight, weaning weight, and preweaning average daily gain was not less than predicted by the dominance model (Gregory et al., 1991a, 1991b, 1999). In MARC III cows, heterosis retained for calf crop born, calf crop weaned, and 200 days weight per female exposed to breeding was less than (P<0.05) the expectation of the dominance model (Gregory et al., 1999). Although not significantly less than that predicted from the dominance model, heterosis retention estimates for reproductive traits from MARC I and MARC II cows were also less than predicted from the dominance model (except for pregnancy rate in MARC I cows).

Various cow traits were evaluated in Hereford, F_1 Hereford x Simmental, ¾ Simmental ¼ Hereford, and ¾ Hereford ¼ Simmental cows by Kress et al. (1990, 1992). Maternal heterosis for weaning weight and calf crop weaned did not differ (P<0.05) from that predicted by the dominance model. In a Montana study involving ¼ Charolais, ¼ Tarentaise ½ Red Angus cows, Newman et al. (1993) reported results for pregnancy rate and calf crop born and weaned in second generation crossbred females that exceeded those of first generation cows. Morris et al. (1986) concluded that epistatic effects for birth weight, weaning weight, and preweaning gain were not significant in a group of Angus x Hereford cows in New Zealand.

Much of the information relating to heterosis retention in *Bos indicus* x *Bos taurus* crosses has been obtained from studies conducted in Australia. A study of Hereford x Shorthorn, Brahman x Hereford, Brahman x Shorthorn, Africander x Hereford, and Africander x Shorthorn cows at the Belmont Station in Queensland, Australia, found a severe loss of heterosis for the Brahman crosses (Seebeck, 1973). F_2 and F_3 Brahman crossbreds had a calf crop born of 60.7%, compared to that of 81.2% for F_1 cows. This drastic loss of heterosis was not observed in the Africander or British crossbred groups. MacKinnon et al. (1989) reported results from groups of F_1, F_2, and F_n (F_3 and greater) cows of the following groups: ½ Africander, ¼ Hereford ¼ Shorthorn, ½ Brahman ¼ Hereford ¼ Shorthorn, and ¼ Africander ¼ Brahman ¼ Hereford ¼ Shorthorn. These groups were also evaluated at the Belmont Station and formed from the animals used in the study reported by Seebeck (1973). In the Africander half-bloods, heterosis levels for calf crop born were 19.1%, 13.3%, and

11.2% for the F_1, F_2, and F_n generations. Heterosis in the Brahman half-blood cows was 16.4%, -5.2%, and 1.6% for the F_1, F_2, and F_n generations. The authors attributed the difference in the Brahman cross F_2 and F_n generations to year x breed interactions resulting from above average years during which the F_2 group was evaluated. Levels of heterosis in the four breed quarter-blood composites were 5.0% for the first cross and 4.8% for the F_2 and F_3 cows combined.

Koger et al. (1975) confirmed high levels of heterosis in *Bos indicus* x *Bos taurus* crosses for weaning performance traits from a study of F_1 and backcross Brahman x Shorthorn females in Florida; however, some of the results of this study indicated that heterosis retention may not be linear with respect to heterozygosity. In their analysis of weaning rate, backcross cows outperformed the F_1 cows. Sacco et al. (1989) reported very small estimates of F_2 maternal heterosis for calf weaning weight in a Texas diallel study of Angus, Hereford, Brahman, Hereford, and Jersey The authors concluded that the results suggested that recombination had negated epistatic advantage. Unfortunately, the project did not continue long enough to adequately evaluate this hypothesis. F_1 and F_2 Brahman x Angus and Brangus (3/8 Brahman 5/8 Angus) cows were compared by Hargrove et al. (1991). Pregnancy rates were 97.4%, 81.7%, and 81.9% for the F_1, F_2, and Brangus groups. Calf crop born means were 96.7%, 81%, and 77.3% for the F_1, F_2, and Brangus groups. Calf crop weaned means were 90.7%, 67.1%, and 80.8% for the F_1, F_2, and Brangus groups, with a lower than expected amount of heterosis retained in the F_2.

Olson et al. (1993) reported results from a Florida study that show fairly good agreement with the dominance model. This study evaluated F_1 and F_2 cows as well as all backcross combinations between Angus, Brahman, and Charolais. Pregnancy rate means were 92.6, 79.2, and 85.5% for the Angus, Brahman, and Charolais cows, for a weighted purebred average of 84.1% (T.A. Olson, personal communication). The F_1 Brahman x Angus and Brahman x Charolais groups had averages of 94.7% and 88.8%, respectively, for an F_1 average of 91.8%. Averages for the F_2 Brahman x Angus and Brahman x Charolais groups were 88.9% and 87.0%, for an F_2 average of 88%. The F_1 groups expressed 7.7% heterosis, while the F_2's retained 3.9% of the F_1 heterosis. This is very close to the amount of retained heterosis that would be predicted by the dominance model.

The early results from the current study involving crosses of Brahman, Angus, and Hereford were evaluated by Riley (2000). The two year old Brahman - Angus F_2 and Brahman - Hereford F_2 females in this study expressed greater heterosis for pregnancy rate than the respective F_1 groups. Based on these results, the author concluded that the dominance model failed to adequately predict heterosis retention for reproductive and maternal traits in this group Brahman - British crossbred females. However, a breed x age of cow interaction was important for all traits evaluated and a limited amount of data for the F_2 and 3/8 B 5/8 A groups made the formation of conclusions difficult.

Models

The genetic components of heterosis and levels of retained heterosis in the F_2 generation and beyond have been evaluated using two categories of models. The first of these is a linear model with breed group as the effect of interest and various discrete and (or) continuous variables. Contrasts of least squares means for breed groups have been used to estimate heterosis and heterosis retained (Knapp et al., 1980; Gregory et al., 1985, 1991a, 1991b, 1992a, 1992b, 1992c; Trail et al., 1985; Dearborn et al., 1987; Winder et al., 1992; Newman et al., 1993). A multiple regression model has also been used to estimate genetic parameters and heritability (Koger et al., 1975; Alenda et al., 1980; Dillard et al., 1980; Robison et al., 1981; Koch et al., 1985; Kinghorn and Vercoe, 1989; Olson et al., 1990; Kress et al., 1992; Schmitt and Distl, 1992). A number of studies have evaluated data using both of these models (Neville et al., 1984a, 1984b; Koch et al., 1985; Roberson et al., 1986; Wyatt and Franke, 1986; Madalena et al., 1990; Williams et al., 1991; Olson et al., 1993; Arthur et al., 1994; Perotto et al., 1994). In general, these studies have indicated that heterosis is adequately explained by dominance effects. While this seems to be true for *Bos taurus* crosses, Australian studies involving *Bos indicus* x *Bos taurus* crossbred cows have found lower degrees of heterosis than 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 that exceed heterosis retention predictions from the dominance model for Brahman x Charolais F_2 cows and results that are lower than predicted in Brahman x Angus F_2 cows. Given these limited and conflicting results, heterosis retention in *Bos indicus* x

Bos taurus crossbred cows has yet to be sufficiently assessed under the environments and production conditions in the United States.

OBJECTIVES

The objectives of this study were to:

1. Estimate heterosis between a *Bos indicus* breed (Brahman) and two *Bos taurus* breeds (Angus and Hereford) for cow reproductive traits and maternal effects on weight traits of their calves.
2. Estimate retained heterosis for each trait in non-F_1 *Bos indicus* x *Bos taurus* crossbreds.
3. Utilize this information to evaluate the adequacy of the dominance model to estimate heterosis retention.

MATERIALS AND METHODS

Description of Data

The data used in this study were collected as part of Texas Agricultural Experiment Station Project H6883 at the McGregor Research Center in Central Texas. Groups of approximately 50 head of cows from each of the following categories were formed:

- Straightbreds: Angus (A)
  Hereford (H)
  Brahman (B)
- F_1: BA (cow's sire breed listed first; cow's dam breed second)
  BH (includes HB)
- F_2: ½ B ½ H (includes BH x BH, HB x HB, BH x HB, and HB x BH)
  ½ B ½ A (includes BA x BA and AB x BA)
- Bn: 3/8 B 5/8 A (produced by ¾ B ¼ A x A and ¾ A ¼ B x ½ B ½ A)
- Bn_2: Second generation 3/8 B 5/8 A produced by *inter se* matings

All of the cows used in the study were produced at the McGregor Research Center, with the oldest cows born in 1994. The BH bulls used to produce the F_2

generation females were raised at the McGregor Research Center, while the HB bulls used to produce the F_2 females were purchased from breeders. The BA bulls used to produce the F_2 generation females were raised at the McGregor Research Center, while the AB bulls used to produce the F_2 females were produced at the Overton station in East Texas. Table 1 shows the number of cows of each breed and the years in which they were born. These cows were first exposed to bulls as yearlings in multiple sire pastures for approximately two months to spring calve as two year olds. In subsequent years, they were exposed in the same manner. B heifers that were born in 1997 were first exposed to bulls to calve at three years of age. Table 2 presents the breeds of bulls that were bred to cows of the various breed groups. All females were palpated for pregnancy detection in the fall of each year, and cow weights and condition scores were recorded at the time of palpation. The majority of calves were born between February and May of each year, and only six calves included in the data set were born outside this range. Birth weights of calves were recorded within 12 hours of birth if possible. Calves were weaned at approximately seven months of age, and weaning weight and condition scores were collected at weaning. Cows included in the study were subject to a culling policy in which cows were culled upon their second failure to wean a calf. Brahman cows, however, were not culled until their second failure to wean a calf after reaching three years of age.

Table 1. Number of cows and birth years for cow breeds[a]

Cow Breed	Number	Birth Years
A	51	1997, 1998, 1999
B	58	1995, 1996, 1997, 1998, 1999, 2000
H	50	1996, 1997, 1998, 1999
BA[b]	52	1997, 1998
BH	34	1994, 1995, 1996
HB	18	1994, 1996
F_2 AB x BA[c]	26	1998, 1999
F_2 BA[d]	26	1997, 1998, 1999
F_2 BH	13	1997, 1998
F_2 HB	13	1996, 1997, 1999
F_2 BH x HB	12	1997, 1998
F_2 HB x BH	12	1996, 1997, 1999
Bn[e] (¾ B ¼ A x A)	53	1996
Bn (¾ A ¼ B x ½ B ½ A)	14	1996
Bn_2[f]	50	1998, 1999, 2000, 2001
Total	474	

[a]A – Angus, B – Brahman, H – Hereford
[b]Pairs of letters indicate a crossbred group with sire breed listed first and dam breed listed second.
[c]First pair of letters designates crossbred sire. Second pair of letters designates crossbred dam.
[d]Both parents were from the same crossbred group.
[e]Bn – Brangus (3/8 B 5/8 A)
[f]Bn_2 – Second generation Brangus (Bn x Bn)

Table 2. Breeds of bulls exposed to cow breed groups

Cow Breed Group	Breeds of Bulls
A	A
B	A, B, H
H	A, B, H, W[a]
F_1 BA	A, BA, ¾ A ¼ B, ¾ A ¼ N[b]
F_1 BH[c]	BH, HB, NA
F_2 BA[d]	A, BA, ¾ A ¼ B, ¾ A ¼ N
F_2 BH[e]	A, BH, NA, ¾ A ¼ N
Bn[f]	Bn
Bn_2	A, Bn

[a]W – Wagyu
[b]N – Nellore
[c]Includes both BH and HB.
[d]Includes both AB x BA and BA x BA.
[e]Includes BH x BH, HB x HB, BH x HB, and HB x BH.
[f]Includes ¾ B ¼ A x A and ¾ A ¼ B x ½ B ½ A.

Traits Analyzed

Cow reproduction traits that were evaluated in this study were calf crop born, calf crop weaned, and calf survival. Table 3 shows the number of observations for each of these traits for each cow breed. Calf crop born is the proportion of all cows exposed to bulls during the breeding season that calved during the calving season. Calf crop weaned is the proportion of the cows exposed to bulls during the breeding season that weaned a calf in the fall of the following year. Calf survival is the proportion of the calves born during the calving season that survive to weaning. These traits were analyzed as binary traits, with zero indicating a failure and one indicating a success for the character of interest.

Weight traits for calves out of the cows included in this study were also analyzed. These traits include birth weight and weaning weight. Table 4 shows the numbers of observations for each of these traits for each cow breed. Birth weight is the weight of the calf as recorded soon after birth, and weaning weight is weight of the calf when weaned in the fall of the year. Cow weight was recorded at the time of palpation and was also included in this analysis, and the number of observations for cow weight across all ages is also presented in Table 4.

Table 3. Numbers of observations for reproductive traits within each cow breed

Cow Breed	Calf Crop Born	Calf Crop Weaned	Calf Survival
A	176	173	144
B	238	238	144
H	202	201	145
BA	217	217	178
BH	223	223	189
HB	135	134	122
F_2 AB x BA	90	90	60
F_2 BA	90	89	54
F_2 BH	45	45	27
F_2 HB	45	44	39
F_2 BH x HB	40	40	28
F_2 HB x BH	55	55	50
Bn (¾ B ¼ A x A)	253	251	188
Bn (¾ A ¼ B x ½ B ½ A)	65	64	46
Bn_2	108	108	89
Total	1982	1972	1503

Table 4. Numbers of observations for calf and cow weight traits within each cow breed

Cow Breed	Calf Birth Weight	Calf Weaning Weight	Cow Weight
A	145	131	179
B	141	127	224
H	146	131	204
BA	178	166	226
BH	188	169	231
HB	122	117	136
F_2 AB x BA	60	53	86
F_2 BA	54	40	95
F_2 BH	27	23	51
F_2 HB	40	37	45
F_2 BH x HB	28	27	42
F_2 HB x BH	50	48	55
Bn (¾ B ¼ A x A)	189	160	274
Bn (¾ A ¼ B x ½ B ½ A)	47	42	66
Bn_2	87	71	95
Total	1502	1342	2009

Statistical Analysis

The data were analyzed using two methods. In the first method, the F_1, F_2, and Bn females were separated according to the breeds of their parents. For example, F_1 BH females were divided into two groups: those that had a B sire and an H dam and those that had an H sire and a B dam. In the second method, F_1, F_2, and Bn were all combined into their respective breed groups.

Cow Reproductive Traits

The traits previously described were evaluated as dependent variables using mixed linear models. For the overall analysis, fixed effects for calf crop born, calf crop weaned, and calf survival included breed of cow and age of cow. Year could not be included because of partial confounding with age of cow. Interactions among these main effects were investigated and included if important (P<0.25). Dam of cow within breed and cow within dam within breed were included as random effects. Calf crop born and calf crop weaned were also evaluated within age of cow categories using a model that included breed of cow and year as fixed effects and dam of cow within breed as a random effect. While B heifers that were born in 1997 were not exposed to breeding as yearlings, they were analyzed as if they had an opportunity to calve as two year olds.

Heterosis expressed in crossbred cows within the different age categories was estimated in units of the trait by linear contrasts of the crossbred adjusted mean from the midparent value of the two breeds involved in the cross. Retained heterosis was estimated by comparing the amount of heterosis expressed in the F_1 generation to the heterosis expressed by other crossbreds and by linear contrasts of the non-F_1 crossbred adjusted mean with the F_1 adjusted mean.

Due to the impact of calf breed on calf survival, this trait was analyzed for all B, H, and B x H crossbred calves by the breed of calf. The model used to evaluate calf survival included calf breed and age of cow as fixed effects and dam of cow within breed and cow within dam within breed as random effects. Linear contrasts were used to estimate heterosis and heterosis retention for calf breed groups.

Weight Traits

Calf birth weight and weaning weight were analyzed by breed of calf for the B, H, and B x H crossbred calves. The model used to analyze birth weight included breed of calf, age of cow, year, and sex of calf as fixed effects. The weaning weight model contained the additional fixed effect of age of calf at weaning. The interaction between breed of calf and sex of calf was significant ($P<0.25$) and included in the model for both birth weight and weaning weight. Both models also contained dam of cow within breed and cow within dam within breed as random effects. Heterosis and retained heterosis were again evaluated using linear contrasts.

Cow weight at palpation was analyzed for four year old cows, as this was the one age that had weight records across all breed types. The model used to evaluate this trait included the fixed effects of breed of cow, year, and lactation status within breed. Dam of cow within breed was also included in the model as a random effect.

RESULTS AND DISCUSSION

Calf Crop Born

Unadjusted means for breed x cow age combinations are presented in Table 5, and unadjusted means for breed group x cow age combinations are presented in Table 6. B heifers had the lowest calf crop born percentage among two year olds. This low performance was expected due to the later age of puberty that is characteristic of B cattle.

Adjusted means for calf crop born are presented by cow breed in Table 7 and by cow breed group in Table 8. Contrast estimates for differences in breed group adjusted means are show in Table 9. F_1 BA females expressed important heterosis ($P<0.01$) for calf crop born, while the F_2 BA group adjusted mean was below the midparent value ($P<0.10$). The F_2 BA group showed a substantial loss of heterosis ($P<0.001$) for calf crop born when compared to the F_1 BA group. Within the F_2 BA group, the females sired by AB bulls had a higher adjusted mean for calf crop born than the females sired by BA bulls (Table 7). Both the F_1 and F_2 BH groups expressed important heterosis ($P<0.001$) for calf crop born. The overall adjusted average for the F_2 BH group (0.87 ± 0.03) was slightly lower than that of the F_1 BH group (0.89 ± 0.02); however, there was a large difference among the different types of F_2 BH females. Adjusted means were 0.69 ± 0.06, 0.98 ± 0.06, 0.79 ± 0.07, and 0.97 ± 0.06 for F_2 BH, F_2 HB, F_2 BH x HB, and F_2 HB x BH, respectively. The F_2 females with HB sires showed higher performance for calf crop born than those with BH sires. Bn cows had a lower adjusted mean than that seen for Bn_2 cows ($P<0.001$).

Table 5. Unadjusted means, standard deviations, and numbers of observations for calf crop born by breed and age of cow

	Age								
Breed	2	3	4	5	6	7	8	9	Total
A	0.76	0.86	0.85	0.89	0.88	-	-	-	0.84
	(0.43)	(0.35)	(0.37)	(0.31)	(0.34)				(0.37)
	51	42	39	28	16				176
B	0.19	0.77	0.58	0.82	0.73	0.93	0.78	-	0.61
	(0.40)	(0.43)	(0.50)	(0.39)	(0.46)	(0.26)	(0.44)		(0.49)
	58	56	45	33	22	15	9		238
H	0.80	0.57	0.66	0.79	0.88	0.83	-	-	0.72
	(0.40)	(0.50)	(0.48)	(0.41)	(0.34)	(0.41)			(0.45)
	50	47	44	39	16	6			202
BA	0.87	0.80	0.71	0.89	0.86	-	-	-	0.82
	(0.34)	(0.41)	(0.46)	(0.32)	(0.35)				(0.38)
	52	49	49	45	22				217
BH	0.41	0.82	1.0	0.91	0.88	0.96	1.0	1.0	0.85
	(0.50)	(0.39)	(0.0)	(0.29)	(0.33)	(0.19)	(0.0)	(0.0)	(0.36)
	34	34	34	34	34	27	15	11	223
HB	0.89	0.56	1.0	1.0	1.0	0.94	0.94	1.0	0.91
	(0.32)	(0.51)	(0.0)	(0.0)	(0.0)	(0.24)	(0.25)	(0.0)	(0.29)
	18	18	17	17	17	17	16	15	135
F_2 AB x	0.85	0.31	0.76	0.85	-	-	-	-	0.67
BA	(0.37)	(0.47)	(0.44)	(0.38)					(0.47)
	26	26	25	13					90
F_2 BA	0.62	0.62	0.84	0.27	0.75	-	-	-	0.61
	(0.50)	(0.50)	(0.37)	(0.46)	(0.50)				(0.49)
	26	26	19	15	4				90

Table 5. Continued

Breed	Age 2	3	4	5	6	7	8	9	Total
F_2 BH	0.46 (0.52) 13	0.67 (0.49) 12	0.55 (0.52) 11	0.67 (0.52) 6	1.0 (0.0) 3	-	-	-	0.60 (0.50) 45
F_2 HB	0.85 (0.38) 13	0.73 (0.47) 11	1.0 (0.0) 11	1.0 (0.0) 4	1.0 (0.0) 4	1.0 (0.0) 2	-	-	0.89 (0.32) 45
F_2 BH x HB	0.58 (0.51) 12	0.40 (0.52) 10	0.89 (0.33) 9	1.0 (0.0) 8	1.0 (-) 1	-	-	-	0.70 (0.46) 40
F_2 HB x BH	0.92 (0.29) 12	0.75 (0.45) 12	0.92 (0.28) 13	1.0 (0.0) 8	1.0 (0.0) 7	1.0 (0.0) 3	-	-	0.91 (0.29) 55
Bn (¾ B ¼ A x A)	0.32 (0.47) 53	0.72 (0.45) 53	0.90 (0.31) 48	0.95 (0.21) 43	0.92 (0.28) 36	0.85 (0.37) 20	-	-	0.75 (0.44) 253
Bn (¾ A ¼ B x ½ B ½ A)	0.36 (0.50) 14	0.64 (0.50) 14	0.75 (0.45) 12	1.0 (0.0) 10	0.88 (0.35) 8	1.0 (0.0) 7	-	-	0.72 (0.45) 65
Bn_2	0.83 (0.38) 42	0.84 (0.37) 32	1.0 (0.0) 17	0.80 (0.45) 5	-	-	-	-	0.82 (0.38) 108
Total	0.62 (0.49) 482	0.70 (0.46) 445	0.80 (0.40) 394	0.86 (0.35) 308	0.88 (0.32) 190	0.93 (0.26) 97	0.93 (0.27) 40	1.0 (0.0) 26	0.76 (0.43) 1982

Table 6. Unadjusted means, standard deviations, and numbers of observations for calf crop born by breed group and age of cow

Breed Group	Age 2	3	4	5	6	7	8	9	Total
A	0.76	0.86	0.85	0.89	0.88	-	-	-	0.84
	(0.43)	(0.35)	(0.37)	(0.31)	(0.34)				(0.37)
	51	42	39	28	16				176
B	0.19	0.77	0.58	0.82	0.73	0.93	0.78	-	0.61
	(0.40)	(0.43)	(0.50)	(0.39)	(0.46)	(0.26)	(0.44)		(0.49)
	58	56	45	33	22	15	9		238
H	0.80	0.57	0.66	0.79	0.88	0.83	-	-	0.72
	(0.40)	(0.50)	(0.48)	(0.41)	(0.34)	(0.41)			(0.45)
	50	47	44	39	16	6			202
F_1 BA	0.87	0.80	0.71	0.89	0.86	-	-	-	0.82
	(0.34)	(0.41)	(0.46)	(0.32)	(0.35)				(0.38)
	52	49	49	45	22				217
F_1 BH[a]	0.58	0.73	1.0	0.94	0.92	0.95	0.97	1.0	0.87
	(0.50)	(0.45)	(0.0)	(0.24)	(0.27)	(0.21)	(0.18)	(0.0)	(0.34)
	52	52	51	51	51	44	31	26	358
F_2 BA[b]	0.73	0.46	0.80	0.54	0.75	-	-	-	0.64
	(0.45)	(0.50)	(0.41)	(0.51)	(0.50)				(0.48)
	52	52	44	28	4				180
F_2 BH[c]	0.70	0.64	0.84	0.92	1.0	1.0	-	-	0.78
	(0.46)	(0.48)	(0.37)	(0.27)	(0.0)	(0.0)			(0.41)
	50	45	44	26	15	5			185
Bn[d]	0.33	0.70	0.87	0.96	0.91	0.89	-	-	0.74
	(0.47)	(0.46)	(0.34)	(0.19)	(0.29)	(0.32)			(0.44)
	67	67	60	53	44	27			318

Table 6. Continued

Breed Group	Age 2	3	4	5	6	7	8	9	Total
Bn_2	0.83	0.84	1.0	0.80	-	-	-	-	0.82
	(0.38)	(0.37)	(0.0)	(0.45)					(0.38)
	42	32	17	5					108
Total	0.62	0.70	0.80	0.86	0.88	0.93	0.93	1.0	0.76
	(0.49)	(0.46)	(0.40)	(0.35)	(0.32)	(0.26)	(0.27)	(0.0)	(0.43)
	482	445	394	308	190	97	40	26	1982

[a]Includes both BH and HB.
[b]Includes both AB x BA and BA x BA.
[c]Includes BH x BH, HB x HB, BH x HB, and HB x BH.
[d]Includes ¾ B ¼ A x A and ¾ A ¼ B x ½ B ½ A.

Table 7. Least squares means and standard errors for calf crop born by cow breed

Cow Breed	LS Mean ± SE
A	0.92 ± 0.03
B	0.67 ± 0.03
H	0.80 ± 0.03
BA	0.89 ± 0.03
BH	0.87 ± 0.03
HB	0.92 ± 0.03
F_2 AB x BA	0.77 ± 0.05
F_2 BA	0.71 ± 0.05
F_2 BH	0.69 ± 0.06
F_2 HB	0.98 ± 0.06
F_2 BH x HB	0.79 ± 0.07
F_2 HB x BH	0.97 ± 0.06
Bn (¾ B ¼ A x A)	0.80 ± 0.03
Bn (¾ A ¼ B x ½ B ½ A)	0.77 ± 0.05
Bn_2	0.97 ± 0.04

Table 8. Least squares means and standard errors for calf crop born by cow breed group[a]

Cow Breed Group	LS Mean ± SE
A	0.93 ± 0.03
B	0.68 ± 0.03
H	0.80 ± 0.03
F_1 BA	0.90 ± 0.03
F_1 BH	0.89 ± 0.02
F_2 BA	0.74 ± 0.03
F_2 BH	0.87 ± 0.03
Bn	0.80 ± 0.03
Bn_2	0.97 ± 0.04

[a]See Table 6 for breed group designations.

Table 9. Calf crop born contrasts and standard errors for breed group[a] differences

L	Contrast ± SE
F_1 BA – MP[b]	0.10 ± 0.03**
F_2 BA – MP	-0.06 ± 0.04†
F_1 BA - F_2 BA	0.16 ± 0.04***
F_1 BH – MP	0.15 ± 0.03***
F_2 BH – MP	0.13 ± 0.04***
F_1 BH - F_2 BH	0.02 ± 0.04
Bn – WMP[c]	-0.03 ± 0.03
Bn_2 – WMP	0.14 ± 0.04**
Bn - Bn_2	-0.18 ± 0.05***
F_1 BA – Bn	0.10 ± 0.04**

[a]See Table 6 for breed group designations.
[b]MP = Midparent value (average of the two straightbreds involved in the cross)
[c]WMP = Weighted midparent value (3/8 B 5/8 A)
† $P < 0.10$
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Adjusted means for calf crop born by cow breed x cow age combinations are presented in Table 10, and adjusted means for calf crop born by cow breed group x cow age combinations are presented in Table 11. Contrast estimates for differences in cow breed groups within cow age groups are presented in Table 12. F_1 heterosis expressed by BA cows was 0.36 ± 0.08 (P<0.001) as two year olds, but this group expressed no heterosis (P>0.10) at three, four, or five years of age. Heterosis for F_2 BA cows was 0.22 ± 0.07 (P<0.01) as two year olds and 0.18 ± 07 (P<0.05) as four year olds. The F_2 BA group was substantially (P<0.001) below the midparent value at three and five years of age. F_1 BH females' performance was below the midparent value for two and three year olds but was above the midparent value at ages four and five. The F_2 BH group outperformed the F_1 BH group at all ages except three years, and the F_2 BH group expressed heterosis of 0.17 ± 0.07 (P<0.05), 0.22 ± 0.07 (P<0.01), and 0.15 ± 0.08 (P<0.10) at ages two, four, and five, respectively. Bn females only exceeded the midparent value at two years of age. Bn_2 cows outperformed the Bn cows at two, three, and four years of age, and they expressed important heterosis of 0.16 ± 0.09 (P<0.10) as two year olds and 0.30 ± 0.10 (P<0.01) as four year olds.

Table 10. Least squares means and standard errors for calf crop born by cow breed and age

Cow Breed	Age			
	2	3	4	5
A	0.75 ± 0.07	0.88 ± 0.08	0.95 ± 0.07	0.94 ± 0.08
B	0.27 ± 0.06	0.74 ± 0.06	0.61 ± 0.06	0.80 ± 0.06
H	0.84 ± 0.07	0.55 ± 0.08	0.77 ± 0.06	0.78 ± 0.06
BA	0.83 ± 0.08	0.81 ± 0.08	0.85 ± 0.07	0.93 ± 0.07
BH	0.43 ± 0.11	0.81 ± 0.11	0.85 ± 0.09	0.89 ± 0.07
HB	0.66 ± 0.15	0.71 ± 0.16	0.85 ± 0.13	1.06 ± 0.11
F_2 AB x BA	0.84 ± 0.09	0.34 ± 0.10	1.02 ± 0.09	0.77 ± 0.10
F_2 BA	0.59 ± 0.09	0.64 ± 0.10	0.88 ± 0.09	0.36 ± 0.09
F_2 BH	0.41 ± 0.13	0.67 ± 0.14	0.61 ± 0.12	0.73 ± 0.14
F_2 HB	0.90 ± 0.12	0.73 ± 0.14	0.99 ± 0.11	1.02 ± 0.16
F_2 BH x HB	0.56 ± 0.13	0.42 ± 0.15	1.18 ± 0.13	0.95 ± 0.12
F_2 HB x BH	1.00 ± 0.12	0.70 ± 0.13	0.88 ± 0.10	1.02 ± 0.11
Bn (¾ B ¼ A x A)	0.63 ± 0.09	0.51 ± 0.10	0.74 ± 0.08	0.85 ± 0.07
Bn (¾ A ¼ B x ½ B ½ A)	0.69 ± 0.14	0.41 ± 0.14	0.57 ± 0.12	0.90 ± 0.12
Bn_2	0.75 ± 0.07	0.83 ± 0.09	1.14 ± 0.10	0.72 ± 0.15

Table 11. Least squares means and standard errors for calf crop born by cow breed group[a] and age

Cow Breed Group	Age 2	3	4	5
A	0.78 ± 0.07	0.88 ± 0.08	0.95 ± 0.07	0.97 ± 0.08
B	0.28 ± 0.06	0.74 ± 0.06	0.61 ± 0.06	0.82 ± 0.06
H	0.87 ± 0.07	0.56 ± 0.08	0.77 ± 0.06	0.80 ± 0.06
F_1 BA	0.89 ± 0.08	0.81 ± 0.08	0.86 ± 0.07	0.97 ± 0.07
F_1 BH	0.42 ± 0.11	0.78 ± 0.11	0.85 ± 0.09	0.90 ± 0.07
F_2 BA	0.75 ± 0.07	0.50 ± 0.08	0.96 ± 0.07	0.58 ± 0.08
F_2 BH	0.75 ± 0.07	0.63 ± 0.08	0.91 ± 0.06	0.95 ± 0.07
Bn	0.61 ± 0.09	0.47 ± 0.09	0.71 ± 0.07	0.86 ± 0.07
Bn_2	0.76 ± 0.07	0.83 ± 0.09	1.12 ± 0.10	0.73 ± 0.15

[a]See Table 6 for breed group designations.

Table 12. Calf crop born contrasts and standard errors within cow age group

L[a]	Age 2	3	4	5
F_1 BA – MP[b]	0.36 ± 0.08***	0.00 ± 0.08	0.08 ± 0.06	0.08 ± 0.07
F_2 BA - MP	0.22 ± 0.07**	-0.31 ± 0.08***	0.18 ± 0.07*	-0.32 ± 0.08***
F_1 BA - F_2 BA	0.14 ± 0.08	0.31 ± 0.09***	-0.09 ± 0.08	0.40 ± 0.08***
F_1 BH - MP	-0.15 ± 0.12	0.13 ± 0.13	0.16 ± 0.11	0.08 ± 0.10
F_2 BH - MP	0.17 ± 0.07*	-0.01 ± 0.08	0.22 ± 0.07**	0.15 ± 0.08†
F_1 BH - F_2 BH	-0.32 ± 0.14*	0.14 ± 0.15	-0.06 ± 0.12	-0.07 ± 0.11
Bn - WMP[c]	0.02 ± 0.11	-0.36 ± 0.12**	-0.12 ± 0.10	-0.06 ± 0.09
Bn_2 - WMP	0.16 ± 0.09†	-0.01 ± 0.10	0.30 ± 0.10**	-0.18 ± 0.15
Bn - Bn_2	-0.15 ± 0.13	-0.37 ± 0.14*	-0.41 ± 0.13**	0.12 ± 0.17
F_1 BA - Bn	0.28 ± 0.12*	0.34 ± 0.13*	0.16 ± 0.11	0.13 ± 0.10

[a]See Table 6 for breed group designations.
[b]MP = Midparent value (average of the two straightbreds involved in the cross)
[c]WMP = Weighted midparent value (3/8 B 5/8 A)
† $P < 0.10$
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Calf Crop Weaned

Unadjusted means for breed x cow age combinations are presented in Table 13, and unadjusted means for breed group x cow age combinations are presented in Table 14. As with calf crop born, B had the lowest performance among the two year olds. This was primarily due to the low percentage of calves born to B heifers.

Adjusted means for calf crop born are presented by cow breed in Table 15 and by cow breed group in Table 16. Contrast estimates for differences in breed group adjusted means are shown in Table 17. These results are very similar to those observed for calf crop born. The performance of the F_1 BA females for calf crop weaned exceeded ($P<0.01$) the midparent value, while the F_2 BA adjusted mean was below ($P<0.10$) the midparent value. Performance of the F_2 BA group was much lower ($P<0.001$) than that of the F_1 BA group, indicating a substantial loss of heterosis. Within the F_2 BA group, performance of the AB-sired females was higher than that of the BA-sired females (Table 15). Both the F_1 and F_2 BH groups expressed important heterosis ($P<0.001$) for calf crop weaned. There was no difference ($P>0.10$) between the performance of the F_1 and F_2 BH groups. Among the females in the F_2 BH group, those sired by HB bulls had higher adjusted means for calf crop weaned than those sired by BH bulls (Table 15). Although the difference between the two groups was not as large as observed for calf crop born, the Bn_2 females again outperformed the Bn females ($P<0.05$).

Table 13. Unadjusted means, standard deviations, and numbers of observations for calf crop weaned by breed and age of cow

	Age								
Breed	2	3	4	5	6	7	8	9	Total
A	0.58	0.83	0.79	0.86	0.88	-	-	-	0.76
	(0.50)	(0.38)	(0.41)	(0.36)	(0.34)				(0.43)
	50	40	39	28	16				173
B	0.14	0.68	0.47	0.76	0.68	0.93	0.67	-	0.53
	(0.35)	(0.47)	(0.50)	(0.44)	(0.48)	(0.26)	(0.50)		(0.50)
	58	56	45	33	22	15	9		238
H	0.70	0.51	0.63	0.77	0.88	0.50	-	-	0.66
	(0.46)	(0.51)	(0.49)	(0.43)	(0.34)	(0.55)			(0.47)
	50	47	43	39	16	6			201
BA	0.81	0.80	0.65	0.80	0.77	-	-	-	0.76
	(0.40)	(0.41)	(0.48)	(0.40)	(0.43)				(0.42)
	52	49	49	45	22				217
BH	0.38	0.76	0.94	0.85	0.79	0.81	0.73	1.0	0.77
	(0.49)	(0.43)	(0.24)	(0.36)	(0.41)	(0.40)	(0.46)	(0.0)	(0.42)
	34	34	34	34	34	27	15	11	223
HB	0.88	0.50	1.0	1.0	1.0	0.82	0.94	0.87	0.87
	(0.33)	(0.51)	(0.0)	(0.0)	(0.0)	(0.39)	(0.25)	(0.35)	(0.33)
	17	18	17	17	17	17	16	15	134
F_2 AB x	0.73	0.27	0.68	0.77	-	-	-	-	0.59
BA	(0.45)	(0.45)	(0.48)	(0.44)					(0.49)
	26	26	25	13					90
F_2 BA	0.46	0.48	0.84	0.20	0.75	-	-	-	0.52
	(0.51)	(0.51)	(0.37)	(0.41)	(0.50)				(0.50)
	26	25	19	15	4				89

Table 13. Continued

Breed	Age 2	3	4	5	6	7	8	9	Total
F_2 BH	0.38	0.67	0.55	0.50	0.67	-	-	-	0.53
	(0.51)	(0.49)	(0.52)	(0.55)	(0.58)				(0.50)
	13	12	11	6	3				45
F_2 HB	0.77	0.64	1.0	1.0	1.0	1.0	-	-	0.84
	(0.44)	(0.50)	(0.0)	(0.0)	(0.0)	(0.0)			(0.37)
	13	11	11	4	3	2			44
F_2 BH x	0.58	0.30	0.89	1.0	1.0	-	-	-	0.68
HB	(0.51)	(0.48)	(0.33)	(0.0)	(-)				(0.47)
	12	10	9	8	1				40
F_2 HB x	0.92	0.75	0.77	1.0	1.0	1.0	-	-	0.87
BH	(0.29)	(0.45)	(0.44)	(0.0)	(0.0)	(0.0)			(0.34)
	12	12	13	8	7	3			55
Bn (¾ B ¼	0.29	0.58	0.79	0.81	0.75	0.74	-	-	0.64
A x A)	(0.46)	(0.50)	(0.41)	(0.39)	(0.44)	(0.45)			(0.48)
	52	53	48	43	36	19			251
Bn (¾ A ¼	0.36	0.54	0.75	0.90	0.88	0.71	-	-	0.66
B x ½ B ½	(0.50)	(0.52)	(0.45)	(0.32)	(0.35)	(0.49)			(0.48)
A)	14	13	12	10	8	7			64
Bn_2	0.62	0.72	0.94	0.80	-	-	-	-	0.66
	(0.49)	(0.46)	(0.24)	(0.45)					(0.48)
	42	32	17	5					108
Total	0.53	0.63	0.74	0.80	0.81	0.80	0.80	0.92	0.69
	(0.50)	(0.48)	(0.44)	(0.40)	(0.39)	(0.40)	(0.41)	(0.27)	(0.46)
	479	441	393	308	189	96	40	26	1972

Table 14. Unadjusted means, standard deviations, and numbers of observations for calf crop weaned by breed group[a] and age of cow

Breed Group	Age 2	3	4	5	6	7	8	9	Total
A	0.58	0.83	0.79	0.86	0.88	-	-	-	0.76
	(0.50)	(0.38)	(0.41)	(0.36)	(0.34)				(0.43)
	50	40	39	28	16				173
B	0.14	0.68	0.47	0.76	0.68	0.93	0.67	-	0.53
	(0.35)	(0.47)	(0.50)	(0.44)	(0.48)	(0.26)	(0.50)		(0.50)
	58	56	45	33	22	15	9		238
H	0.70	0.51	0.63	0.77	0.88	0.50	-	-	0.66
	(0.46)	(0.51)	(0.49)	(0.43)	(0.34)	(0.55)			(0.47)
	50	47	43	39	16	6			201
F_1 BA	0.81	0.80	0.65	0.80	0.77	-	-	-	0.76
	(0.40)	(0.41)	(0.48)	(0.40)	(0.43)				(0.42)
	52	49	49	45	22				217
F_1 BH	0.55	0.67	0.96	0.90	0.86	0.82	0.84	0.92	0.81
	(0.50)	(0.47)	(0.20)	(0.30)	(0.35)	(0.39)	(0.37)	(0.27)	(0.40)
	51	52	51	51	51	44	31	26	357
F_2 BA	0.60	0.37	0.75	0.46	0.75	-	-	-	0.55
	(0.50)	(0.49)	(0.44)	(0.51)	(0.50)				(0.50)
	52	51	44	28	4				179
F_2 BH	0.66	0.60	0.80	0.88	0.93	1.0	-	-	0.74
	(0.48)	(0.50)	(0.41)	(0.33)	(0.27)	(0.0)			(0.44)
	50	45	44	26	14	5			184
Bn	0.30	0.58	0.78	0.83	0.77	0.73	-	-	0.64
	(0.46)	(0.50)	(0.42)	(0.38)	(0.42)	(0.45)			(0.48)
	66	66	60	53	44	26			315

Table 14. Continued

Breed Group	Age								Total
	2	3	4	5	6	7	8	9	
Bn_2	0.62	0.72	0.94	0.80	-	-	-	-	0.66
	(0.49)	(0.46)	(0.24)	(0.45)					(0.48)
	42	32	17	5					108
Total	0.53	0.63	0.74	0.80	0.81	0.80	0.80	0.92	0.69
	(0.50)	(0.48)	(0.44)	(0.40)	(0.39)	(0.40)	(0.41)	(0.27)	(0.46)
	479	441	393	308	189	96	40	26	1972

[a]See Table 6 for breed group designations.

Table 15. Least squares means and standard errors for calf crop weaned by cow breed

Cow Breed	LS Mean ± SE
A	0.82 ± 0.04
B	0.59 ± 0.03
H	0.72 ± 0.04
BA	0.82 ± 0.03
BH	0.78 ± 0.03
HB	0.88 ± 0.04
F_2 AB x BA	0.67 ± 0.05
F_2 BA	0.59 ± 0.05
F_2 BH	0.61 ± 0.07
F_2 HB	0.91 ± 0.07
F_2 BH x HB	0.75 ± 0.07
F_2 HB x BH	0.92 ± 0.06
Bn (¾ B ¼ A x A)	0.68 ± 0.03
Bn (¾ A ¼ B x ½ B ½ A)	0.70 ± 0.06
Bn_2	0.78 ± 0.05

Table 16. Least squares means and standard errors for calf crop weaned by cow breed group[a]

Cow Breed Group	LS Mean ± SE
A	0.83 ± 0.04
B	0.59 ± 0.03
H	0.72 ± 0.04
F_1 BA	0.82 ± 0.03
F_1 BH	0.82 ± 0.02
F_2 BA	0.64 ± 0.04
F_2 BH	0.81 ± 0.04
Bn	0.69 ± 0.03
Bn_2	0.79 ± 0.05

[a]See Table 6 for breed group designations.

Table 17. Calf crop weaned contrasts and standard errors for breed group[a] differences

L	Contrast ± SE
F_1 BA – MP[b]	0.11 ± 0.04**
F_2 BA - MP	-0.07 ± 0.04†
F_1 BA - F_2 BA	0.19 ± 0.04***
F_1 BH - MP	0.16 ± 0.03***
F_2 BH - MP	0.15 ± 0.04***
F_1 BH - F_2 BH	0.01 ± 0.04
Bn - WMP[c]	-0.06 ± 0.03
Bn_2 - WMP	0.05 ± 0.05
Bn - Bn_2	-0.10 ± 0.05*
F_1 BA - Bn	0.14 ± 0.04***

[a]See Table 6 for breed group designations.
[b]MP = Midparent value (average of the two straightbreds involved in the cross)
[c]WMP = Weighted midparent value (3/8 B 5/8 A)
† $P < 0.10$
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Adjusted means for calf crop weaned by cow breed x cow age combinations are presented in Table 18, and adjusted means for calf crop weaned by cow breed group x cow age combinations are presented in Table 19. Contrast estimates for differences in cow breed groups within cow age groups are presented in Table 20. Heterosis for F_1 BA females was 0.43 ± 0.08 (*P*<0.001) at two years of age but was not significant at the other ages. The F_2 BA group expressed heterosis of 0.22 ± 0.08 (*P*<0.01) as both two and four year olds but fell below the midparent value at three and five years of age. Performance of F_1 BH females was below the midparent value at two years of age but was substantially above the midparent value at ages three and four. The F_2 BH group outperformed the F_1 group as two, four, and five year olds. F_2 BH females expressed heterosis of 0.24 ± 0.08 (*P*<0.01) and 0.23 ± 0.08 (*P*<0.01) at two and four years of age. Bn females did not express heterosis (*P*>0.10) at any age, and Bn_2 females only expressed heterosis (*P*<0.05) of 0.26 ± 0.11 at four years of age.

Table 18. Least squares means and standard errors for calf crop weaned by cow breed and age

Cow Breed	Age 2	Age 3	Age 4	Age 5
A	0.58 ± 0.08	0.84 ± 0.09	0.89 ± 0.08	0.90 ± 0.09
B	0.19 ± 0.06	0.64 ± 0.07	0.51 ± 0.06	0.76 ± 0.07
H	0.73 ± 0.08	0.50 ± 0.08	0.76 ± 0.07	0.76 ± 0.07
BA	0.78 ± 0.08	0.80 ± 0.09	0.79 ± 0.08	0.84 ± 0.08
BH	0.35 ± 0.12	0.82 ± 0.12	0.81 ± 0.10	0.82 ± 0.09
HB	0.63 ± 0.17	0.69 ± 0.17	0.82 ± 0.15	1.00 ± 0.14
F_2 AB x BA	0.73 ± 0.10	0.26 ± 0.11	0.96 ± 0.09	0.70 ± 0.12
F_2 BA	0.46 ± 0.10	0.51 ± 0.11	0.87 ± 0.10	0.28 ± 0.12
F_2 BH	0.36 ± 0.14	0.68 ± 0.15	0.60 ± 0.13	0.56 ± 0.16
F_2 HB	0.84 ± 0.13	0.66 ± 0.15	0.99 ± 0.13	1.03 ± 0.19
F_2 BH x HB	0.56 ± 0.14	0.29 ± 0.16	1.20 ± 0.14	0.96 ± 0.15
F_2 HB x BH	1.00 ± 0.13	0.75 ± 0.14	0.73 ± 0.11	1.03 ± 0.14
Bn (¾ B ¼ A x A)	0.53 ± 0.10	0.50 ± 0.10	0.70 ± 0.09	0.75 ± 0.09
Bn (¾ A ¼ B x ½ B ½ A)	0.62 ± 0.15	0.41 ± 0.16	0.64 ± 0.14	0.82 ± 0.14
Bn_2	0.54 ± 0.08	0.65 ± 0.10	1.03 ± 0.11	0.73 ± 0.18

Table 19. Least squares means and standard errors for calf crop weaned by cow breed group[a] and age

Cow Breed Group	Age 2	3	4	5
A	0.62 ± 0.08	0.84 ± 0.09	0.89 ± 0.08	0.94 ± 0.09
B	0.20 ± 0.07	0.64 ± 0.07	0.50 ± 0.06	0.78 ± 0.07
H	0.77 ± 0.08	0.50 ± 0.08	0.76 ± 0.07	0.79 ± 0.07
F_1 BA	0.85 ± 0.08	0.81 ± 0.09	0.79 ± 0.08	0.88 ± 0.08
F_1 BH	0.35 ± 0.12	0.78 ± 0.12	0.82 ± 0.10	0.82 ± 0.09
F_2 BA	0.64 ± 0.08	0.39 ± 0.08	0.91 ± 0.08	0.51 ± 0.09
F_2 BH	0.72 ± 0.08	0.60 ± 0.08	0.86 ± 0.07	0.93 ± 0.09
Bn	0.51 ± 0.10	0.45 ± 0.10	0.70 ± 0.08	0.75 ± 0.08
Bn_2	0.55 ± 0.08	0.66 ± 0.10	1.01 ± 0.11	0.74 ± 0.18

[a]See Table 6 for breed group designations.

Table 20. Calf crop weaned contrasts and standard errors within cow age group

L[a]	Age 2	Age 3	Age 4	Age 5
F_1 BA - MP[b]	0.43 ± 0.08***	0.07 ± 0.09	0.10 ± 0.08	0.03 ± 0.08
F_2 BA - MP	0.22 ± 0.08**	-0.35 ± 0.09***	0.22 ± 0.08**	-0.35 ± 0.09***
F_1 BA - F_2 BA	0.21 ± 0.09*	0.42 ± 0.10***	-0.12 ± 0.08	0.38 ± 0.09***
F_1 BH - MP	-0.14 ± 0.13	0.21 ± 0.14	0.19 ± 0.12	0.03 ± 0.12
F_2 BH - MP	0.24 ± 0.08**	0.03 ± 0.09	0.23 ± 0.08**	0.14 ± 0.09
F_1 BH - F_2 BH	-0.37 ± 0.15*	0.18 ± 0.15	-0.05 ± 0.13	-0.11 ± 0.14
Bn - WMP[c]	0.04 ± 0.12	-0.32 ± 0.13*	0.05 ± 0.11	-0.13 ± 0.11
Bn_2 - WMP	0.09 ± 0.09	-0.11 ± 0.11	0.26 ± 0.11*	-0.14 ± 0.18
Bn - Bn_2	-0.04 ± 0.14	-0.21 ± 0.15	-0.31 ± 0.14*	0.00 ± 0.20
F_1 BA - Bn	0.33 ± 0.13*	0.36 ± 0.14*	0.10 ± 0.12	0.14 ± 0.12

[a]See Table 6 for breed group designations.
[b]MP = Midparent value (average of the two straightbreds involved in the cross)
[c]WMP = Weighted midparent value (3/8 B 5/8 A)
† $P < 0.10$
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Calf Survival

Unadjusted means by cow breed x cow age combinations are presented in Table 21, and unadjusted means by cow breed group x cow age combinations are presented in Table 22. For the majority of the breeds, the lowest calf survival percentage was observed for two year old dams. The Bn_2 group had the lowest performance for calf survival with a mean across all ages of only 0.80. Least squares means for calf survival are presented by cow breeds in Table 23 and by cow breed groups in Table 24. Contrast estimates for differences in adjusted means between cow breed groups are shown in Table 25. No differences (P>0.10) for calf survival were observed between the F_1 and F_2 BA groups or F_1 and F_2 BH groups.

Unadjusted means by breed of calf for B- and H-influenced calves are presented in Table 26. The $F_{2.5}$ BH had a survival rate of 100%; however, there were only four calves of this breed type included in the analysis. Adjusted means by breed of calf for B- and H-influenced calves are presented in Table 27. B calves had the lowest adjusted mean (0.79 ± 0.03) for survival among all of the calf breed groups. Contrast estimates for differences in calf breed groups are presented in Table 28. The F_1 BH calves expressed heterosis (P<0.10) of 0.11 ± 0.11. The F_2 BH group performance was 0.14 ± 0.03 above (P<0.001) the midparent value.

Table 21. Unadjusted means, standard deviations, and numbers of observations for calf survival by breed and age of cow

	Age								
Breed	2	3	4	5	6	7	8	9	Total
A	0.76	0.97	0.94	0.96	1.0 (0.0)	-	-	-	0.97
	(0.43)	(0.17)	(0.24)	(0.20)	14				(0.29)
	38	34	33	25					144
B	0.73	0.88	0.81	0.93	0.94	1.0 (0.0)	0.86	-	0.88
	(0.47)	(0.32)	(0.40)	(0.27)	(0.25)	14	(0.38)		(0.32)
	11	43	26	27	16		7		144
H	0.88	0.89	0.96	0.97	1.0 (0.0)	0.60	-	-	0.92
	(0.33)	(0.32)	(0.19)	(0.18)	14	(0.55)			(0.28)
	40	27	28	31		5			145
BA	0.93	1.0 (0.0)	0.91	0.90	0.89	-	-	-	0.93
	(0.25)	39	(0.28)	(0.30)	(0.32)				(0.25)
	45		35	40	19				178
BH	0.93	0.93	0.94	0.94	0.90	0.85	0.73	1.0 (0.0)	0.90
	(0.27)	(0.26)	(0.24)	(0.25)	(0.31)	(0.37)	(0.46)	11	(0.29)
	14	28	34	31	30	26	15		189
HB	1.0 (0.0)	0.90	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	0.88	1.0 (0.0)	0.87	0.96
	15	(0.32)	17	17	17	(0.34)	15	(0.35)	(0.20)
		10				16		15	122
F_2 AB x BA	0.86	0.88	0.89	0.91	-	-	-	-	0.88
	(0.35)	(0.35)	(0.32)	(0.30)					(0.32)
	22	8	19	11					60
F_2 BA	0.75	0.80	1.0 (0.0)	0.75	1.0 (0.0)	-	-	-	0.85
	(0.45)	(0.41)	16	(0.50)	3				(0.36)
	16	15		4					54

Table 21. Continued

Breed	Age 2	3	4	5	6	7	8	9	Total
F_2 BH	0.83 (0.41) 6	1.0 (0.0) 8	1.0 (0.0) 6	0.75 (0.50) 4	0.67 (0.58) 3	-	-	-	0.89 (0.32) 27
F_2 HB	0.91 (0.30) 11	0.88 (0.35) 8	1.0 (0.0) 11	1.0 (0.0) 4	1.0 (0.0) 3	1.0 (0.0) 2	-	-	0.95 (0.22) 39
F_2 BH x HB	1.0 (0.0) 7	0.75 (0.50) 4	1.0 (0.0) 8	1.0 (0.0) 8	1.0 (0.0) 1	-	-	-	0.96 (0.19) 28
F_2 HB x BH	1.0 (0.0) 11	1.0 (0.0) 9	0.83 (0.39) 12	1.0 (0.0) 8	1.0 (0.0) 7	1.0 (0.0) 3	-	-	0.96 (0.20) 50
Bn (¾ B ¼ A x A)	0.88 (0.33) 17	0.82 (0.39) 38	0.88 (0.32) 43	0.85 (0.36) 41	0.82 (0.39) 33	0.88 (0.34) 16	-	-	0.85 (0.36) 188
Bn (¾ A ¼ B x ½ B ½ A)	1.0 (0.0) 5	0.88 (0.35) 8	1.0 (0.0) 9	0.90 (0.32) 10	1.0 (0.0) 7	0.71 (0.49) 7	-	-	0.91 (0.28) 46
Bn_2	0.69 (0.47) 39	0.86 (0.36) 28	0.89 (0.32) 18	1.0 (0.0) 4	-	-	-	-	0.80 (0.40) 89
Total	0.85 (0.36) 297	0.90 (0.30) 307	0.92 (0.27) 315	0.92 (0.26) 265	0.92 (0.27) 167	0.87 (0.34) 89	0.86 (0.35) 37	0.92 (0.27) 26	0.90 (0.30) 1503

Table 22. Unadjusted means, standard deviations, and numbers of observations for calf survival by breed group[a] and age of cow

Breed Group	Age 2	3	4	5	6	7	8	9	Total
A	0.76 (0.43) 38	0.97 (0.17) 34	0.94 (0.24) 33	0.96 (0.20) 25	1.0 (0.0) 14	-	-	-	0.91 (0.29) 144
B	0.73 (0.47) 11	0.88 (0.32) 43	0.81 (0.40) 26	0.93 (0.27) 27	0.94 (0.25) 16	1.0 (0.0) 14	0.86 (0.38) 7	-	0.88 (0.32) 144
H	0.88 (0.33) 40	0.89 (0.32) 27	0.96 (0.19) 28	0.97 (0.18) 31	1.0 (0.0) 14	0.60 (0.55) 5	-	-	0.92 (0.28) 145
F_1 BA	0.93 (0.25) 45	1.0 (0.0) 39	0.91 (0.28) 35	0.90 (0.30) 40	0.89 (0.32) 19	-	-	-	0.93 (0.25) 178
F_1 BH	0.97 (0.19) 29	0.92 (0.27) 38	0.96 (0.20) 51	0.96 (0.20) 48	0.94 (0.25) 47	0.86 (0.35) 42	0.87 (0.35) 30	0.92 (0.27) 26	0.92 (0.26) 311
F_2 BA	0.82 (0.39) 38	0.83 (0.39) 23	0.94 (0.24) 35	0.87 (0.35) 15	1.0 (0.0) 3	-	-	-	0.87 (0.34) 114
F_2 BH	0.94 (0.24) 35	0.93 (0.26) 29	0.95 (0.23) 37	0.96 (0.20) 24	0.93 (0.27) 14	1.0 (0.0) 5	-	-	0.94 (0.23) 144
Bn	0.91 (0.29) 22	0.83 (0.38) 46	0.90 (0.30) 52	0.86 (0.35) 51	0.85 (0.36) 40	0.83 (0.39) 23	-	-	0.86 (0.34) 234

Table 22. Continued

Breed Group	Age								Total
	2	3	4	5	6	7	8	9	
Bn_2	0.69	0.86	0.89	1.0 (0.0)	-	-	-	-	0.80
	(0.47)	(0.36)	(0.32)	4					(0.40)
	39	28	18						89
Total	0.85	0.90	0.92	0.92	0.92	0.87	0.86	0.92	0.90
	(0.36)	(0.30)	(0.27)	(0.26)	(0.27)	(0.34)	(0.35)	(0.27)	(0.30)
	297	307	315	265	167	89	37	26	1503

[a]See Table 6 for breed group designations.

Table 23. Least squares means and standard errors for calf survival by cow breed

Cow Breed	LS Mean ± SE
A	0.87 ± 0.03
B	0.86 ± 0.03
H	0.89 ± 0.03
BA	0.91 ± 0.03
BH	0.89 ± 0.03
HB	0.95 ± 0.04
F_2 AB x BA	0.88 ± 0.05
F_2 BA	0.82 ± 0.05
F_2 BH	0.88 ± 0.07
F_2 HB	0.92 ± 0.06
F_2 BH x HB	0.93 ± 0.07
F_2 HB x BH	0.94 ± 0.05
Bn (¾ B ¼ A x A)	0.81 ± 0.03
Bn (¾ A ¼ B x ½ B ½ A)	0.90 ± 0.06
Bn_2	0.78 ± 0.04

Table 24. Least squares means and standard errors for calf survival by cow breed group[a]

Cow Breed Group	LS Mean ± SE
A	0.88 ± 0.03
B	0.86 ± 0.03
H	0.89 ± 0.03
F_1 BA	0.91 ± 0.03
F_1 BH	0.91 ± 0.02
F_2 BA	0.85 ± 0.03
F_2 BH	0.92 ± 0.03
Bn	0.83 ± 0.03
Bn_2	0.78 ± 0.04

[a]See Table 6 for breed group designations.

Table 25. Calf survival contrasts and standard errors for breed group[a] differences

L	Contrast ± SE
F_1 BA – MP[b]	0.04 ± 0.03
F_2 BA - MP	-0.02 ± 0.04
F_1 BA - F_2 BA	0.06 ± 0.04
F_1 BH - MP	0.03 ± 0.03
F_2 BH - MP	0.04 ± 0.04
F_1 BH - F_2 BH	-0.01 ± 0.04
Bn - WMP[c]	-0.04 ± 0.03
Bn_2 - WMP	-0.09 ± 0.04*
Bn - Bn_2	0.05 ± 0.04
F_1 BA - Bn	0.08 ± 0.04*

[a]See Table 6 for breed group designations.
[b]MP = Midparent value (average of the two straightbreds involved in the cross)
[c]WMP = Weighted midparent value (3/8 B 5/8 A)
† $P < 0.10$
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Table 26. Unadjusted means, standard deviations, and numbers of observations for calf survival by breed of calf

Breed of Calf	Calf Survival	n
Brahman	0.80 ± 0.40	65
Hereford	0.93 ± 0.26	97
F_1 HB	0.96 ± 0.20	71
F_1 BH	1.00 ± 0.00	8
F_2 BH	0.98 ± 0.13	110
$F_{2.5}$ BH[a]	1.00 ± 0.00	4
BANH[b]	0.90 ± 0.30	198
$BANH_2$[c]	0.94 ± 0.23	124

[a]$F_{2.5}$ BH – BH x F_2 BH
[b]BANH – NA x BH
[c]$BANH_2$ – NA x F_2 BH

Table 27. Least squares means and standard errors for calf survival by breed of calf[a]

Breed of Calf	LS Mean ± SE
Brahman	0.79 ± 0.03
Hereford	0.91 ± 0.03
F_1 HB	0.95 ± 0.03
F_1 BH	0.98 ± 0.09
F_2 BH	0.98 ± 0.09
$F_{2.5}$ BH	1.06 ± 0.14
BANH	0.89 ± 0.02
$BANH_2$	0.93 ± 0.03

[a]See Table 26 for breed of calf designations.

Table 28. Calf survival contrasts and standard errors

L	Contrast ± SE
F_1[a] – MP[b]	0.11 ± 0.05*
F_2 - MP	0.14 ± 0.03***
$F_{2.5}$ [c]- MP	0.21 ± 0.14
F_1 BH - F_1 HB	0.04 ± 0.10
F_1 - F_2	-0.02 ± 0.06
F_1 - $F_{2.5}$	-0.10 ± 0.15
BANH[d] - $BANH_2$[e]	-0.04 ± 0.04

[a]Includes BH and HB
[b]MP = Midparent value (average of the two straightbreds involved in the cross)
[c]$F_{2.5}$ – BH x F2 BH
[d]BANH – NA x BH
[e]$BANH_2$ – NA x F_2 BH
† $P < 0.10$
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Birth Weight

Unadjusted means for calf birth weight by breed of cow are presented in Table 29, and unadjusted means for calf birth weight by breed group of cow are presented in Table 30. The Bn cows produced calves that were heaviest at birth, while the calves out of the H females were the lightest. Unadjusted means for birth weight by breed of calf are presented in Table 31 for the Brahman-Hereford comparison. Adjusted means for birth weight by breed of calf are presented in Table 32 for the Brahman-Hereford comparison. The F_1 BH calves had the highest adjusted birth weight (38.4 ± 1.9 kg) of all the calf breed groups, while the reciprocal F_1 cross (F_1 HB) had the lowest adjusted birth weight (32.9 ± 1.0 kg).

Contrast estimates for differences in calf breed groups are presented in Table 33. None of the crossbred groups expressed heterosis (P>0.10) for birth weight. When the two F_1 groups were compared, the B-sired group was 5.5 ± 1.8 kg heavier (P<0.01) than the H-sired group. This difference was expected, as it is well documented that B-sired F_1 calves have heavier birth weights than the reciprocal F_1 cross (Cartwright et al., 1964; Roberson et al., 1986).

Table 29. Unadjusted means, standard deviations, and numbers of observations for calf birth weight by breed of dam

Breed	Birth Weight (kg)	n
A	34.3 (5.3)	145
B	33.7 (4.7)	141
H	33.5 (6.1)	146
BA	35.1 (6.0)	178
BH	35.9 (4.8)	188
HB	34.4 (6.0)	122
F_2 AB x BA	32.4 (6.3)	60
F_2 BA	36.9 (6.9)	54
F_2 BH	35.9 (5.6)	27
F_2 HB	33.7 (4.2)	40
F_2 BH x HB	34.5 (6.2)	28
F_2 HB x BH	32.5 (5.0)	50
Bn (¾ B ¼ A x A)	37.0 (5.0)	189
Bn (¾ A ¼ B x ½ B ½ A)	37.5 (6.3)	47
Bn_2	36.0 (6.3)	87
Total	35.0 (5.7)	1502

Table 30. Unadjusted means, standard deviations, and numbers of observations for calf birth weight by breed group[a] of dam

Breed Group	Birth Weight (kg)	n
A	34.3 (5.3)	145
B	33.7 (4.7)	141
H	33.5 (6.1)	146
F_1 BA	35.1 (6.0)	178
F_1 BH	35.3 (5.3)	310
F_2 BA	34.5 (6.9)	114
F_2 BH	33.8 (5.3)	145
Bn	37.1 (5.3)	236
Bn_2	36.0 (6.3)	87
Total	35.0 (5.7)	1502

[a]See Table 6 for breed group designations.

Table 31. Unadjusted means, standard deviations, and numbers of observations for calf birth weight by breed of calf[a]

Breed of Calf	Birth Weight (kg)	n
Brahman	33.9 (4.5)	62
Hereford	35.2 (5.0)	98
F_1 HB	33.8 (4.7)	71
F_1 BH	38.6 (4.3)	8
F_2 BH	33.9 (5.3)	110
$F_{2.5}$ BH	31.1 (1.7)	4
BANH	36.0 (5.2)	197
$BANH_2$	34.5 (5.2)	119

[a]See Table 26 for breed of calf designations.

Table 32. Least squares means and standard errors for calf birth weight by breed of calf[a]

Breed of Calf	LS Mean ± SE (kg)
Brahman	33.5 ± 0.9
Hereford	34.5 ± 0.9
F_1 HB	32.9 ± 1.0
F_1 BH	38.4 ± 1.9
F_2 BH	34.5 ± 0.8
$F_{2.5}$ BH	35.0 ± 3.1
BANH	35.2 ± 0.6
$BANH_2$	34.3 ± 1.0

[a]See Table 26 for breed of calf designations.

Table 33. Calf birth weight contrasts and standard errors

L^a	Contrast ± SE (kg)
F_1 - MP	1.6 ± 1.0
F_2 - MP	0.5 ± 1.2
$F_{2.5}$ - MP	1.0 ± 3.1
F_1 BH - F_1 HB	5.5 ± 1.8**
F_1 - F_2	1.2 ± 1.6
F_1 - $F_{2.5}$	0.7 ± 3.2
BANH - $BANH_2$	0.9 ± 0.8

[a]See Table 28 for contrast descriptions.
† $P < 0.10$
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Weaning Weight

Unadjusted means for calf weaning weight by breed of cow are presented in Table 34, and unadjusted means for calf weaning weight by breed group of cow are presented in Table 35. Calves out of the F_1 BH cows were heaviest at weaning, while the H cows produced the calves that were lightest at weaning. Unadjusted means for weaning weight by breed of calf are presented in Table 36 for the Brahman-Hereford comparison. Adjusted means for weaning weight by breed of calf are presented in Table 37 for the Brahman-Hereford comparison. In this comparison, the BANH calves had the highest adjusted weaning weight of 239.1 ± 3.0 kg, while the H calves had the lightest adjusted weaning weight (175.9 ± 4.7 kg).

Contrast estimates for differences in calf breed groups are presented in Table 38 for the Brahman-Hereford comparison. F_1, F_2, and $F_{2.5}$ groups all exceeded the midparent value for weaning weight. Heterosis expressed was 22.4 ± 5.8 (P<0.001), 26.2 ± 5.6 (P<0.001), and 19.2 ± 12.6 kg for the F_1, F_2, and $F_{2.5}$ groups, respectively. The heterosis estimate for F_1 calves is an estimate of heterosis for direct effects on weaning weight. Due to the fact that the F_2 and $F_{2.5}$ calves had F_1 and F_2 dams, respectively, the estimates of heterosis for these groups are estimates of heterosis for both direct and maternal effects on weaning weight. F_1 calves sired by H bulls were 20.7 ± 11.5 kg heavier (P<0.10) than those sired by B bulls. This difference is in the opposite direction as that observed for birth weight and is due to the higher milking ability of the B dam as compared to the H dams. The first generation BANH calves outperformed (P<0.001) the offspring of the second generation cows by 18.5 ± 4.4 kg.

Table 34. Unadjusted means, standard deviations, and numbers of observations for calf weaning weight by breed of dam

Breed	Weaning Weight (kg)	n
A	203.1 (40.0)	131
B	212.5 (36.4)	127
H	173.3 (36.2)	131
BA	221.2 (37.2)	166
BH	234.0 (30.0)	169
HB	231.9 (36.0)	117
F_2 AB x BA	209.7 (38.4)	53
F_2 BA	207.2 (35.0)	40
F_2 BH	206.7 (29.3)	23
F_2 HB	219.1 (26.5)	37
F_2 BH x HB	215.8 (41.8)	27
F_2 HB x BH	207.3 (30.6)	48
Bn (¾ B ¼ A x A)	217.2 (37.3)	160
Bn (¾ A ¼ B x ½ B ½ A)	211.2 (39.2)	42
Bn_2	206.5 (38.3)	71
Total	213.1 (39.4)	1342

Table 35. Unadjusted means, standard deviations, and numbers of observations for calf weaning weight by breed group[a] of dam

Breed Group	Weaning Weight (kg)	n
A	203.1 (40.0)	131
B	212.5 (36.4)	127
H	173.3 (36.2)	131
F_1 BA	221.2 (37.2)	166
F_1 BH	233.1 (32.5)	286
F_2 BA	208.7 (36.8)	93
F_2 BH	212.1 (32.0)	135
Bn	216.0 (37.7)	202
Bn_2	206.5 (38.3)	71
Total	213.1 (39.4)	1342

[a]See Table 6 for breed group designations.

Table 36. Unadjusted means, standard deviations, and numbers of observations for calf weaning weight by breed of calf[a]

Breed of Calf	Weaning Weight (kg)	n
Brahman	192.9 (23.6)	52
Hereford	185.4 (35.3)	88
F_1 HB	232.3 (32.4)	68
F_1 BH	168.6 (30.1)	8
F_2 BH	212.8 (30.8)	108
$F_{2.5}$ BH	179.3 (10.1)	4
BANH	245.3 (27.0)	176
$BANH_2$	217.5 (30.6)	110

[a]See Table 26 for breed of calf designations.

Table 37. Least squares means and standard errors for calf weaning weight by breed of calf[a]

Breed of Calf	LS Mean ± SE (kg)
Brahman	208.7 ± 4.5
Hereford	175.9 ± 4.7
F_1 HB	225.1 ± 4.9
F_1 BH	204.3 ± 11.6
F_2 BH	218.5 ± 3.6
$F_{2.5}$ BH	211.5 ± 12.7
BANH	239.1 ± 3.0
$BANH_2$	220.6 ± 4.8

[a]See Table 26 for breed of calf designations.

Table 38. Calf weaning weight contrasts and standard errors

L^a	Contrast ± SE (kg)
F_1 - MP	22.4 ± 5.8***
F_2 - MP	26.2 ± 5.6***
$F_{2.5}$ - MP	19.2 ± 12.6
F_1 BH - F_1 HB	-20.7 ± 11.5†
F_1 - F_2	-3.8 ± 7.9
F_1 - $F_{2.5}$	3.2 ± 13.7
BANH - $BANH_2$	18.5 ± 4.4***

[a]See Table 28 for contrast descriptions.
† $P < 0.10$
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Cow Weight at Palpation

Unadjusted means for cow weight at palpation for cows of all ages are presented by breed in Table 39, and unadjusted means for cow weight at palpation for cows of all ages are presented by breed group in Table 40. The F_1 BH cows were the heaviest of all the breed groups, while the Bn_2 cows were the lightest. Unadjusted means for cow weight at palpation for four year old cows are presented by cow breed in Table 41 and by cow breed group in Table 42. As four year olds, the B cows were the heaviest among the breed groups, and the Bn cows had the lightest unadjusted mean. Unadjusted means for cow weight at palpation for four year olds by lactation status are presented by cow breed in Table 43 and by cow breed group in Table 44. Cows that are lactating at the time that weight is recorded are expected to be lighter than dry cows, and this trend was observed across all breeds evaluated.

Adjusted means for cow weight at palpation for four year old cows by cow breed are presented in Table 45, and adjusted means for cow weight at palpation for four year old cows by cow breed group are presented in Table 46. Cow weight was evaluated for four year old cows because it was the highest age that had weight observations for all cow breeds. The F_1 BA group had the highest adjusted cow weight (534.5 ± 10.6 kg) among the cow breed groups. The F_2 BH group had a slightly lower cow weight (533.7 ± 13.6 kg); however, there were large differences among the different types of cows within that group. Within the F_2 BH group, the cows sired by BH bulls were heavier than those sired by HB bulls (Table 41).

Table 39. Unadjusted means, standard deviations, and numbers of observations for cow weight by breed

Breed	Cow Weight (kg)	n
A	421.8 (73.9)	179
B	447.3 (85.3)	224
H	407.6 (82.9)	204
BA	460.3 (80.4)	226
BH	491.6 (84.5)	231
HB	504.9 (78.7)	136
F_2 AB x BA	413.2 (75.9)	86
F_2 BA	441.3 (97.5)	95
F_2 BH	462.4 (75.6)	51
F_2 HB	437.2 (76.1)	45
F_2 BH x HB	437.2 (109.3)	42
F_2 HB x BH	436.0 (69.8)	55
Bn (¾ B ¼ A x A)	434.7 (94.5)	274
Bn (¾ A ¼ B x ½ B ½ A)	433.7 (105.4)	66
Bn_2	406.9 (83.0)	95
Total	445.3 (89.6)	2009

Table 40. Unadjusted means, standard deviations, and numbers of observations for cow weight by breed group[a]

Breed Group	Cow Weight (kg)	n
A	421.8 (73.9)	179
B	447.3 (85.3)	224
H	407.6 (82.9)	204
F_1 BA	460.3 (80.4)	226
F_1 BH	496.5 (82.6)	367
F_2 BA	427.9 (88.8)	181
F_2 BH	443.5 (82.8)	193
Bn	434.5 (96.5)	340
Bn_2	406.9 (83.0)	95
Total	445.3 (89.6)	2009

[a]See Table 6 for breed group designations.

Table 41. Unadjusted means, standard deviations, and numbers of observations for cow weight at 4 years of age by breed

Breed	Cow Weight (kg)	n
A	485.8 (66.8)	28
B	523.7 (63.6)	32
H	464.2 (95.4)	40
BA	513.6 (75.6)	47
BH	500.4 (42.3)	34
HB	508.7 (43.0)	17
F_2 AB x BA	507.8 (63.4)	16
F_2 BA	457.0 (56.6)	14
F_2 BH	518.2 (56.9)	10
F_2 HB	443.8 (30.9)	4
F_2 BH x HB	524.3 (66.7)	8
F_2 HB x BH	453.1 (38.7)	8
Bn (¾ B ¼ A x A)	466.7 (52.3)	46
Bn (¾ A ¼ B x ½ B ½ A)	498.6 (46.5)	10
Bn_2	479.1 (85.1)	6
Total	491.8 (68.3)	320

Table 42. Unadjusted means, standard deviations, and numbers of observations for cow weight at 4 years of age by breed group[a]

Breed Group	Cow Weight (kg)	n
A	485.8 (66.8)	28
B	523.7 (63.6)	32
H	464.2 (95.4)	40
F_1 BA	513.6 (75.6)	47
F_1 BH	503.2 (42.3)	51
F_2 BA	484.1 (64.7)	30
F_2 BH	492.5 (61.7)	30
Bn	472.4 (52.4)	56
Bn_2	479.1 (85.1)	6
Total	491.8 (68.3)	320

[a]See Table 6 for breed group designations.

Table 43. Unadjusted means (kg), standard deviations, and numbers of observations for cow weight at 4 years of age by breed and lactation status

	Lactation Status	
Breed	Dry	Wet
A	554.9 (62.3) 5	470.7 (58.7) 23
B	561.5 (46.2) 16	485.9 (56.3) 16
H	537.8 (47.1) 12	432.7 (93.9) 28
BA	601.0 (50.5) 15	472.7 (43.6) 32
BH	501.5 (70.7) 3	500.3 (40.5) 31
HB	-	508.7 (43.0) 17
F_2 AB x BA	558.8 (18.7) 3	496.1 (64.6) 13
F_2 BA	525.8 (61.6) 3	438.2 (40.0) 11
F_2 BH	552.4 (47.1) 4	495.4 (54.2) 6
F_2 HB	-	443.8 (30.9) 4
F_2 BH x HB	-	524.3 (66.7) 8
F_2 HB x BH	515.3 (-) 1	444.2 (31.9) 7
Bn (¾ B ¼ A x A)	545.6 (33.9) 8	450.1 (38.5) 38
Bn (¾ A ¼ B x ½ B ½ A)	580.5 (9.5) 2	478.1 (19.2) 8
Bn_2	-	479.1 (85.1) 6
Total	558.8 (51.8) 72	472.3 (59.7) 248

Table 44. Unadjusted means (kg), standard deviations, and numbers of observations for cow weight at 4 years of age by breed group[a] and lactation status

	Lactation Status	
Breed Group	Dry	Wet
A	554.9 (62.3) 5	470.7 (58.7) 23
B	561.5 (46.2) 16	485.9 (56.3) 16
H	537.8 (47.1) 12	432.7 (93.9) 28
F_1 BA	601.0 (50.5) 15	472.7 (43.6) 32
F_1 BH	501.5 (70.7) 3	503.3 (41.1) 48
F_2 BA	542.3 (44.6) 6	469.6 (61.2) 24
F_2 BH	545.0 (44.0) 5	482.0 (59.9) 25
Bn	552.6 (33.4) 10	455.0 (37.3) 46
Bn_2	-	479.1 (85.1) 6
Total	558.8 (51.8) 72	472.3 (59.7) 248

[a]See Table 6 for breed group designations.

Table 45. Least squares means and standard errors for cow weight at 4 years of age by breed

Breed	LS Mean ± SE (kg)
A	521.7 ± 14.5
B	504.8 ± 10.2
H	480.3 ± 10.8
BA	538.0 ± 10.9
BH	516.3 ± 16.8
HB	544.2 ± 18.2
F_2 AB x BA	500.6 ± 18.3
F_2 BA	496.5 ± 17.7
F_2 BH	551.0 ± 18.0
F_2 HB	464.5 ± 25.0
F_2 BH x HB	506.8 ± 19.6
F_2 HB x BH	495.3 ± 27.2
Bn (¾ B ¼ A x A)	508.8 ± 12.6
Bn (¾ A ¼ B x ½ B ½ A)	535.0 ± 21.2
Bn_2	452.3 ± 22.3

Table 46. Least squares means and standard errors for cow weight at 4 years of age by breed group[a]

Breed Group	LS Mean ± SE (kg)
A	518.5 ± 14.2
B	504.7 ± 10.1
H	478.5 ± 10.5
F_1 BA	534.5 ± 10.6
F_1 BH	524.3 ± 16.6
F_2 BA	494.0 ± 13.7
F_2 BH	533.7 ± 13.6
Bn	521.8 ± 11.5
Bn_2	447.7 ± 22.0

[a]See Table 6 for breed group designations.

Table 47. Cow weight contrasts and standard errors

L^{a}	Contrast ± SE (kg)
F_1 BA - MP[b]	22.9 ± 11.5†
F_2 BA - MP	-17.6 ± 14.4
F_1 BA - F_2 BA	40.5 ± 13.9**
F_1 BH - MP	32.7 ± 19.5
F_2 BH - MP	42.1 ± 14.4**
F_1 BH - F_2 BH	-9.4 ± 22.6
Bn - WMP[c]	8.5 ± 16.0
Bn_2 - WMP	-65.7 ± 22.6**
Bn - Bn_2	74.1 ± 25.4**
F_1 BA - Bn	12.7 ± 16.5

[a]See Table 6 for breed group designations.
[b]MP = Midparent value (mean of the two straightbreds involved in the cross)
[c]WMP = Weighted midparent value (3/8 B 5/8 A)
† $P < 0.10$
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Contrast estimates for differences among the breed groups for adjusted cow weight are shown in Table 47. F_1 BA cows exceeded (*P*<0.10) the midparent value by 22.9 ± 11.5 kg and were 40.5 ± 13.9 kg heavier (*P*<0.01) than the F_2 BA cows. The F_2 BH females were 42.1 ± 14.4 kg heavier (*P*<0.01) than their respective midparent value. The Bn_2 cows were the smallest of all the groups. They were 65.7 ± 22.6 kg lighter (*P*<0.01) than the midparent value and 74.1 ± 25.4 kg lighter (*P*<0.01) than the first generation Bn females.

SUMMARY AND CONCLUSIONS

Calf Crop Born and Weaned

Heterosis for calf crop born and calf crop weaned by cow breed group was estimated using linear contrasts of least squares means. The F_1 BA females expressed heterosis (*P*<0.001) for both calf crop born and calf crop weaned. Performance of the F_2 BA group was below the midparent value for both calf crop born and calf crop weaned (*P*<0.10). Both the F_1 and F_2 BH groups expressed heterosis (*P*<0.001) for calf crop born and calf crop weaned. The F_2 BH group did not show a loss of heterosis (*P*>0.10) when compared to the F_1 BH group. Bn_2 females outperformed Bn females for both calf crop born (*P*<0.001) and calf crop weaned (*P*<0.05).

Heterosis for calf crop born and calf crop weaned by cow breed group was also estimated using contrasts of least squares means within cow age groups. Heterosis for calf crop born was important for two year old F_1 BA cows (*P*<0.001), two year old F_2 BA cows (*P*<0.01), and four year old F_2 BA cows (*P*<0.05). None of the F_1 BH females expressed heterosis (*P*>0.10) for calf crop born, but the F_2 BH females expressed heterosis at four (*P*<0.01) and five (*P*<0.10) years of age. Heterosis for calf crop born was also important (*P*<0.01) for the Bn_2 cows at ages two and four.

F_1 BA females only expressed heterosis (*P*<0.001) for calf crop weaned at two years of age. F_2 BA females expressed heterosis (*P*<0.01) at two and four years of age. These results are the same as those seen for calf crop born. There was again no heterosis *P*>0.10) for calf crop weaned by the F_1 BH group, while heterosis was important (*P*<0.01) for the two and four year old F_2 BH cows. In the first and second generation

Bn groups, heterosis for calf crop weaned was only expressed (*P*<0.01) by the four year old Bn_2 cows.

Heterosis retained by the F_2 cows varied between breed groups. There was a difference (*P*<0.001) for calf crop born and calf crop weaned between the F_1 and F_2 BA groups at three and five years of age, indicating a loss of heterosis at these two ages for the F_2 females. Based on the results of the analysis across all ages, the F_2 BA group showed a substantial loss (*P*<0.001) of the heterosis expressed by the F_1 BA group for calf crop born. This is similar to results for *Bos indicus* x *Bos taurus* crosses in Australia reported by Seebeck (1973) and MacKinnon et al. (1989). F_1 BA females also had a higher (P<0.05) adjusted mean for calf crop weaned at two years of age than the F_2 BA females. Again, the results of the analysis across all ages show a substantial loss (*P*<0.001) of F_1 heterosis for calf crop weaned in the F_2 generation. Hargrove et al. (1991) also reported lower than expected estimates of retained heterosis for calf crop weaned in F_2 BA cows. F_2 BH cows had a higher (*P*<0.05) adjusted mean for calf crop born and calf crop weaned as two year olds than the F_1 BH group. Koger et al. (1975) reported results in which backcross B x Shorthorn females outperformed the F_1 generation females. In the analysis across all ages, no difference (*P*>0.10) was observed between the performance of F_1 and F_2 BH females for either calf crop born or calf crop weaned. The adjusted mean for calf crop born for Bn_2 cows was higher than that of the Bn cows at three (*P*<0.05) and four (*P*<0.01) years of age. Bn_2 cows also had a higher (*P*<0.05) adjusted mean for calf crop weaned at four years of age than that of the Bn cows. F_1 BA females also outperformed ($P<0.05$) the Bn females for calf crop born and calf crop weaned as two and three year olds.

According to the dominance model, F_1 females would be expected to express maximum heterosis, while F_2 females would be expected to retain half of the heterosis observed in the F_1 generation. When calf crop born was analyzed across all ages, heterosis expressed by the F_1 BA females was 0.10 ± 0.03. The F_2 BA adjusted mean (0.74 ± 0.03) was below the midparent value, so all of the heterosis expressed in the F_1 generation was lost. For calf crop weaned, all of the F_1 BA heterosis (0.11 ± 0.04) was lost in the F_2 generation, whose adjusted mean was again below the midparent average. Retained heterosis for both calf crop born and calf crop weaned for F_2 BA females was much less than predicted by the dominance model. Heterosis for calf crop born was 0.15 ± 0.03 for the F_1 BH group, and the F_2 BH group retained 86.7% of the F_1 heterosis. The F_1 BH group expressed heterosis of 0.16 ± 0.03 for calf crop weaned, and 93.8% of this heterosis was retained in the F_2 generation. In the F_2 BH group, heterosis retention exceeded expectations of the dominance model for calf crop born and calf crop weaned. Based on these results, it appears that the dominance model does not predict heterosis retention very well for these traits.

Within the F_2 BA and F_2 BH groups, there were differences in the performance of the different types of females in each group for both calf crop born and calf crop weaned. The AB-sired females in the F_2 BA group had higher adjusted means for calf crop born and calf crop weaned than the BA-sired females. Within the F_2 BH group, the females sired by HB bulls outperformed those sired by BH bulls for both calf crop born and calf crop weaned. Based on these observations, it may be advantageous for beef producers using Brahman x British F_2 females to consider the breed composition of the sires of these females. F_1 sires out of British bulls and Brahman dams may produce females that excel in reproductive efficiency.

Calf Survival

Calf survival was evaluated for cow breed groups using linear contrasts to estimate differences in adjusted means. None of the F_1 or F_2 cow breed groups expressed heterosis (P>0.10) for calf survival, and there were no differences (P>0.10) between the F_1 and F_2 generations within each breed group. The Bn_2 females had the lowest survival rate (0.78 ± 0.04) among all breed groups analyzed. This analysis by cow breed group fails to account for heterosis for direct effects on calf survival resulting from the calf being crossbred, as some of the breed groups produced only straightbred calves while others produced various types of crossbred calves.

Heterosis for calf survival was estimated for B- and H-influenced calf breed groups using linear contrasts of least squares means. Both the F_1 BH (P<0.05) and F_2 BH (P<0.001) groups expressed heterosis for calf survival, but there was no difference (P>0.1) between the F_1 and F_2 groups. There was no significant heterosis expressed in the $F_{2.5}$ BH, BANH, and $BANH_2$ groups. No difference was observed for calf survival between the reciprocal (B-sired vs. H-sired) F_1 BH crosses.

Birth and Weaning Weight

Linear contrasts of least squares means were used to estimate heterosis retention for birth and weaning weight in calf breed groups. None of the calf breed groups expressed significant heterosis for birth weight. B-sired F_1 BH calves were heavier (P<0.01) than the H-sired calves at birth. This reciprocal difference in birth weight was expected, as it is well-documented from previous studies (Cartwright et al., 1964; Roberson et al., 1986).

Both the F_1 and F_2 BH calves expressed heterosis (P<0.001) for weaning weight. The heterosis estimate for the F_1 BH calves is an approximation of heterosis for direct effects on weaning weight. The heterosis estimate for the F_2 BH calves estimates heterosis for maternal effects and retained heterosis for direct effects on weaning weight, as these calves were produced by F_1 generation dams. BANH calves were heavier (P<0.001) than the $BANH_2$ calves at weaning. The difference in reciprocal F_1 BH calves for weaning weight was the opposite of that observed for birth weight. The H-sired F_1 BH calves were heavier (P<0.10) than the B-sired calves. There were no differences (P<0.10) between the F_1 and F_2 BH groups for birth or weaning weight.

Cow Weight at Palpation

Heterosis for cow weight at four years of age was also estimated using linear contrasts of least squares means. F_1 BA females expressed heterosis (P<0.10) for cow weight and were heavier (P<0.01) than the F_2 BA females, indicating a loss of heterosis from the F_1 to F_2 generation. The F_1 BH cows did not express heterosis for cow weight, but heterosis was important (P<0.01) for the F_2 BH cows. The Bn_2 females were the lightest of all breeds analyzed.

Conclusions

The results of this study present additional questions regarding the validity of the dominance model for prediction of heterosis and heterosis retention for reproductive and maternal traits in *Bos indicus* x *Bos taurus* females. Heterosis retention estimates for the traits of interest were found to be lower than expectations of the dominance model for some groups and higher than expectations of the dominance model for other groups. Cows utilized in the present study will continue to be evaluated for lifetime production for reproductive and maternal traits to obtain additional information regarding heterosis retention in these types of crosses.

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VITA

Name:	Kelli Loren Key
Date of Birth:	November 25, 1974
Place of Birth:	Bryan, Texas
Parents:	Pierce and Emily Key
Education:	Texas A&M University, 1993-1997 B.S., Genetics, 1997
	Texas A&M University, 2000-2004 Ph.D., Animal Breeding, 2004
Address:	1607 Harpers Ferry College Station, TX 77845