EVALUATION OF HETEROSIS AND HETEROSIS RETENTION IN *BOS TAURUS-BOS INDICUS* CROSSBRED CATTLE FOR REPRODUCTIVE AND MATERNAL TRAITS IN COWS

A Thesis

by

RODNEY OLIVER NEUFELD ARCE

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

MASTER OF SCIENCE

December 2006

Major Subject: Animal Breeding

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Approved by:

Chair of Committee, James O. Sanders
Committee Members, Andy D. Herring
Wayne Hamilton
Head of Department, Gary Acuff

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ABSTRACT

Evaluation of Heterosis and Heterosis Retention in *Bos taurus-Bos indicus* Crossbred Cattle for Reproductive and Maternal Traits in Cows. (December 2006)

Rodney Oliver Neufeld Arce, DVM, National University of Asunción, Asunción

Chair of Advisory Committee: Dr. James O. Sanders

Reproductive, maternal and weight traits were analyzed for Angus (A), Brahman (B), Hereford (H), and Nellore (N) straightbred cows; F_1 NA; 3/8N 5/8A cows; and four breed composite cows (BANH) at the McGregor Research Station in Central Texas. Heterosis was estimated for calf crop born (CCB) (n = 1,698), calf crop weaned (CCW) (n = 1,698), calf survival (CS) (n = 1,388), birth weight (BW) (n = 1380), weaning weight (WW) (n = 1,198), and cow weight at palpation (PWT) (n = 1,929) by linear contrasts for cow breed and cow breed group. F_1 NA and the quarter breed composite BANH dam group expressed significant ($P < 0.0001$) heterosis for calf crop born and calf crop weaned. The 3/8 N 5/8 A_a produced by matings of 3/4 A 1/4 N bulls to NA dams expressed significantly more heterosis for CCB ($P < 0.0001$) and CCW ($P < 0.01$), while the 3/8 N 5/8 A_c dams expressed less heterosis than predicted from the dominance model for both traits.

For CS the 3/8 N 5/8 A_a expressed the same amount of heterosis as predicted from the dominance model of 0.05, while the 3/8 N 5/8 A_b and 3/8 N 5/8 A_c dams expressed less heterosis than predictions based on the dominance model. Heterosis estimates were only significantly higher ($P < 0.10$) for $BANH_b$ dams than expectations

from the dominance model. For BW all the BANH cows expressed significant heterosis except for the $BANH_2$ cows which expressed significant ($P < 0.05$) negative heterosis of -0.96 kg.

Calves out of F_1 NA cows were heaviest at weaning with 239 kg. All BANH cows expressed significant ($P < 0.0001$) heterosis for weaning weight except for the $BANH_c$ cows. These heterosis estimates were higher than those expected from the dominance model for $BANH_b$ and $BANH_2$ cows, while the heterosis estimate was slightly lower in $BANH_a$ cows and similar for $BANH_c$ cows. All 3/8 N 5/8 A cows expressed less heterosis for WW than prediction from the dominance model.

Nellore cows were the heaviest at four years of age with 542 kg. Only the $BANH_b$ and $BANH_c$ cows expressed significant ($P < 0.05$) heterosis for PWT. None of the 3/8 N 5/8 A cows expressed heterosis for cow weight at palpation.

Results from this study showed that heterosis levels expressed by the different crossbred cow types were generally equal or higher to those predicted by the dominance model.

DEDICATION

To my parents Heinrich and Mirtha

To Anna, Alexandra and Gregor

To Vanessa

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I would like to thank my committee chair Dr. James Sanders for his excellent guidance, expertise, and thoughts provided during my studies at Texas A&M University. I also would like to thank Dr. Andy Herring for his support and help provided during my stay in the U.S, and Mr. Wayne Hamilton for sharing his knowledge in the area of range management. A special thanks to Dr. Jason Sawyer for his time and helpful discussions. I also would like to extend my gratitude to all Animal Science graduate students for their help and support.

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INTRODUCTION

Heterosis is the superior performance of crossbred animals over the average of their purebred parental breeds. Heterosis is important for traits such as fertility, calf survival, growth and longevity. The highest level of heterosis is considered to be in the F_1 animal resulting from the mating of two different breeds. After subsequent *inter se* matings of F_1 animals the amount of heterosis to be maintained in these crosses is referred to as retained heterosis. The dominance model has been used successfully to estimate heterosis retained for most traits in *inter se* matings of *Bos taurus* crossbreds.

Crossbreeding to enhance productivity has been used in most countries around the world to increase productivity. Crossbred *Bos taurus-Bos indicus* females are widely used for their excellent productivity and longevity in subtropical and tropical regions of the world. While some crossbreeding systems present limitations to maintain an adequate and uniform genetic composition from generation to generation, others are difficult to apply in small herds or are not self contained.

The formation of composite breeds offers a valid alternative to existing crossbreeding systems. A composite breed is formed with contributions of two or more breeds and *inter se* mated to animals of the same breed composition. Composite breeds with an optimum number of specialized breeds can benefit from heterosis and breed complementarity and still maintain consistent performance levels, even in small herds.

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

The use of heterosis from crossbreeding of beef cattle breeds can increase the productivity for the beef cattle producer and the beef cattle industry. The cumulative effects of heterosis for combined traits such as weight weaned per cow exposed are economically important (Gregory and Cundiff, 1980).

Heterosis retention in composite breeds with exclusively *Bos taurus* breeds show good agreement with the dominance model for most of the traits evaluated, while heterosis retention in *Bos taurus/Bos indicus* composite breeds has not been evaluated adequately for reproductive and maternal traits.

LITERATURE REVIEW

Heterosis or hybrid vigor is the increased performance of crossbred animals over the average of their straightbred parental breeds. Crossbreeding in beef cattle has been proven effective to enhance the productivity in *Bos taurus* and *Bos indicus* crosses.

Heterosis in beef cattle is important for bioeconomic traits such as reproduction, calf survival, maternal ability, growth rate, and longevity (Gregory et al., 1999).

The F_1 animal, resulting from the mating of two different breeds, is expected to express the highest level of heterosis. After *inter se* matings of F_1 animals a certain amount of this F_1 heterosis is expected to remain in later generations.

Experimental results show that "…there is a high relationship between retained heterosis and retained heterozygosity, the relationship is not linear for all situations" (Gregory et al., 1999).

Gregory and Cundiff (1980) stated that a large percentage of the beef breeding herds in the United States are too small to make use of crossbreeding systems that are self contained. In addition, fluctuations among generations in additive genetic composition in rotational crossbreeding systems restrict the full advantage to be taken from crossbreeding systems.

The formation of composites through careful selection and matings among specific breeds to contribute to a specific composite breed was suggested by Gregory and Cundiff (1980) as an alternative to other crossbreeding systems.

The use of composite breeds gives the advantage to accomplish and maintain high levels of heterosis, consistent performance levels across generations, and an ideal breed composition matched to specific production scenarios and market requirements (Gregory et al., 1999).

Efficiency of Beef Production

Increasing the efficiency of beef production relies on improving economically important traits. These improvements can be made through selection within breeds to enhance certain characters considered desirable and through selection of combinations of breeds that fit better certain production conditions and available resources (Long, 1980).

Lifetime production depends upon survival and reproduction of cows and of growth rate and survival of their offspring. Crossbred cows can increase cumulative calf weight weaned over a cow's lifetime by 30% (Cundiff et al., 1992).

Breeds of Cattle Used in This Study

Angus and Hereford are British *Bos taurus* breeds used extensively in the U.S beef cattle industry. The Angus breed is originally from the northeastern part of Scotland from an area delimited by the counties of Aberdeen, Banff, Kincardine, and Angus. This breed is high in milk production and marbling. The Hereford breed is from Herefordshire in the west central part of England. Herefords are known for their superior performance under range conditions and their ability to withstand rigorous environmental influences (Briggs, 1969).

Bos indicus cattle were introduced to the Gulf Coast Region in the USA to improve adaptation of cattle to this area (Cartwright, 1980).

Brahman cattle were developed in the United States from different Zebu breeds imported from Brazil and India. It is known that different Zebu breeds like Gir, Guzerat, Indu-Brazil, and Nellore made important contributions to the Brahman breed. The Nellore or Ongole is a *Bos indicus* breed from India. Nellore cattle are the most numerous breed in Brazil. This breed differs from the Brahman in having smaller ears, females have tighter udders and bulls tend to have a tighter sheath (Sanders, 1980).

Straightbred Brahman cattle usually have low calving rates, calf survival rates, and weaning rates (Franke, 1980).

Gregory and Cundiff (1980) stated that "…although the straightbred performance of *Bos indicus* cattle that have been available has generally been low for most economic traits, the performance of crosses of *Bos indicus* and *Bos taurus* cattle has been impressive for most traits that contribute to maternal performance".

Cundiff (2005) stated that no individual breed excels in all traits of importance to beef production. Crosses of two or more breeds could be used to improve the performance for different traits. In order to increase production levels and reduce costs of production an increase in subtropical germplasm is needed in subtropical regions of the United States.

Heterosis and Heterosis Retention

Heterosis was defined by Lush (1945) as "the superiority of the outbred animals over the average of their parents in individual merit".

Different genetic models have been proposed to explain the causes of heterosis. One possible cause of heterosis has been described as dominance, or the interaction of alleles within a locus. Another possible cause for heterosis is epistasis, which can be defined as interaction between loci (Sheridan, 1981).

Bowman (1959) suggested that "…it is highly probable that there is no single genetical explanation for heterosis, but dominance, whether partial or complete, and all types of genetic interaction combined in different proportions in different situations result in heterosis."

Different types of heterosis have been described such as individual heterosis, which is the superior performance of the crossbred animal, and maternal heterosis, which is the enhanced performance of the offspring due to gene combinations in the dam.

The highest level of heterosis is expected to be in the F_1 animal resulting from the mating of two different breeds. When F_1 animals are *inter se* mated a certain amount of this F_1 heterosis is expected to remain in later generations. This remaining amount is considered as retained heterosis. The greatest amount of heterosis is lost from the F_1 to the F_2 generation when composites are *inter se* mated, but, if inbreeding is avoided, more loss should not occur based on the assumption that heterosis is proportional to degree of heterozygosity (Dickerson, 1969).

The response of heterosis is not restricted by low heritability, and has been found to be higher for traits that are low in heritability like fertility in females (Cartwright et al., 1964).

Gregory et al. (1999) suggested that higher levels of heterosis are achieved from crossing *Bos indicus* and *Bos taurus* breeds due to larger differences among these breeds. "Zebu cattle are valuable in crossbreeding, with adaptive aspects transmitted and large amounts of heterosis in growth, maternal effects, and reproductive traits" (Turner, 1980).

Gregory et al. (1999) in a long term study evaluated heterosis and heterosis retention in *Bos taurus* crosses. Several composite populations were formed from different *Bos taurus* breeds. The composites were denominated MARC I, II, III, and had the following breed composition:

MARC I: 1/4 Braunvieh 1/4 Charolais 1/4 Limousin 1/8 Hereford 1/8 Angus

MARC II: 1/4 Gelbvieh 1/4 Simmental 1/4 Hereford 1/4 Angus

MARC III: 1/4 Pinzgauer 1/4 Red Poll 1/4 Hereford 1/4 Angus

The traits analyzed in this study were maternal and reproductive traits in cows, growth traits, puberty traits in females and carcass traits in steers.

Heterosis retention in crosses where each of n breeds contributed equally was estimated by calculating (n-1)/n. This assumes that heterosis is proportional to degree of heterozygosity. When breeds did not contribute equally, then the amount of heterosis retained is estimated from one minus the squared fractions of each breed's contribution. Retained heterozygosity relative to the F_1 (maximum heterozygosity), for rotational crosses and composites containing different numbers of breeds were described in this study. The largest amount of heterozygosity expected to be retained is in a four breed rotation with 93.3%. Composites are expected to retain less heterozygosity than a four breed rotation. An eight breed composite with equal contributions of each breed is expected to retain 87.5%, while a four breed composite with equal contributions of each breed is expected to retain 75% of the initial heterozygosity.

A review by Long (1980) summarized heterosis effects in *Bos taurus* crosses and *Bos taurus-Bos indicus* crosses for different traits including maternal and weight traits. Average heterosis estimates for calving rate ranged from -12% to 11%. Heterosis estimates for calf survival to weaning ranged from -2% to 15%. Average heterosis effects for birth weight and weaning weight varied from 1% to 11% and 3% to 16%, respectively.

From a study in Florida, Hargrove et al. (1991a, 1991b) reported reproductive and weight traits from *inter se* mated F_1 and F_2 1/2 Brahman 1/2 Angus dams (BA) and 3/8 Brahman 5/8 Angus dams (3/8 B 5/8 A). The F_1 BA dams had significantly higher pregnancy rates ($P < 0.007$), higher calving rates ($P < 0.0001$), and higher weaning rates ($P < 0.0002$) then the F_2 BA and the 3/8B 5/8A dams indicating an important loss of heterosis for these breed groups. Calves out of F_1 BA dams were heavier at weaning with 239.09 kg, while calves out of 3/8B 5/8A and F_2 BA dams weighed 218.72 kg and 226.21 kg, respectively.

The reproductive traits evaluated by Gregory et al. (1999) were percentage pregnant, percentage born, and percentage of calves weaned. In general, results from this study support the hypothesis that retained heterosis in generations later than the F_1 is proportional to heterozygosity and can be accounted for by dominance effects of genes. Heterosis expressed for these traits in F_1 generation cows that produced F_2 calves were higher in the MARC I population than in the MARC II and III population. Average retained heterosis for F_2 and F_3 dams that produced F_3 and F_4 calves in the MARC I and MARC II population for reproductive traits did not differ ($P > 0.05$) from the amount of expected heterosis based on retained heterozygosity. For the MARC III population, heterosis retention for calf crop born and calf crop weaned was less than expected between the F_1 generation cows that produced F_2 offspring and F_2 and F_3 generation dams that produced F_3 and F_4 calves based on the retained heterozygosity, but not for percent pregnant. Retained heterosis for 200-day calf weight for the overall average of the three composite populations and the MARC II population was higher than expected based on retained heterozygosity.

In a study by Newman et al. (1993a) heterotic effects were evaluated for reproductive traits in a crossbred population of 1/2 Red Angus 1/4 Charolais and 1/4 Tarentaise. The F_1 generation was produced by matings of straightbred Red Angus x Charolais and Red Angus x Tarentaise. The F_2 generation was formed from reciprocal matings of 1/2 Red Angus 1/2 Tarentaise and 1/2 Red Angus 1/2 Charolais resulting in two breed groups, both with the same breed composition of 1/2 Red Angus 1/4 Charolais and 1/4 Tarentaise. The F_3 and F_4 generations were formed by *inter se* matings of these two breed groups. Results from this study showed 17.2% higher pregnancy rates ($P < 0.01$), 3.2% higher calving rates, and 2.1% higher weaning rates ($P < 0.05$) in the F_2 generation than in the F_1 generation. Generation F_3 and F_4 dams had lower pregnancy rates, calving rates, and weaning rates than the F_2 generation dams. Weaning weights from this same study were reported by Newman et al. (1993b) showing higher weaning weights in both the F_3 and F_4 generations over the F_2 and F_1 generation.

Magaña & Segura (2003) evaluated birth weights and weaning weights from various *Bos indicus* breeds and their crosses. Breeds evaluated were straightbred

Brahman, Gyr, Indu-brazil, commercial Zebu, and their crosses. Among all crosses, non-significant (P > 0.05) heterotic effects for the traits evaluated were observed suggesting less heterotic effects in *Bos indicus* x *Bos indicus* crosses than in *Bos taurus* x *Bos indicus* crosses.

A study from Brazil reported maternal and individual heterosis effects on preweaning gain in crossbred Nellore x Angus cattle from a large evaluation program involving 50 herds. Estimates for individual heterosis were 13.31 kg and for maternal heterosis 22.62 kg (Roso and Fries, 2000).

Sacco et al. (1991) evaluated heterosis retention for birth and weaning characters of calves in the third generation from a five breed diallel involving *Bos taurus* and *Bos indicus* breeds. Results from this study showed that heterosis retained varied for the different traits evaluated. Significant average heterosis was retained for weaning weight and hip height, but not for any of the birth traits or calf survival.

Key (2004) evaluated heterosis and heterosis retention for reproductive and maternal traits among *Bos taurus* (Angus and Hereford) and *Bos indicus* (Brahman and Nellore) cattle and their crosses. Results from this study showed that heterosis retention for the traits evaluated differed among the different breed groups. In some breed groups heterosis retention was found to be lower than expected from the dominance model, while in other groups heterosis retention was found to be higher. Heterosis estimates for calf crop born between Brahman and Angus and between Brahman and Hereford were 0.10 and 0.15, respectively. For calf crop weaned, heterosis estimates between Brahman and Angus and between Brahman and Hereford were 0.11 and 0.16, respectively. For the

F_2 Brahman/Angus breed group almost all heterosis was lost for calf crop born, calf survival, and calf crop weaned, while for the F_2 Brahman/Hereford breed group more heterosis was retained than predicted from the dominance model,

Morris et al. (1994) evaluated cow reproductive and maternal traits from *inter se* matings of Angus-Hereford cattle. For cow pregnancy rates the F_1 cows expressed heterosis (87.2%) over the purebred average (83.8%), while the F_2 cows expressed more heterosis (88.3%) than the F_1 group. The average of the F_3 and F_4 groups expressed less heterosis (86.3%) than the F_1's. For calf survival percentage the F_1 cows expressed heterosis (92.7%) when compared to the purebred average (90.6%), while the F_2 dams (91.7%) and combined F_3 and F_4 dams (92.3%) expressed less heterosis than the F_1 cow group. The F_1 cow group expressed heterosis for calf crop weaned (76.7%) over the purebred average (71.4%), while the combined F_3 and F_4 dams (70.5%) lost all of the heterosis expressed by the F_1 group. Adjusted weaning weights for purebred and F_1 calves were 143 kg and 148 kg, respectively. The F_2 calves had higher weaning weights (157 kg) than the F_1 calves, while the combined average of F_3, F_4, and F_5 calves was lower (146 kg) than in the F_1 calves.

Meuchel (2005) evaluated reproductive and weight traits for straightbred Angus (A), Brahman (B), Hereford (H), and Nellore (N) cows; 3/8N 5/8A cows; F_1 NA cows and quarter blood composite cows (BANH). The 3/8N 5/8A and the BANH cow groups were separated into different cow breed types according to the breeds of their parents. All three crossbred cow groups expressed significant heterosis effects for calf crop born and for calf crop weaned ($P < 0.0001$). Heterosis estimates for calf survival were near zero for almost all crossbred cow types. For birth weight, all crossbred types expressed positive heterosis with the exception of the F_1 NA group. Heterosis estimates for weaning weight varied among the different crossbred cow types. For some cow breed types less heterosis was expressed for weaning weight than expectations from the dominance model.

Models

In studies evaluating heterosis and heterosis retention results have typically been compared to what is expected from the dominance model. This model is used to estimate the amount of heterosis that is retained in later generations or in certain crosses. This model uses the fractions of the breeds involved in the cross in order to estimate the amount of heterosis. If heterosis for traits evaluated in different crosses is proportional to degree of heterozygosity, then heterosis can be accounted for by dominance effects of genes. The dominance model has been used in various studies to effectively predict heterosis retention for crosses involving *Bos taurus* breeds (Robison et al., 1981: Koch et al., 1985; Gregory at al., 1999), and in rotational crosses involving *Bos taurus* breeds and Brahman (Williams et al., 1990), but this model has not been found to adequately predict heterosis in *inter se* matings of *Bos indicus-Bos taurus* breeds, in at least some cases.

In a study by Koger et al. (1975) the authors evaluated heterosis effects in Brahman-Shorthorn crosses for weaning rate, weaning age, condition score, weaning weight, and 205-day weight. Results showed that the "…level of hybrid vigor observed in different mating groups was approximately linear with breed heterozygosity except for weaning rate where backcross dams were superior to F_1 cows”. Backcross and F_1 dams had average weaning rates of 75% and 65%, respectively. The authors suggest that “… a two breed rotation using Brahman and European breeds would be an effective procedure for crossbreeding cattle in a sustained program”.

MacKinnon et al. (1989) evaluated Africander, Brahman, and unselected and selected Hereford-Shorthorn crosses, the F_1 crosses of both the Brahman and Africander with the Hereford-Shorthorn crosses, the F_2 generations, and the combined F_3 generations and later (F_n). Heterosis estimates for calving rate for the F_1 Africander crosses (1/2 Africander 1/4 Shorthorn 1/4 Hereford) and for the F_1 Brahman crosses (1/2 Brahman 1/4 Shorthorn 1/4 Hereford) were 19.1% and 16.4%, respectively. Heterosis for calving rate in F_2 and F_n Africander crosses was 13.3% and 11.2%, respectively. Heterosis for the F_2 and F_n Brahman crosses was -5.2% and 1.6%, respectively. In reciprocal matings of the Africander and Brahman crosses (1/4 Africander 1/4 Brahman 1/4 Hereford 1/4 Shorthorn) the heterosis estimate for the F_1’s was 5.0% and was 4.8% for the F_2’s and F_n’s combined. Similar results were observed in a previous report by Seebeck (1973) reporting no loss of heterosis for calving rate for F_2 and F_3 combined Africander crosses, and a large loss of heterosis for the Brahman crosses.

Olson et al. (1993), and T. A. Olson (personal communication) evaluated heterosis and heterosis retention in two breed crosses and *inter se* matings of these crosses for Angus, Brahman, and Charolais cattle. Calves out of F_1 Brahman-Angus dams had survival rates of 95.0%, calves out of F_2’s had survival rates of 92.4%, while the purebred average for Brahman and Angus dams was 90.5%. Results for survival rates for F_2 Brahman-Angus dams are in good agreement with the dominance model. For Brahman-Charolais cows the amount of heterosis expressed for calf survival in calves out of F_1 and F_2 cows was lower than the midparent average of 91.5%. The F_2 cows had higher calf survival rates (88.6%) than the F_1 cows (82.4%).

For weaning weight of their calves, all F_1 dams combined expressed heterosis of 21.5 kg, while F_2 dams lost all the heterosis expressed in the F_1's (-0.8 kg). F_1 Brahman-Angus and F_1 Brahman-Charolais dams had average pregnancy rates of 94.7% and 88.8%, respectively. The F_2 Brahman-Angus dams and the F_2 Brahman-Charolais dams had pregnancy rates of 88.9% and 87.0%, respectively. F_1 and F_2 dams had averages of 91.8% and 88.0%, respectively. The overall average for purebred dams for pregnancy rate was 84.1%, with 92.6%, 79.2% and 85.5% for Angus, Brahman, and Charolais, respectively. Average F_1 heterosis for these crosses was 7.7%, while the F_2's retained 3.9%. The authors suggest that, "…epistatic recombination loss may have a greater effect on heterosis retention in *Bos taurus* x *Bos indicus* crosses…"

Discussion of Composites

The use of crossbreeding in beef cattle production can result in high levels of heterosis and increase productivity. Results from rotational crosses show that high levels of hybrid vigor can be retained in advanced generations, but fluctuations among generations in genetic composition makes it difficult to make use of breed complementarity (Gregory and Cundiff, 1980). Breed complementarity has been described by Gregory et al. (1999) as the utilization of breeds through specific matings to take advantage of the more desirable characteristics and decrease the influence of less desirable characteristics from each breed.

A composite breed is a breed formed from two or more base breeds in order to make use of heterosis with no further inclusion of other breeds. Composites are easy to manage, are mated to their same type, and yet retain high amounts of hybrid vigor (Bourdon, 2000). The use of composite breeds can offer a breeding system that generally can be comparable to crossbreeding for using heterosis and can be managed easier independently of herd size. High levels of uniformity can be reached within and between generations, and both heterosis and breed complementarity can simultaneously be achieved (Gregory, 1999).

Baker and Black (1950) evaluated weight traits for Angus, Brahman and Africander crosses to develop crossbred lines that fit better the production environment of the Gulf coast region. Results from this early study showed that higher weaning weights were obtained from crossbred animals when compared to purebred Angus cattle. Second generation offspring were obtained from crosses among different lines. Lower weaning weights in the second generation offspring was observed for the 1/4 Brahman 3/4 Angus, 3/8 Brahman 5/8 Angus, and 1/2 Brahman 1/2 Africander cross when compared to their respective first generation cross.

From most studies it can be concluded that heterosis retained in crossbred animals formed from two or more breeds is proportional to the degree of heterozygosity. Crosses among *Bos indicus* and *Bos taurus* breeds have been proven to produce high levels of heterosis. Gregory et al. (1999) suggest that "… a large scale, comprehensive experiment is needed to estimate retention of heterosis in advanced generations of *inter se* mated composite populations with contributions by both *Bos taurus* and *Bos indicus* breeds."

Gregory et al. (1992) evaluated heterosis and heterosis retention in three composite populations formed from different *Bos taurus* breeds including Angus, Hereford, Red Poll, Limousin, Braunvieh, Pinzgauer, Gelbvieh, Simmental, and Charolais. Percentage calf crop born, percentage pregnant, calf crop weaned percentage, 200-day calf weight, and 200-day calf weight per cow exposed were the traits evaluated. Retained heterosis for all traits evaluated was significant ($P<.01$) in the combined F_2 and F_3 MARC I population, and did not differ ($P>.05$) from expectation based on heterozygosity.

Cow Weight of *Bos indicus* Influenced Dams

Riley et al. (2001) evaluated cows out of Hereford dams and sired by bulls of several *Bos indicus* breeds and Angus bulls for reproductive, maternal, and size traits. Results from this study showed that all *Bos indicus* crossbred dams were heavier than Angus-sired dams, but only Gray Brahman, Red Brahman, and Indu-Brazil crossbred dams were significantly heavier ($P < 0.10$) than Angus sired cows.

In a study from Texas evaluating a five breed diallel, Sacco et al. (1990) reported that first generation Brahman-Hereford cross cows were heavier at first calving among all crossbred dams (500 kg), while second generation Brahman-Hereford cows were lighter (432 kg).

Key (2004) evaluated cow weight at palpation for Brahman-British crossbred cows in Central Texas. F_1 Hereford - Brahman crossbred dams (including Hereford x Brahman, where sire breed is listed first, and Brahman x Hereford cross dams) were the heaviest (496.5 kg) among all breed groups ($P < 0.10$). F_1 Brahman - Angus cows were 22.9 kg heavier than the midparent average for these two breeds. F_1 Brahman - Hereford dams were 32.7 kg heavier than the midparent average.

Arango et al. (2004) reported body measurements for crossbred cows from different sire breeds out of Hereford and Angus dams. Nellore-sired cows out of Angus dams weighed 466 kg and 553 kg at two and five years of age, respectively. In this study these Nellore-Angus dams ranked intermediate in weight when compared to large and moderate size *Bos taurus* sired dams.

Hargrove et al. (1991a) reported cow weights from F_1 and F_2 1/2 Brahman 1/2 Angus and 3/8 Brahman 5/8 Angus dams. F_1 dams were heavier (461.31 kg) than the F_2 dams (421.62 kg) and 3/8 Brahman 5/8 Angus dams (440.71 kg).

Environmental Influences on the Expression of Heterosis

Griffing and Zsiros (1971) suggested, based on experiments with plants, that the level of heterosis expressed is dependent upon how environmental influences affect the heterotic phenomena.

Long (1980) suggested that designing an optimal breeding system should be suited to a specific production system since variation in production environments will always exist, even at a local level.

Koger et al. (1975) evaluated heterosis effects in Brahman-Shorthorn crosses under three different pasture programs (native, combination of native and improved pastures, and high quality improved pasture). For weaning rates the level of hybrid vigor increased progressively from native to improved pasture programs, while heterosis for weaning weight was similar under native and highly improved pasture programs with 25% and 24%, respectively. Heterosis for production of weight weaned per cow exposed for crossbred dams increased gradually with pasture quality.

Plasse (1983) summarized crossbreeding results from Latin America involving different *Bos indicus* breeds, native *Bos taurus* (Criollo), and different European breeds. The author stated that the success of crossbreeding with specialized European breeds is dependent upon forage quality and effective disease control. If these conditions cannot be met, the use of native *Bos taurus* and Zebu breeds in crossbreeding programs, or Zebu breeds under a strict selection program seem to be more productive under extreme environmental conditions (e.g. parasites, disease, low forage quality) in some tropical and subtropical regions of the world.

OBJECTIVES

The objectives of this study are to:

1. Estimate heterosis between two *Bos indicus* (Nellore and Brahman) and two *Bos taurus* breeds (Angus and Hereford) for cow reproductive traits and maternal effects on traits of their calves.
2. Estimate retained heterosis for each trait in crosses produced by *inter se* matings of crosses between these *Bos indicus* and *Bos taurus* breeds.
3. Evaluate the adequacy of the dominance model to estimate heterosis retention in crosses produced by *inter se* matings between crosses of these *Bos indicus* and *Bos taurus* breeds.

MATERIALS AND METHODS

Description of Data

Data for this study were collected at the McGregor Research Center as part of Texas Agricultural Experiment Station Project H6883. Breed groups of approximately 50 cows have been formed for every breed and their crosses.

1. Straightbreds: Angus (A)

Brahman (B)

Nellore (N)

Hereford (H)

2. Crossbreds: a) **3/8N 5/8A** (the sire breed of the cow is listed first and the cow's dam breed is listed second) including 3/4A 1/4N x 1/2N 1/2A, 3/4N 1/4A x A, and 1/2N 1/2A x 3/4A 1/4N.

b) **F_1 1/2N 1/2A**

c) **1/4B 1/4A 1/4N 1/4H** including, 1/2B 1/2A x 1/2N 1/2H, 1/2N 1/2A x 1/2B 1/2H, 1/2N 1/2A x 1/2H 1/2B and 1/2N 1/2A x F_2 BH (including all possible breed combinations for the F_2 BH, which are BH x BH, HB x HB, HB x BH, and BH x HB).

All cows included in this study were produced at the McGregor Research Station and born between 1996 and 2002. Table 1 shows the breed designations and different matings to produce the cow breed types. In Table 2 are shown the number of cows evaluated and their respective birth years. In Table 3 are presented the breeds of bulls bred to dams in their respective breed group. Tables 4 and 5 show the number of observations for each trait evaluated.

Table 1. Breed designations and matings used to produce different breed combinations

Breeds	Mating
Angus (A)	A x A
Brahman (B)	B X B
Hereford (H)	H x H
Nellore (N)	N x N
Nellore x Angus (F_1 NA)	N x A
3/8Nellore 5/8Angus (3/8N 5/8A(a))	3/4A 1/4N x 1/2N 1/2A
3/8Nellore 5/8Angus (3/8N 5/8A(b))	3/4N 1/4A x A
3/8Nellore 5/8Angus (3/8N 5/8A(c))	1/2N 1/2A x 3/4A 1/4N
1/4Brahman 1/4Angus 1/4Nellore 1/4Hereford (BANH(a))	1/2B 1/2A x 1/2N1/2H
1/4Brahman 1/4Angus 1/4Nellore 1/4Hereford (BANH(b))	1/2N1/2A x 1/2B 1/2H
1/4Brahman 1/4Angus 1/4Nellore 1/4Hereford (BANH(c))	1/2N1/2A x 1/2H1/2B
1/4Brahman 1/4Angus 1/4Nellore 1/4Hereford ($BANH_2$)	1/2N1/2A x F_2 1/2B1/2H[a]

[a]F_2 BH represents al possible second generation breed combinations with BH x BH, HB x HB, HB x BH, and BH x HB

Table 2. Number and birth years for each cow breed

Cow Breed	Numbers	Birth Years
A	51	1997, 1998, 1999
B	58	1996, 1997, 1998, 1999, 2000
H	50	1996, 1997,1998,1998
N	42	1997, 1998, 1999, 2000, 2001, 2002
F_1 NA	50	1997, 1998, 1999
3/8N 5/8A(a)	61	2000, 2001, 2002
3/8N 5/8A(b)	10	1997
3/8N 5/8A(c)	9	1999, 2000, 2001, 2002
BANH(a)	16	1996, 1998, 1999, 2000
BANH(b)	27	1999, 2000, 2001, 2003
BANH(c)	6	2000, 2001
$BANH_2$	14	1999, 2000, 2001, 2003
Total	394	

[a]See Table 1 for breed designations

Table 3. Breeds of bulls exposed to cow breed groups

Cow breed group	Breeds of Bulls
A	A, C[a], N, 1/2N 1/2A, 3/4A 1/4N, 3/8N 5/8A
B	A, B, H, 1/2N 1/2A, 3/4A 1/4N, 3/8N 5/8A
H	A, B, H, N, W[b]
N	N, A
F_1 NA	A, 3/4A 1/4N
3/8N 5/8A[d]	1/2N 1/2A, 3/8N 5/8A, A, 3/4A 1/4N
BANH[e]	Bn[c], 3/4A 1/4N, A, 3/8N 5/8

[a]C - Charolais
[b]W - Wagyu
[c]Bn -Brangus
[d]Includes a, b , and c
[e]Includes a, b, c, and $BANH_2$

Table 4. Numbers of observations for reproductive traits within each cow breed[a]

Cow Breed	Calf Crop Born	Calf Crop Weaned	Calf Survival
A	231	231	197
B	310	310	205
H	252	252	192
N	149	149	99
F_1 NA	283	283	266
3/8N 5/8A(a)	172	172	161
3/8N 5/8A(b)	46	46	43
3/8N 5/8A(c)	25	25	21
BANH(a)	79	79	69
BANH(b)	93	93	82
BANH(c)	20	20	19
$BANH_2$	38	38	34
Total	1698	1698	1388

[a]See Table 1 for breed designations

Table 5. Numbers of observations for weight traits within each cow breed[a]

Cow Breed	Birth Weight	Weaning Weight	Cow Weight
A	195	173	265
B	202	177	350
H	192	174	280
N	97	73	158
F_1 NA	266	241	329
3/8N 5/8A(a)	161	140	216
3/8N 5/8A(b)	43	33	47
3/8N 5/8A(c)	21	17	31
BANH(a)	69	53	86
BANH(b)	82	74	99
BANH(c)	18	16	23
$BANH_2$	34	27	45
Total	1380	1198	1929

[a]See Table 1 for breed designations

All heifers were first exposed to bulls for two months as yearlings to calve at two years of age. All cows were bred to bulls to calve during the spring so that the majority of the births occurred between February and May. The following traits were recorded: calf birth weight and date, weaning date and weight, and condition score of calves at weaning. Cows were palpated for pregnancy at the time of weaning. Birth weights of all calves were recorded within 48 hours of birth. All calves were weaned at an approximate age of seven months. Straightbred *Bos taurus* cows and crossbred cows with *Bos indicus* breeds were culled from their herd when they failed to wean a calf for the second time. Brahman and Nellore cows were allowed to fail to wean a calf one more time before being culled from their herds (i.e., a total of three failures). Cows were also culled from their herds due to structural unsoundness or reproductive problems at any time of the year. At the time of palpation, cow weight and body condition score were recorded.

Traits Analyzed

Cow reproductive traits analyzed were: calf crop born, calf survival, and calf crop weaned. Calf crop born is expressed as the percentage of cows that gave birth to a calf during the season relative to the number of cows exposed. Calf survival is expressed as the percentage of cows that succeeded to wean a calf relative to the number of cows that gave birth (alive of dead) to a calf during that season. Calf crop weaned is expressed as percentage of cows that were successful in weaning a calf relative to the number of cows that were exposed to bulls in the previous breeding season. These traits were analyzed as binary traits, one indicating success and zero indicating failure. Weight traits analyzed were calf birth weight, calf weaning weight and cow weight at palpation.

Statistical Analysis

All reproductive and weight traits were analyzed in SAS using the PROC MIXED procedure (SAS, 1990). The data were analyzed using two methods. The crossbred females were separated according to the breeds of their parents. For example, the BANH females were divided into four groups: those that had 1/2B 1/2A sires and 1/2N 1/2H dams, 1/2N 1/2A sires and 1/2B 1/2H dams, 1/2N 1/2A sires and 1/2H 1/2B dams, and those that had 1/2N 1/2A sires and F_2 BH dams. In the second method, the crossbred females were combined into their respective breed groups according to their own breed combination.

Reproductive traits

Calf crop born, calf crop weaned, and calf survival were analyzed as dependent variables using mixed linear models. Fixed effects for these traits included breed of cow and age of cow for the overall analysis. Dam within dam breed and cow within cow breed were included as random effects. These traits were also evaluated by age of dam using a model that included age of the dam and breed of cow as fixed effects and dam of cow within cow breed and cow within breed as random effects. Heterosis expressed by crossbred cows was estimated for the different crossbred cow types and crossbred groups by linear contrasts of the adjusted crossbred mean from the midparent value of the breeds in the crossbred female. In addition, heterosis expressed by crossbred cows within four different age groups (2, 3, 4, and 5 year old dams) was also estimated by linear contrasts of the adjusted crossbred mean from the midparent value of the breeds in the crossbred female. Ages 2, 3, 4, and 5 were used due to larger number of observations available.

Weight traits

Calf birth weight and calf weaning weight were analyzed by cow breed and cow breed group. The model used to analyze birth weight included breed of dam, sex of calf, age of cow, and year as fixed effects. Age of calf at weaning within year/age of dam was included as a covariate in the weaning weight model for the overall analysis. For two to five year old cows, age of calf at weaning within age of dam was included as a covariate in the weaning weight model. Both models also included dam within dam breed and cow within breed as random effects. Heterosis was estimated by cow breed, cow breed group, and in 2, 3, 4, and 5 year old dams. Cow weight at palpation was analyzed for 4 year old cows, as this was the one age that had the most weight records across all breed types. The model used to evaluate cow weight included the fixed effects of breed of cow, year, and lactation status within breed. Dam of cow within cow breed and cow within breed were included in the model as random effects. Heterosis effects for this trait were also evaluated using linear contrasts.

RESULTS AND DISCUSSION

Calf Crop Born

Adjusted means for calf crop born by cow breed are presented in Table 6, and adjusted means for calf crop born by cow breed group are shown in Table 7. $BANH_c$ dams had the highest calf crop born among all cow breeds at 0.950. The F_1 NA cows had the highest calf crop born at 0.939 among cow breed groups. The 3/8N $5/8A_a$ produced by matings of 3/4 Nellore 1/4Angus bulls out of 1/2Nellore 1/2Angus cows were similar for calf crop born to F_1 NA dams at 0.94. Similar results for calf crop born were observed for straightbred Brahman and Nellore cows at 0.661 and 0.664, respectively. Note that these values for Brahman and Nellore include calvings at two years of age; since few of the Brahman and Nellore cows calved at two years of age, the values are reduced, accordingly. The $BANH_2$ dams produced by mating 1/2N 1/2A bulls to F_2 BH cows had a higher calf crop born than the $BANH_a$ and $BANH_b$ dams.

Adjusted means by dam age for cow breed are shown in Table 8 and adjusted means by dam age for cow breed group are presented in Table 9. Nellore and Brahman dams had the lowest calf crop born among all cow breeds at 2 years of age at 0.058 and 0.189, respectively. Lower calving rates are expected as two year olds due to later onset of puberty in *Bos indicus* females (Franke, 1980).

Calf crop born contrasts by cow breed and cow breed group are presented in Tables 10 and 11, respectively.

Table 6. Least squares means and standard errors (SE) for calf crop born by cow breed[a]

Cow breed	LS means $\pm$ SE
A	0.853 $\pm$ 0.02
B	0.661 $\pm$ 0.02
H	0.762 $\pm$ 0.02
N	0.664 $\pm$ 0.03
F_1 NA	0.939 $\pm$ 0.02
3/8N 5/8A(a)	0.936 $\pm$ 0.03
3/8N 5/8A(b)	0.935 $\pm$ 0.05
3/8N 5/8A(c)	0.840 $\pm$ 0.07
BANH(a)	0.873 $\pm$ 0.04
BANH(b)	0.882 $\pm$ 0.04
BANH(c)	0.950 $\pm$ 0.08
$BANH_2$	0.895 $\pm$ 0.06

[a]See Table 1 for breed designations

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

Cow breed group	**LS means ± SE**
A	0.853 ± 0.02
B	0.661 ± 0.02
H	0.762 ± 0.02
N	0.664 ± 0.03
F_1 NA	0.939 ± 0.02
3/8N 5/8A[a]	0.926 ± 0.02
BANH[b]	0.887 ± 0.02

[a]Includes 3/8N 5/8A a, b and c
[b]Includes BANH a, b, c and $BANH_2$

Table 8. Least squares means and standard errors (SE) for calf crop born[a] by cow age

	2 yrs	3 yrs	4 yrs	5 yrs
A	0.804 ± 0.05	0.878 ± 0.05	0.868 ± 0.06	0.829 ± 0.06
B	0.189 ± 0.05	0.768 ± 0.05	0.604 ± 0.05	0.877 ± 0.05
H	0.800 ± 0.05	0.575 ± 0.05	0.659 ± 0.05	0.789 ± 0.06
N	0.058 ± 0.06	0.857 ± 0.05	0.827 ± 0.06	0.950 ± 0.08
F_1 NA	0.938 ± 0.05	0.843 ± 0.05	0.980 ± 0.05	0.979 ± 0.05
3/8N 5/8A(a)	0.951 ± 0.04	0.902 ± 0.04	0.944 ± 0.06	1.00 ± 0.09
3/8N 5/8A(b)	1.00 ± 0.11	0.800 ± 0.11	0.889 ± 0.11	1.00 ± 0.12
3/8N 5/8A(c)	0.889 ± 0.11	0.875 ± 0.12	0.667 ± 0.14	1.00 ± 0.34
BANH(a)	0.813 ± 0.09	0.812 ± 0.09	0.929 ± 0.09	0.923 ± 0.10
BANH(b)	0.857 ± 0.06	0.826 ± 0.07	0.905 ± 0.07	0.944 ± 0.08
BANH(c)	1.00 ± 0.14	1.00 ± 0.14	0.833 ± 0.14	1.00 ± 0.24
$BANH_2$	0.786 ± 0.09	0.889 ± 0.11	1.00 ± 0.11	1.00 ± 0.17

[a]See Table 1 for breed designations

Table 8. Continued

6 yrs	**7 yrs**	**8 yrs**	**9 yrs**	**10 yrs**
0.903 ± 0.06	0.864 ± 0.08	0.846 ± 0.10	—	—
0.756 ± 0.06	0.769 ± 0.07	0.875 ± 0.09	1.00 ± 0.11	0.800 ± 0.15
0.935 ± 0.06	0.896 ± 0.06	0.800 ± 0.11	1.00 ± 0.20	—
0.733 ± 0.09	0.833 ± 0.14	0.667 ± 0.20	—	—
0.936 ± 0.05	0.965 ± 0.06	1.00 ± 0.11	—	—
—	—	—	—	—
1.00 ± 0.17	1.00 ± 0.20	1.00 ± 0.24	—	—
1.00 ± 0.34	—	—	—	—
1.00 ± 0.11	0.800 ± 0.15	0.750 ± 0.17	1.00 ± 0.24	—
1.00 ± 0.10	—	—	—	—
—	—	—	—	—
1.00 ± 0.24	—	—	—	—

[a]See Table 1 for breed designations

Table 9. Least squares means and standard errors (SE) for calf crop born by cow breed group by cow age

	2 yrs	3 yrs	4 yrs	5 yrs
A	0.804 $\pm$ 0.05	0.878 $\pm$ 0.05	0.868 $\pm$ 0.06	0.829 $\pm$ 0.06
B	0.189 $\pm$ 0.04	0.768 $\pm$ 0.05	0.604 $\pm$ 0.05	0.878 $\pm$ 0.05
H	0.800 $\pm$ 0.05	0.575 $\pm$ 0.05	0.659 $\pm$ 0.05	0.789 $\pm$ 0.06
N	0.059 $\pm$ 0.06	0.857 $\pm$ 0.05	0.827 $\pm$ 0.06	0.950 $\pm$ 0.08
F_1 NA	0.939 $\pm$ 0.05	0.843 $\pm$ 0.05	0.979 $\pm$ 0.05	0.979 $\pm$ 0.05
3/8N 5/8A[a]	0.950 $\pm$ 0.04	0.886 $\pm$ 0.04	0.902 $\pm$ 0.05	1.00 $\pm$ 0.07
BANH[b]	0.843 $\pm$ 0.04	0.852 $\pm$ 0.05	0.920 $\pm$ 0.05	0.946 $\pm$ 0.06

[a]Includes 3/8N 5/8A a, b and c

[b]Includes BANH a, b, c and $BANH_2$

Table 9. Continued

6 yrs	7 yrs	8 yrs	9 yrs	10 yrs
0.903 ± 0.06	0.864 ± 0.07	0.846 ± 0.09	—	—
0.757 ± 0.06	0.769 ± 0.07	0.875 ± 0.09	1.00 ± 0.11	0.800 ± 0.15
0.935 ± 0.06	0.897 ± 0.06	0.800 ± 0.11	1.00 ± 0.20	—
0.733 ± 0.09	0.833 ± 0.14	0.667 ± 0.20	—	—
0.936 ± 0.05	0.965 ± 0.06	1.00 ± 0.11	—	—
1.00 ± 0.15	1.00 ± 0.20	1.00 ± 0.24	—	—
1.00 ± 0.09	0.800 ± 0.15	0.750 ± 0.17	1.00 ± 0.24	—

[a]See Table 1 for breed designations
[b]Includes 3/8N 5/8A a, b and c
[c]Includes BANH a, b, c and $BANH_2$

Table 10. Calf crop born contrasts and standard errors (SE) by cow breed[a]

L	**Contrast ± SE**
F_1 NA vs MP[b]	0.18 ± 0.03***
3/8N 5/8A(a) vs WMP[c]	0.15 ± 0.03***
3/8N 5/8A(b) vs WMP[c]	0.15 ± 0.06*
3/8N 5/8A(c) vs WMP[c]	0.06 ± 0.08
3/8N 5/8A(a) vs EPV[e]	0.06 ± 0.03°
3/8N 5/8A(b) vs EPV[f]	0.02 ± 0.03
3/8N 5/8A(c) vs EPV[e]	-0.03 ± 0.07
BANH(a) vs MP	0.14 ± 0.04*
BANH(b) vs MP	0.15 ± 0.04**
BANH(c) vs MP	0.21 ± 0.08**
$BANH_2$ vs MP	0.16 ± 0.06*
$BANH_2$ vs F_1 BANH[d]	0.04 ± 0.06

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]WMP – weighted midparent value (3/8N 5/8A)
[d]F_1 BANH average calf crop born for BANH a, b, and c
[e]EPV – Expected performance value (WMP + 1/2 F_1 NA heterosis)
[f]EPV – Expected performance value (WMP + 3/4 F_1 NA heterosis)
§ P < 0.10
° P < 0.05
* P < 0.01
** P < 0.001
*** P < 0.0001

Table 11. Calf crop born contrasts and standard errors (SE) by cow breed group[a]

L	**Contrast + SE**
F_1 NA vs Mp[b]	0.18 + 0.03***
BANH[c] vs MP	0.15 + 0.03***
3/8N 5/8A[d] vs WMP[e]	0.14 + 0.03***

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]Includes 3/8N 5/8A a, b and c
[d]Includes BANH a, b, c and $BANH_2$
[e]WMP – weighted midparent value (3/8N 5/8A)
*** P < 0.0001

Heterosis estimates for the F_1 NA dams and BANH dams were estimated by linear contrasts from the midparent value of the purebreds in the cross. Contrasts estimates for 3/8N 5/8A dams were estimated from their weighted midparent value, which is 3/8 of Nellore and 5/8 of Angus. F_1 NA dams expressed significant heterosis ($P < 0.0001$) for calf crop born of 0.18. Both, the 3/8N 5/$8A_a$ ($P < 0.0001$) and 3/8N 5/$8A_b$ ($P < 0.01$) dams had significantly higher calf crop born (0.15) than their weighted midparent value. The 3/8N 5/$8A_c$ dams produced by mating 1/2N 1/2A bulls to 3/4A 1/4N dams had a higher calf crop born (0.06) than the weighted midparent average, but the difference was not significant.

All three BANH dam breeds expressed significant heterosis for calf crop born. The $BANH_a$ dams produced by mating 1/2N 1/2A bulls to 1/2B 1/2H dams had a higher heterosis estimate of 0.21 than the $BANH_a$ and $BANH_b$ dams with 0.14 and 0.15, respectively. $BANH_2$ dams produced by mating 1/2N 1/2A bulls to F_2BH dams also expressed significant ($P < 0.01$) heterosis for calf crop born of 0.16. If heterosis is proportional to the degree of heterozygosity, the $BANH_a$ dams would be expected to express one-fourth of the heterosis between Brahman and Nellore plus one-fourth of the heterosis between Brahman and Hereford plus one-fourth of the heterosis between Angus and Nellore plus one-fourth of the heterosis between Angus and Hereford. The heterosis expected to be expressed in the $BANH_b$, $BANH_c$, and $BANH_2$ dams if heterosis is proportional to degree of heterozygosity would be one-fourth the heterosis between Nellore and Brahman plus one-fourth of the heterosis between Nellore and Hereford plus one-fourth of the heterosis between Brahman and Angus plus one-fourth of the heterosis between Angus and Hereford. In this study the estimated heterosis for calf crop born between Nellore and Angus was 0.18. Heterosis estimates between other breeds were not made in this study. Key (2004) reported estimates for heterosis for calf crop born between Brahman and Hereford at 0.15 and between Brahman and Angus at 0.10. Heterosis levels between Brahman and Nellore, Nellore and Hereford, and Angus and Hereford can be estimated based on other studies. Heterosis levels between *Bos indicus* and *Bos indicus* and *Bos taurus* and *Bos taurus* crosses reported generally have been lower than those reported for crosses between *Bos indicus* and *Bos taurus* (Gregory et al., 1999; Magana and Segura, 2003). Based on this, heterosis levels between Nellore and Hereford could be estimated taking the average of the available heterosis levels of 0.18, 0.15 and 0.10 which is 0.14. Assuming that the heterosis expressed between *Bos indicus* and *Bos taurus* breeds is generally twice as large, it is expected that heterosis levels between *Bos indicus* x *Bos indicus* and *Bos taurus* x *Bos taurus* crosses would be half of this value (0.07). This heterosis estimate of 0.07 for calf crop born between *Bos indicus* x *Bos indicus* and *Bos taurus* x *Bos taurus* crosses is in the range of results reported by Long (1980).

Using these estimates to predict the heterosis based on the dominance model, the heterosis expected for the dominance model for $BANH_a$ dams is 0.12, and the heterosis expected for $BANH_b$, $BANH_c$, and $BANH_2$ dams is 0.10. Comparing these predictions from the dominance model to the heterosis estimates obtained in this study, which range from 0.14 to 0.21, it can be concluded that the amount of heterosis expressed by all BANH dams seems to be higher than the amount predicted from the dominance model.

Heterosis estimates can also be predicted for 3/8N 5/8A dams. The 3/8N $5/8A_a$ dams resulting from matings of 3/4A 1/4N bulls to 1/2N 1/2A cows and the 3/8N $5/8A_c$ dams resulting from matings of 1/2N 1/2A bulls to 3/4A 1/4N cows are expected to express one half of the heterosis of the F_1 NA. The 3/8N $5/8A_b$ dams resulting from mating 3/4N 1/4A bulls to Angus dams are expected to express 3/4 of the heterosis of the F_1. Based on this the 3/8N $5/8A_a$ and 3/8N $5/8A_c$ should express heterosis of about 0.09, and the 3/8N $5/8A_b$ dams should express heterosis of about 0.135. The 3/8N $5/8A_a$ dams expressed significantly ($P < 0.0001$) more heterosis at 0.15 than predicted from the dominance model (0.09), while the 3/8N $5/8A_c$ dams expressed less heterosis of 0.06, although the difference from expectation was not significant. The 3/8N $5/8A_b$ dams expressed more heterosis ($P < 0.01$) than predicted from the dominance model of 0.15.

The difference between the observed performance and the expected performance for calf crop born was estimated by linear contrast for 3/8N 5/8A dams and is presented in Table 10. The expected performance value is the estimated value obtained based on the dominance model. For 3/8N $5/8A_a$ and 3/8N $5/8A_c$ dams the expected performance value is the sum of the weighted midparent value (3/8N and 5/8A) and 1/2 of the heterosis expressed by the F_1. For the 3/8N $5/8A_b$ dams the expected performance value is the sum of the weighted midparent value (3/8N and 5/8A) and 3/4 of the heterosis expressed by the F_1. The 3/8N $5/8A_a$ ($P < 0.10$) and 3/8N $5/8A_b$ dams had higher performance levels than the expectations of the dominance model by 0.06

and 0.02, respectively. The 3/8N 5/8A_c dams had a lower performance than expected by 0.02.

Adjusted means for calf crop born by cow breed group for dams of two to five years of age are presented in Table 12. Averaging from two to five years of age, the F_1 NA dams and the 3/8N 5/8A dam had similar adjusted means for calf crop born of 0.935 and 0.934. Among straightbreds the Angus dams had the highest calf crop born of 0.845.

Calf crop born contrasts for two to five year old cows by cow breed group are presented in Table 13. All three breed groups at the age of two to five years expressed significantly higher ($P< 0.001$) calf crop born than their midparent or weighted midparent value. Calf crop born contrasts for two, three, four, and five year old dams are presented in Table 14.

At two years of age, all three breed groups expressed significantly higher ($P < 0.0001$) calf crop born than their midparent or weighted midparent value. These high calf crop born contrasts results at two years of age are due to very low calf crop born for Nellore and Brahman at 0.058 and 0.189, respectively. The F_1 NA group expressed negative heterosis at three years of age at -0.02, but expressed significant heterosis ($P < 0.10$) of 0.13 at four years of age. Note that the extremely high heterosis estimate at two years of age and the negative heterosis at three years of age are because almost none (0.058) of the Nellore heifers calved at two years of age, but most (0.857) calved at three years of age. The BANH group also expressed significant heterosis ($P < 0.01$) at four years of age at 0.18.

Table 12. Least squares means and standard errors (SE) for calf crop born by cow breed group for 2, 3, 4, and 5 year old dams

	2 yrs	**3 yrs**	**4 yrs**	**5 yrs**	**Overall**
A	0.804 ± 0.05	0.878 ± 0.05	0.868 ± 0.06	0.828 ± 0.06	0.845 ± 0.03
B	0.189 ± 0.04	0.768 ± 0.05	0.604 ± 0.05	0.878 ± 0.05	0.609 ± 0.03
H	0.800 ± 0.05	0.575 ± 0.05	0.659 ± 0.05	0.788 ± 0.06	0.706 ± 0.03
N	0.058 ± 0.06	0.857 ± 0.05	0.827 ± 0.06	0.950 ± 0.08	0.674 ± 0.03
F_1 NA	0.939 ± 0.05	0.843 ± 0.05	0.979 ± 0.05	0.979 ± 0.05	0.935 ± 0.03
3/8N 5/8A[a]	0.950 ± 0.04	0.886 ± 0.04	0.902 ± 0.05	1.00 ± 0.07	0.934 + 0.03
BANH[b]	0.84 ± 0.04	0.85 ± 0.05	0.92 ± 0.05	0.95 ± 0.06	0.890 ± 0.03

[a]Includes 3/8N 5/8A a, b and c
[b]Includes BANH a, b, c and $BANH_2$

Table 13. Calf crop born contrasts and standard errors (SE) by cow breed group[a] for 2 to 5 year old dams

L	**Contrast ± SE**
F_1 NA vs Mp[b]	0.18 ± 0.03***
BANH[c] vs MP	0.18 ± 0.03***
3/8N 5/8A[d] vs WMP[e]	0.15 ± 0.04***

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]Includes 3/8N 5/8A a, b and c
[d]Includes BANH a, b, c and $BANH_2$
[e]WMP – weighted midparent value (3/8N 5/8A)
*** P < 0.0001

Table 14. Calf crop born contrasts and standard errors (SE) by cow breed group for 2, 3, 4, and 5 year old dams

L	**2 yrs**	**3 yrs**	**4 yrs**	**5 yrs**
F_1 NA vs Mp[a]	0.51 $\pm$ 0.06***	-0.02 $\pm$ 0.07	0.13 $\pm$ 0.07[§]	0.09 $\pm$ 0.06
BANH[b] vs MP	0.38 $\pm$ 0.05***	0.08 $\pm$ 0.06	0.18 $\pm$ 0.06*	0.08 $\pm$ 0.05
3/8N 5/8A[c] vs WMP[d]	0.51 $\pm$ 0.05***	0.02 $\pm$ 0.06	0.05 $\pm$ 0.07	0.11 $\pm$ 0.07

[a]See Table 1 for breed designations

[b]MP - midparent average for the purebreds in the cross

[c]Includes 3/8N 5/8A a, b and c

[d]Includes BANH a, b, c and $BANH_2$

[e]WMP - weighted midparent value (3/8N 5/8A)

[§] $P < 0.10$

* $P < 0.01$

*** $P < 0.0001$

Calf Crop Weaned

Adjusted means for calf crop weaned by cow breed and by cow breed group are presented in Tables 15 and 16, respectively. The F_1 NA dams had the highest calf crop weaned at 0.859 among all cow breeds. The Nellore and Brahman dams had the lowest calf crop weaned at 0.488 and 0.569, respectively. Among the 3/8N 5/8A dams the 3/8N $5/8A_c$ group, produced by mating 1/2N 1/2A bulls to 3/4A 1/4N dams, had the lowest calf crop weaned at 0.678. The 3/8N $5/8A_a$ dams had the highest calf crop weaned in their group at 0.814. Among all BANH dams the $BANH_b$ and the $BANH_c$ dams had the highest calf crop weaned at 0.807 and 0.799, respectively. The $BANH_2$ dams had higher calf crop weaned at 0.712 than the $BANH_a$ dams with 0.678.

Adjusted means for calf crop weaned by breed by dam age and for breed group by dam age are presented in Tables 17 and 18, respectively. The F_1 NA dams had the highest calf crop weaned at 0.820 at two years of age. In Tables 19 and 20 are presented the estimated contrasts for calf crop weaned by cow breed and by cow breed group, respectively. Significant heterosis ($P < 0.0001$) for calf crop weaned of 0.23 was observed for F_1 NA dams. All 3/8N 5/8A dams expressed higher calf crop weaned than their weighted midparent value, but the difference was only significant ($P < 0.01$) for the 3/8N $5/8A_a$ dams at 0.17. All BANH dams expressed heterosis for calf crop weaned, but the contrasts were only significant for $BANH_b$ ($P < 0.05$) and $BANH_c$ ($P < 0.10$) dams at 0.17 and 0.19, respectively. All cow breed groups expressed significantly ($P < 0.0001$) higher calf crop weaned than their weighted or midparent value.

Table 15. Least squares means and standard errors (SE) for calf crop weaned by cow breed[a]

Cow breed	LS means $\pm$ SE
A	0.746 $\pm$ 0.03
B	0.569 $\pm$ 0.03
H	0.688 $\pm$ 0.03
N	0.488 $\pm$ 0.04
F_1 NA	0.859 $\pm$ 0.03
3/8N 5/8A(a)	0.814 $\pm$ 0.03
3/8N 5/8A(b)	0.759 $\pm$ 0.07
3/8N 5/8A(c)	0.678 $\pm$ 0.09
BANH(a)	0.669 $\pm$ 0.05
BANH(b)	0.807 $\pm$ 0.05
BANH(c)	0.799 $\pm$ 0.10
$BANH_2$	0.712 $\pm$ 0.07

[a]See Table 1 for breed designations

Table 16. Least squares means and standard errors (SE) for calf crop weaned by cow breed group

Cow breed group	LS means ± SE
A	0.747 ± 0.03
B	0.569 ± 0.03
H	0.688 ± 0.03
N	0.489 ± 0.04
F_1 NA	0.858 ± 0.03
3/8N 5/8A[a]	0.789 ± 0.03
BANH[b]	0.739 ± 0.03

[a]Includes 3/8N 5/8A a, b and c

[b]Includes BANH a, b, c and $BANH_2$

Table 17. Least squares means and standard errors (SE) for calf crop weaned[a] by cow breed by cow age

	2 yrs	3 yrs	4 yrs	5 yrs
A	0.568 $\pm$ 0.06	0.804 $\pm$ 0.07	0.814 $\pm$ 0.07	0.798 $\pm$ 0.07
B	0.138 $\pm$ 0.06	0.678 $\pm$ 0.06	0.490 $\pm$ 0.06	0.795 $\pm$ 0.06
H	0.700 $\pm$ 0.06	0.489 $\pm$ 0.06	0.590 $\pm$ 0.06	0.762 $\pm$ 0.07
N	0.028 $\pm$ 0.07	0.714 $\pm$ 0.06	0.428 $\pm$ 0.08	0.751 $\pm$ 0.09
F_1 NA	0.820 $\pm$ 0.06	0.800 $\pm$ 0.06	0.840 $\pm$ 0.06	0.875 $\pm$ 0.06
3/8N 5/8A(a)	0.705 $\pm$ 0.05	0.836 $\pm$ 0.05	0.918 $\pm$ 0.07	0.929 $\pm$ 0.11
3/8N 5/8A(b)	0.800 $\pm$ 0.13	0.700 $\pm$ 0.13	0.665 $\pm$ 0.14	0.873 $\pm$ 0.15
3/8N 5/8A(c)	0.555 $\pm$ 0.14	0.749 $\pm$ 0.15	0.665 $\pm$ 0.17	0.993 $\pm$ 0.41
BANH(a)	0.500 $\pm$ 0.10	0.687 $\pm$ 0.10	0.713 $\pm$ 0.11	0.844 $\pm$ 0.12
BANH(b)	0.785 $\pm$ 0.08	0.653 $\pm$ 0.09	0.857 $\pm$ 0.09	0.944 $\pm$ 0.10
BANH(c)	0.666 $\pm$ 0.17	0.833 $\pm$ 0.17	0.833 $\pm$ 0.17	0.995 $\pm$ 0.30
$BANH_2$	0.500 $\pm$ 0.11	0.779 $\pm$ 0.14	0.891 $\pm$ 0.14	1.00 $\pm$ 0.20

[a]See Table 1 for breed designations

Table 17. Continued

6 yrs	7 yrs	8 yrs	9 yrs	10 yrs
0.836 ± 0.08	0.769 ± 0.09	0.688 ± 0.12	—	—
0.675 ± 0.07	0.729 ± 0.08	0.685 ± 0.10	0.696 ± 0.13	0.798 ± 0.19
0.900 ± 0.08	0.824 ± 0.08	0.595 ± 0.13	0.991 ± 0.24	—
0.532 ± 0.11	0.829 ± 0.17	0.667 ± 0.24	—	—
0.872 ± 0.6	0.927 ± 0.08	0.898 ± 0.13	—	—
—	—	—	—	—
0.498 ± 0.21	0.997 ± 0.24	0.994 ± 0.30	—	—
0.993 ± 0.42	—	—	—	—
0.996 ± 0.14	0.396 ± 0.19	0.247 ± 0.21	0.499 ± 0.30	—
1.00 ± 0.24	—	—	—	—
—	—	—	—	—
0.504 ± 0.30	—	—	—	—

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

	2 yrs	**3 yrs**	**4 yrs**	**5 yrs**
A	0.568 $\pm$ 0.06	0.804 $\pm$ 0.07	0.815 $\pm$ 0.07	0.798 $\pm$ 0.07
B	0.138 $\pm$ 0.06	0.678 $\pm$ 0.06	0.490 $\pm$ 0.06	0.795 $\pm$ 0.06
H	0.700 $\pm$ 0.06	0.489 $\pm$ 0.06	0.590 $\pm$ 0.06	0.762 $\pm$ 0.07
N	0.029 $\pm$ 0.07	0.714 $\pm$ 0.06	0.414 $\pm$ 0.08	0.751 $\pm$ 0.09
F_1 NA	0.816 $\pm$ 0.06	0.804 $\pm$ 0.06	0.837 $\pm$ 0.06	0.875 $\pm$ 0.06
3/8N 5/8A[a]	0.700 $\pm$ 0.05	0.810 $\pm$ 0.05	0.843 $\pm$ 0.06	0.913 $\pm$ 0.09
BANH[b]	0.641 $\pm$ 0.05	0.704 $\pm$ 0.06	0.800 $\pm$ 0.06	0.918 $\pm$ 0.07

[a]Includes 3/8N 5/8A a, b and c

[b]Includes BANH a, b, c and $BANH_2$

Table 18. Continued

6 yrs	7 yrs	8 yrs	9 yrs	10 yrs
0.836 ± 0.08	0.770 ± 0.09	0.689 ± 0.12	—	—
0.675 ± 0.07	0.730 ± 0.08	0.685 ± 0.10	0.697 ± 0.13	0.798 ± 0.19
0.900 ± 0.08	0.825 ± 0.08	0.596 ± 0.13	0.993 ± 0.24	—
0.533 ± 0.11	0.831 ± 0.17	0.667 ± 0.24	—	—
0.872 ± 0.06	0.929 ± 0.08	0.899 ± 0.13	—	—
0.599 ± 0.19	0.999 ± 0.24	0.997 ± 0.30	—	—
0.928 ± 0.11	0.398 ± 0.19	0.249 ± 0.21	0.500 ± 0.30	—

Table 19. Calf crop weaned contrasts and standard errors (SE) by cow breed[a]

L	**Contrast ± SE**
F_1 NA vs MP[b]	0.24 ± 0.04***
3/8N 5/8A(a) vs WMP[c]	0.16 ± 0.07*
3/8N 5/8A(b) vs WMP[c]	0.11 ± 0.07
3/8N 5/8A(c) vs WMP[c]	0.03 ± 0.10
3/8N 5/8A(a) vs EPV[e]	0.05 ± 0.04
3/8N 5/8A(b) vs EPV[f]	-0.07 ± 0.07
3/8N 5/8A(c) vs EPV[e]	-0.09 ± 0.09
BANH(a) vs MP	0.05 ± 0.05
BANH(b) vs MP	0.18 ± 0.05*
BANH(c) vs MP	0.18 ± 0.10[§]
$BANH_2$ vs MP	0.09 ± 0.08
$BANH_2$ vs F_1 BANH[d]	-0.04 ± 0.08

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]WMP – weighted midparent value (3/8N 5/8A)
[d]F_1 BANH average calf crop born for BANH a, b, and c
[e]EPV – Expected performance value (WMP + 1/2 F_1 NA heterosis)
[f]EPV – Expected performance value (WMP + 3/4 F_1 NA heterosis)
[§] P < 0.10
[o] P < 0.05
* P < 0.01
** P < 0.001
*** P < 0.0001

Table 20. Calf crop weaned contrasts and standard errors (SE) by cow breed group[a]

L	**Contrast ± SE**
F_1 NA vs Mp[a]	0.24 ± 0.04***
BANH[b] vs MP	0.12 ± 0.03**
3/8N 5/8A[c] vs WMP[d]	0.14 ± 0.04**

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]Includes BANH a, b, c and $BANH_2$
[d]Includes 3/8N 5/8A a, b and c
[e]WMP – weighted midparent value (3/8N 5/8A)
** P < 0.001
*** P < 0.0001

The heterosis estimate for calf crop weaned between Nellore and Angus was 0.24. Heterosis estimates for calf crop weaned were reported by Key (2004) for Brahman and Hereford and between Brahman and Angus as 0.16 and 0.11, respectively. Applying the same reasoning as in calf crop born, the heterosis expectations based on the dominance model for calf crop weaned can be calculated. Based on the dominance model the 3/8N $5/8A_a$ and 3/8N $5/8A_c$ should express heterosis of about 0.12 and the 3/8N $5/8A_b$ dams heterosis of about 0.18 for calf crop weaned. The 3/8N $5/8A_a$ dams expressed ($P < 0.01$) more heterosis than predicted from the dominance model of 0.16, while the 3/8N $5/8A_b$ and 3/8N $5/8A_c$ dams expressed less heterosis than predicted from the dominance model. The expected performance for 3/8N 5/8A_a dams was higher than expected from predictions based on the dominance model by 0.05, while for 3/8N 5/8A_b dams and 3/8N 5/8A_c dams the value was lower than predicted by 0.07 and 0.09, respectively.

For the $BANH_a$ crosses the amount of heterosis is expected to be 0.15; and expectations for the $BANH_b$, $BANH_c$ and the $BANH_2$ crosses are 0.12. Heterosis estimates from this study for the $BANH_a$ crosses were lower (0.05) than expected from the dominance model (0.15), and not significantly different from their midparent value. For the $BANH_b$ (0.18) and $BANH_c$ (0.18) crosses, heterosis estimates were higher than expectations from the dominance model at 0.12. Heterosis estimates for the $BANH_2$ crosses were lower (0.09) than expectations based on the dominance model.

Adjusted means for calf crop weaned for two to five year old dams are presented in Table 21; calf crop weaned contrasts for two to five year old dams are presented in Table 22, and calf crop weaned contrasts for two, three, four, and five year old dams are presented in Table 23. At five years of age the BANH breed group had the highest calf crop weaned at 0.919. All breed groups between two to five years of age (i.e., averaged across these ages) had significantly higher ($P < 0.0001$) calf crop weaned than their weighted midparent values.

Calf crop weaned for all breed groups were significantly higher ($P < 0.0001$) at the age of two years than their weighted midparent value. Also, significantly higher (P 0.01) calf crop weaned was observed for all breed groups at four years of age. For the three and five year old dams, higher calf crop weaned than the midparent average was observed, but was only significantly different for the BANH group ($P < 0.05$) at 0.14 at five years of age. Note that the very high heterosis estimate at two years of age and the lower heterosis estimates for three year old dams are due to very low calf crop weaned by Nellore and Brahman heifers at two years of age.

Table 21. Least squares means and standard errors (SE) for calf crop weaned by cow breed group for 2, 3, 4, and 5 year old dams

	2 yrs	**3 yrs**	**4 yrs**	**5 yrs**	**Overall**
A	0.568 ± 0.06	0.805 ± 0.07	0.816 ± 0.07	0.800 ± 0.07	0.747 ± 0.03
B	0.138 ± 0.06	0.679 ± 0.06	0.491 ± 0.06	0.796 ± 0.06	0.526 ± 0.03
H	0.700 ± 0.06	0.489 ± 0.06	0.591 ± 0.06	0.763 ± 0.07	0.636 ± 0.03
N	0.029 ± 0.07	0.714 ± 0.06	0.414 ± 0.08	0.750 ± 0.09	0.477 ± 0.04
F_1 NA	0.816 ± 0.06	0.804 ± 0.06	0.837 ± 0.06	0.875 ± 0.06	0.833 ± 0.03
3/8N 5/8A[a]	0.700 ± 0.05	0.811 ± 0.05	0.843 ± 0.06	0.913 ± 0.09	0.816 ± 0.03
BANH[b]	0.641 ± 0.05	0.704 ± 0.06	0.800 ± 0.06	0.919 ± 0.07	0.767 ± 0.03

[a]Includes 3/8N 5/8A a, b and c
[b]Includes BANH a, b, c and $BANH_2$

Table 22. Calf crop weaned contrasts and standard errors (SE) by cow breed group[a] for 2 to 5 year old dams

L	**Contrast ± SE**
F_1 NA vs Mp[b]	0.22 ± 0.04***
BANH[c] vs MP	0.17 ± 0.04***
3/8N 5/8A[d] vs WMP[e]	0.17 ± 0.04***

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]Includes 3/8N 5/8A a, b and c
[d]Includes BANH a, b, c and $BANH_2$
[e]WMP – weighted midparent value (3/8N 5/8A)
*** P < 0.0001

Table 23. Calf crop weaned contrasts and standard errors (SE) by cow breed group for 2, 3, 4, and 5 year old dams

L	**2 yrs**	**3 yrs**	**4 yrs**	**5 yrs**
F_1 NA vs Mp[a]	0.52 + 0.08***	0.04 + 0.08	0.22 + 0.08*	0.10 + 0.08
BANH[b] vs MP	0.28 + 0.06***	0.03 + 0.07	0.22 + 0.07*	0.14 + 0.07°
3/8N 5/8A[c] vs WMP[d]	0.40 + 0.07***	0.05 + 0.07	0.23 + 0.08*	0.14 + 0.09

[a]See Table 1 for breed designations
[b]MP - midparent average for the purebreds in the cross
[c]Includes 3/8N 5/8A a, b and c
[d]Includes BANH a, b, c and $BANH_2$
[e]WMP - weighted midparent value (3/8N 5/8A)
° P < 0.05
* P < 0.01
*** P < 0.0001

Calf Survival

Adjusted means for calf survival by cow breed and by cow breed group are presented in Tables 24 and 25, respectively. Note that sire breed of calf is partially confounded with breed of cow. Hereford and F_1 NA dams had the highest calf survival at 0.90 among cow breed groups. The 3/8N $5/8A_c$ dams produced by mating 1/2N 1/2A bulls to 3/4A 1/4N dams had lower calf survival at 0.80 than the 3/8N $5/8A_a$ dams produced by mating 3/4A 1/4N bulls to 1/2N 1/2A dams at 0.87. $BANH_b$ dams had the highest calf survival among all BANH dams at 0.92. Nellore dams had the lowest calf survival rates at 0.74.

Adjusted means for calf survival by breed x dam age and by breed group x dam age are presented in Tables 26 and 27, respectively. The $BANH_b$ dams produced by mating 1/2N 1/2A bulls to 1/2B 1/2H dams had the highest calf survival rates at 0.92.

Calf survival contrasts by dam breed and by dam breed group are presented in Tables 28 and 29, respectively. The F_1 NA dams expressed significant ($P < 0.01$) heterosis for calf survival of 0.10. Most of the contrast estimates were negative, but not significantly different, except for the $BANH_a$ dams which expressed significant ($P < 0.10$) negative heterosis for calf survival of 0.08. The $BANH_b$ crosses expressed significant ($P < 0.10$) heterosis for calf survival of 0.08. Among cow breed groups the BANH crosses expressed negative heterosis for calf survival of 0.01, while the 3/8N 5/8A group expressed higher calf survival than their weighted midparent value by 0.03. Applying the same reasoning as before, we can estimate the amount of heterosis expected for the BANH crosses. Heterosis levels for calf survival reported by Key

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

Cow breed	**LS means ± SE**
A	0.871 ± 0.03
B	0.863 ± 0.03
H	0.903 ± 0.03
N	0.735 ± 0.04
F_1 NA	0.904 ± 0.02
3/8N 5/8A(a)	0.869 ± 0.03
3/8N 5/8A(b)	0.807 ± 0.06
3/8N 5/8A(c)	0.802 ± 0.08
BANH(a)	0.764 ± 0.04
BANH(b)	0.916 ± 0.04
BANH(c)	0.838 ± 0.08
$BANH_2$	0.797 ± 0.06

[a]See Table 1 for breed designations

Table 25. Least squares means and standard errors (SE) for calf survival by cow breed group

Cow breed group	LS means ± SE
A	0.872 ± 0.03
B	0.863 ± 0.03
H	0.903 ± 0.03
N	0.736 ± 0.04
F_1 NA	0.904 ± 0.02
3/8N 5/8A[a]	0.852 ± 0.03
BANH[b]	0.834 ± 0.03

[a]Includes 3/8N 5/8A a, b and c
[b]Includes BANH a, b, c and $BANH_2$

Table 26. Least squares means and standard errors (SE) for calf survival[a] by cow breed by cow age

	2 yrs	**3 yrs**	**4 yrs**	**5 yrs**
A	0.706 ± 0.05	0.910 ± 0.06	0.935 ± 0.06	0.961 ± 0.06
B	0.719 ± 0.10	0.887 ± 0.05	0.814 ± 0.06	0.902 ± 0.05
H	0.873 ± 0.05	0.852 ± 0.06	0.895 ± 0.06	0.964 ± 0.06
N	0.515 ± 0.23	0.831 ± 0.06	0.498 ± 0.07	0.793 ± 0.08
F_1 NA	0.872 ± 0.05	0.953 ± 0.05	0.857 ± 0.05	0.892 ± 0.05
3/8N 5/8A(a)	0.741 ± 0.05	0.926 ± 0.05	0.975 ± 0.06	0.935 ± 0.09
3/8N 5/8A(b)	0.800 ± 0.11	0.868 ± 0.12	0.746 ± 0.12	0.868 ± 0.12
3/8N 5/8A(c)	0.621 ± 0.12	0.856 ± 0.13	0.998 ± 0.17	0.982 ± 0.33
BANH(a)	0.617 ± 0.09	0.845 ± 0.09	0.766 ± 0.09	0.904 ± 0.10
BANH(b)	0.916 ± 0.07	0.719 ± 0.08	0.949 ± 0.08	1.00 ± 0.08
BANH(c)	0.667 ± 0.14	0.833 ± 0.14	0.996 ± 0.15	0.983 ± 0.24
$BANH_2$	0.640 ± 0.10	0.879 ± 0.12	0.896 ± 0.11	1.00 ± 0.17

[a]See Table 1 for breed designations

Table 26. Continued

6 yrs	7 yrs	8 yrs	9 yrs	10 yrs
0.921 ± 0.06	0.885 ± 0.08	0.811 ± 0.10	—	—
0.890 ± 0.06	0.947 ± 0.07	0.783 ± 0.09	0.699 ± 0.11	1.00 ± 0.17
0.961 ± 0.06	0.919 ± 0.07	0.744 ± 0.12	0.978 ± 0.19	—
0.726 ± 0.10	0.993 ± 0.15	1.00 ± 0.24	—	—
0.929 ± 0.05	0.955 ± 0.06	0.896 ± 0.11	—	—
—	—	—	—	—
0.494 ± 0.17	0.984 ± 0.19	0.976 ± 0.24	—	—
0.982 ± 0.33	—	—	—	—
0.987 ± 0.11	0.482 ± 0.17	0.324 ± 0.19	0.503 ± 0.24	—
1.00 ± 0.19	—	—	—	—
—	—	—	—	—
0.505 ± 0.24	—	—	—	—

Table 27. Least squares means and standard errors (SE) for calf survival by cow breed group by cow age

	2 yrs	3 yrs	4 yrs	5 yrs
A	0.706 ± 0.05	0.911 ± 0.06	0.935 ± 0.06	0.961 ± 0.06
B	0.719 ± 0.10	0.89 ± 0.05	0.813 ± 0.06	0.902 ± 0.05
H	0.874 ± 0.05	0.852 ± 0.06	0.895 ± 0.06	0.964 ± 0.06
N	0.513 ± 0.24	0.831 ± 0.06	0.498 ± 0.07	0.793 ± 0.08
F_1 NA	0.869 ± 0.05	0.953 ± 0.05	0.854 ± 0.05	0.892 ± 0.05
3/8N 5/8A[a]	0.736 ± 0.04	0.912 ± 0.04	0.937 ± 0.05	0.915 ± 0.07
BANH[b]	0.759 ± 0.05	0.826 ± 0.05	0.871 ± 0.05	0.967 ± 0.06

[a]Includes 3/8N 5/8A a, b and c

[b]Includes BANH a, b, c and $BANH_2$

Table 27. Continued

6 yrs	**7 yrs**	**8 yrs**	**9 yrs**	**10 yrs**
0.921 ± 0.06	0.886 ± 0.08	0.812 ± 0.10	—	—
0.891 ± 0.06	0.947 ± 0.07	0.784 ± 0.09	0.699 ± 0.11	1.00 ± 0.17
0.961 ± 0.06	0.919 ± 0.07	0.745 ± 0.12	0.980 ± 0.19	—
0.726 ± 0.10	0.993 ± 0.15	1.00 ± 0.24	—	—
0.929 ± 0.05	0.957 ± 0.06	0.897 ± 0.11	—	—
0.597 ± 0.15	0.993 ± 0.20	0.988 ± 0.24	—	—
0.937 ± 0.09	0.489 ± 0.17	0.331 ± 0.19	0.507 ± 0.24	—

Table 28. Calf survival contrasts and standard errors (SE) by cow breed[a]

L	**Contrast ± SE**
F_1 NA vs MP[b]	0.10 ± 0.03*
3/8N 5/8A(a) vs WMP[c]	0.05 ± 0.03
3/8N 5/8A(b) vs WMP[c]	-0.01 ± 0.06
3/8N 5/8A(c) vs WMP[c]	-0.02 ± 0.06
3/8N 5/8A(a) vs EPV[e]	-0.001 ± 0.03
3/8N 5/8A(b) vs EPV[f]	-0.09 ± 0.06
3/8N 5/8A(c) vs EPV[e]	-0.07 ± 0.08
BANH(a) vs MP	-0.08 ± 0.05[§]
BANH(b) vs MP	0.08 ± 0.04[§]
BANH(c) vs MP	-0.01 ± 0.08
$BANH_2$ vs MP	-0.04 ± 0.06
$BANH_2$ vs F_1 BANH[d]	-0.06 ± 0.07

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]WMP – weighted midparent value (3/8N 5/8A)
[d]F_1 BANH average calf crop born for BANH a, b, and c
[e]EPV – Expected performance value (WMP + 1/2 F_1 NA heterosis)
[f]EPV – Expected performance value (WMP + 3/4 F_1 NA heterosis)
[§] $P < 0.10$
* $P < 0.01$

Table 29. Calf survival contrasts and standard errors (SE) by cow breed group[a]

L	**Contrast ± SE**
F_1 NA vs Mp[b]	0.10 ± 0.03*
BANH[c] vs MP	-0.01 ± 0.03
3/8N 5/8A[d] vs WMP[e]	0.03 ± 0.03

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]Includes BANH a, b, c and $BANH_2$
[d]Includes 3/8N 5/8A a, b and c
[e]WMP – weighted midparent value (3/8N 5/8A)
* $P < 0.01$

(2004) were 0.03 between Brahman and Hereford, and 0.04 between Brahman and Angus. The heterosis estimate between Nellore and Angus from this study is 0.10. Based on the dominance model the 3/8N $5/8A_a$ and 3/8N $5/8A_c$ should express heterosis levels of 0.05 and the 3/8N $5/8A_b$ dams heterosis levels of about 0.075 for calf survival. The 3/8N $5/8A_a$ dams expressed the same amount of heterosis as predicted from the dominance model of 0.05, while the 3/8N $5/8A_b$ and 3/8N $5/8A_c$ dams expressed less heterosis than predicted from the dominance model of -0.01 and -0.02, respectively. The expected performance for 3/8N $5/8A_b$ and 3/8N $5/8A_c$ dams was lower than expected from predictions based on the dominance model, although not significantly different. For

3/8N 5/8A_a dams the expected performance level was similar to the predictions from the dominance model.

For BANH dams, it can be expected based on the dominance model that the BANH$_a$ dams would express heterosis of about 0.05, and that the BANH$_b$, BANH$_c$, and BANH$_2$ crosses would express about 0.04.

The BANH$_a$ dams expressed significantly less heterosis (-0.08) than predicted from the dominance model. The BANH$_c$ and the BANH$_2$ crosses also expressed less heterosis than predicted from the dominance model. The BANH$_b$ females expressed significantly ($P < 0.10$) more heterosis (0.08) than predicted from the dominance model (0.04).

Adjusted means by breed group for two, three, four, and five year old dams are presented in Table 30. Contrast estimates for calf survival by cow breed group for two to five year old dams are presented in Table 31. All breed groups expressed higher calf survival at two to five years of age than their weighted midparent value. The F_1 NA dams expressed significant ($P < 0.001$) heterosis for calf survival at two to five years of 0.14. Calf survival contrasts for two, three, four, and five year old dams are presented in Table 32. All breed groups expressed higher calf survival between two to five years of age than their midparent or weighted value, except for the BANH crosses at two years of age (-0.02), and the 3/8N 5/8A crosses at five years of age (-0.03). At four years of age the F_1 NA dams expressed significant heterosis for calf survival of 0.13.

Table 30. Least squares means and standard errors (SE) for calf survival by cow breed group for 2, 3, 4, and 5 year old dams

	2 yrs	**3 yrs**	**4 yrs**	**5 yrs**	**Overall**
A	0.706 ± 0.05	0.902 ± 0.06	0.930 ± 0.06	0.958 ± 0.06	0.873 ± 0.03
B	0.718 ± 0.10	0.888 ± 0.05	0.815 ± 0.06	0.889 ± 0.05	0.863 ± 0.03
H	0.874 ± 0.05	0.849 ± 0.06	0.895 ± 0.06	0.963 ± 0.06	0.903 ± 0.03
N	0.525 ± 0.24	0.828 ± 0.06	0.498 ± 0.07	0.786 ± 0.08	0.649 ± 0.03
F_1 NA	0.868 ± 0.05	0.953 ± 0.05	0.854 ± 0.05	0.891 ± 0.05	0.894 ± 0.02
3/8N 5/8A[a]	0.737 ± 0.04	0.911 ± 0.04	0.938 ± 0.05	0.916 ± 0.07	0.872 ± 0.02
BANH[b]	0.76 ± 0.05	0.83 ± 0.05	0.87 ± 0.05	0.97 ± 0.06	0.834 ± 0.02

[a]Includes 3/8N 5/8A a, b and c
[b]Includes BANH a, b, c and $BANH_2$

Table 31. Calf survival contrasts and standard errors (SE) by cow breed group[a] for 2 to 5 year old dams

L	**Contrast ± SE**
F_1 NA vs Mp[b]	0.14 ± 0.04**
BANH[c] vs MP	0.02 ± 0.04
3/8N 5/8A[d] vs WMP[e]	0.04 ± 0.05

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]Includes 3/8N 5/8A a, b and c
[d]Includes BANH a, b, c and $BANH_2$
[e]WMP – weighted midparent value (3/8N 5/8A)
** P < 0.001

Table 32. Calf survival contrasts and standard errors (SE) by cow breed group for 2, 3, 4, and 5 year old dams

L	2 yrs	3 yrs	4 yrs	5 yrs
F_1 NA vs Mp[a]	0.24 $\pm$ 0.16	0.06 $\pm$ 0.06	0.13 $\pm$ 0.07*	0.03 $\pm$ 0.06
BANH[b] vs MP	-0.02 $\pm$ 0.12	0.03 $\pm$ 0.06	0.01 $\pm$ 0.07	0.04 $\pm$ 0.06
3/8N 5/8A[c] vs WMP[d]	0.06 $\pm$ 0.15	0.08 $\pm$ 0.07	0.01 $\pm$ 0.08	-0.03 $\pm$ 0.08

[a]See Table 1 for breed designations
[b]MP - midparent average for the purebreds in the cross
[c]Includes 3/8N 5/8A a, b and c
[d]Includes BANH a, b, c and $BANH_2$
[e]WMP - weighted midparent value (3/8N 5/8A)
* P < 0.01

Birth Weight

Adjusted means for birth weight by dam breed and dam breed group are presented in Tables 33 and 34, respectively. Note that sire breed of calf is partially confounded with breed of cow. Among all breeds the Nellore dams produced the lightest calves at 30.16 kg. The heaviest calves among the BANH dams were produced by $BANH_c$ dams, resulting from mating 1/2A 1/2N bulls to 1/2H 1/2B dams, at 36.65 kg. Among the straightbred cows the Angus dams produced the heaviest calves at 36.22 kg. Among all crossbred groups in Table 34, the BANH group produced the heaviest calves at 35.37 kg. Adjusted birth weights by dam age by dam breed and dam breed group are presented in Tables 35 and 36, respectively. At two years of age the Nellore and the $BANH_2$ dams produced the lightest calves at 28.45 kg and 28.63 kg, respectively. In Tables 37 and 38 are presented the birth weight contrasts by cow breed and cow breed group, respectively. The F_1 NA dams had higher birth weights than their midparent average by 0.68 kg. The $BANH_a$ and the $BANH_b$ dams expressed significant heterosis ($P < 0.05$) for birth weight of 2.09 kg and 2.16 kg, respectively. The calves out of $BANH_c$ dams had significantly ($P < 0.10$) higher birth weights than the midparent value by 2.84 kg. The 3/8N $5/8A_a$ dams had lower birth weights than their weighted midparent value by 0.54 kg, although the difference was not significant. The $BANH_2$ dams had significantly lower birth weights ($P < 0.05$) than their midparent value by 0.96 kg.

The BANH breed group expressed significant ($P < 0.01$) heterosis for birth weight of 3.94 kg. The 3/8N 5/8A breed group had lower birth weight than their weighted midparent value by 0.05 kg.

Table 33. Least squares means and standard errors (SE) for birth weight (kg) by cow breed[a]

Cow breed	LS means ± SE
A	36.22 ± 0.54
B	32.55 ± 0.44
H	35.45 ± 0.55
N	30.16 ± 0.65
F_1 NA	33.80 ± 0.49
3/8N 5/8A(a)	33.59 ± 0.73
3/8N 5/8A(b)	34.44 ± 0.97
3/8N 5/8A(c)	34.95 ± 1.33
BANH(a)	35.67 ± 0.79
BANH(b)	35.90 ± 0.78
BANH(c)	36.65 ± 1.45
$BANH_2$	33.54 ± 1.10

[a]See Table 1 for breed designations

Table 34. Least squares means and standard errors (SE) for birth weight (kg) by cow breed group

Cow breed group	LS means ± SE
A	36.19 ± 0.54
B	32.51 ± 0.44
H	35.40 ± 0.52
N	30.23 ± 0.64
F_1 NA	33.81 ± 0.49
3/8N 5/8A[a]	33.94 ± 0.57
BANH[b]	35.37 ± 0.51

[a]Includes 3/8N 5/8A a, b and c
[b]Includes BANH a, b, c and $BANH_2$

Table 35. Least squares means and standard errors (SE) for birth weight (kg) by cow breed[a] by cow age

	2 yrs	**3 yrs**	**4 yrs**	**5 yrs**	**6 yrs**	**7 yrs**	**8 yrs**	**9 yrs**	**10 yrs**
A	31.66 ± 0.82	33.78 ± 0.87	36.55 ± 0.90	37.81 ± 0.96	37.27 ± 0.97	38.35 ± 1.18	34.96 ± 1.54	—	—
B	31.80 ± 1.71	32.51 ± 0.80	34.39 ± 0.91	33.54 ± 0.79	33.82 ± 0.97	34.80 ± 1.15	33.91 ± 1.37	31.92 ± 1.61	36.40 ± 2.54
H	28.70 ± 0.82	32.91 ± 0.99	34.76 ± 0.96	37.11 ± 0.94	39.16 ± 0.96	38.83 ± 1.01	36.88 ± 1.80	37.79 ± 2.94	—
N	28.45 ± 3.64	30.06 ± 0.86	32.19 ± 1.08	30.44 ± 1.19	29.33 ± 1.56	29.67 ± 2.29	31.89 ± 5.09	—	—
F_1 NA	28.71 ± 0.76	32.25 ± 0.79	33.93 ± 0.75	33.53 ± 0.76	36.20 ± 0.78	37.47 ± 0.97	37.08 ± 1.61	—	—
3/8N 5/8A(a)	31.88 ± 0.68	33.11 ± 0.70	34.13 ± 0.88	35.06 ± 1.37	—	—	—	—	—
3/8N 5/8A(b)	28.72 ± 1.64	35.59 ± 1.83	34.05 ± 1.83	37.63 ± 1.83	36.18 ± 2.57	32.88 ± 2.96	29.91 ± 3.60	—	—
3/8N 5/8A(c)	30.91 ± 1.83	35.20 ± 1.96	37.04 ± 2.58	45.86 ± 5.12	39.51 ± 5.12	—	—	—	—
BANH(a)	28.63 ± 1.43	35.44 ± 1.43	35.46 ± 1.43	39.21 ± 1.49	37.37 ± 1.72	36.15 ± 2.56	42.31 ± 2.95	39.18 ± 3.60	—
BANH(b)	32.49 ± 1.06	33.96 ± 1.19	36.21 ± 1.19	38.31 ± 1.25	39.78 ± 2.96	—	—	—	—
BANH(c)	34.28 ± 2.31	36.49 ± 2.12	35.83 ± 2.31	41.95 ± 3.63	—	—	—	—	—
$BANH_2$	29.91 ± 1.56	30.34 ± 1.83	34.81 ± 1.72	32.62 ± 2.57	32.15 ± 5.11	—	—	—	—

[a]See Table 1 for breed designations

Table 36. Least squares means and standard errors (SE) for birth weight (kg) by cow breed group[a] by cow age

	2 yrs	3 yrs	4 yrs	5 yrs	6 yrs	7 yrs	8 yrs	9 yrs	10 yrs
A	31.66 ± 0.83	33.78 ± 0.88	36.55 ± 0.91	37.81 ± 0.97	37.27 ± 0.98	38.35 ± 1.19	34.96 ± 1.56	—	—
B	31.80 ± 1.73	32.51 ± 0.81	34.39 ± 0.92	33.54 ± 0.80	33.82 ± 0.98	34.80 ± 1.16	33.92 ± 1.38	31.92 ± 1.63	36.42 ± 2.57
H	28.70 ± 0.83	32.91 ± 1.00	34.76 ± 0.97	37.12 ± 0.95	39.15 ± 0.97	38.83 ± 1.02	36.86 ± 1.82	37.77 ± 2.97	—
N	28.48 ± 3.68	30.06 ± 0.87	32.20 ± 1.09	30.44 ± 1.20	29.33 ± 1.58	29.67 ± 2.31	31.88 ± 5.14	—	—
F_1 NA	28.72 ± 0.77	32.25 ± 0.80	33.93 ± 0.75	33.53 ± 0.76	36.21 ± 0.79	37.47 ± 0.98	37.08 ± 1.63	—	—
3/8N 5/8A[b]	31.36 ± 0.60	33.60 ± 0.62	34.37 ± 0.77	36.45 ± 1.08	36.63 ± 2.31	32.90 ± 2.97	29.93 ± 3.63	—	—
BANH[c]	31.13 ± 0.72	34.04 ± 0.77	35.69 ± 0.77	38.17 ± 0.88	35.52 ± 1.38	35.99 ± 2.57	42.13 ± 2.97	38.95 ± 3.63	—

[a]See Table 1 for breed designations

[b]Includes 3/8N 5/8A a, b and c

[c]Includes BANH a, b, c and $BANH_2$

Table 37. Birth weight (kg) contrasts and standard errors (SE) by cow breed[a]

L	**Contrast ± SE**
F_1 NA vs MP[b]	0.68 ± 0.55
3/8N 5/8A(a) vs WMP[c]	-0.54 ± 0.82
3/8N 5/8A(b) vs WMP[c]	0.47 ± 1.00
3/8N 5/8A(c) vs WMP[c]	0.87 ± 1.38
BANH(a) vs MP	2.09 ± 0.82[o]
BANH(b) vs MP	2.16 ± 0.83[o]
BANH(c) vs MP	2.84 ± 1.49[§]
$BANH_2$ vs MP	-0.96 ± 1.13[o]
$BANH_2$ vs F_1 BANH[d]	-2.74 ± 1.11[o]

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]WMP – weighted midparent value (3/8N 5/8A)
[d]F_1 BANH average calf crop born for BANH a, b, and c
[§] $P < 0.10$
[o] $P < 0.05$

Table 38. Birth weight (kg) contrasts and standard errors (SE) by cow breed group[a]

L	**Contrast ± SE**
F_1 NA vs Mp[a]	0.69 ± 1.21
BANH[b] vs MP	3.94 ± 1.27*
3/8N 5/8A[c] vs WMP[d]	-0.05 ± 1.48

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]Includes BANH a, b, c and $BANH_2$
[d]Includes 3/8N 5/8A a, b and c
[e]WMP – weighted midparent value (3/8N 5/8A)
* P < 0.01

Adjusted means for birth weight by dam breed group for two, three, four, and five year old dams are presented in Table 39. At five years of age the BANH dam group had calves with the highest birth weight of 38.17 kg. Birth weight contrasts for two to five year old dams are shown in Table 40. BANH dams expressed significant ($P < 0.01$) heterosis for birth weight of 1.85 kg at two to five years of age. F_1 NA dams expressed negative heterosis ($P > 0.10$) for birth weight of -0.34 kg at two to five year of age.

Birth weight contrasts by dam breed group for two, three, four, and five year old dams are presented in Table 41. F_1 NA dams expressed negative heterosis at two, four, and five years of age, although these differences were not significant. The BANH dams expressed positive heterosis for birth weight at two to five years of age. Heterosis was significant at three ($P < 0.05$) and five years ($P < 0.001$) of age for the BANH dams at 1.86 kg and 3.59 kg, respectively. The 3/8N 5/8A dams exceeded ($P > 0.10$) the weighted midparent value for birth weight at two, three, four, and five years of age.

Table 39. Least squares means and standard errors (SE) for birth weight (kg) by cow breed group for 2, 3, 4, and 5 year old dams

	2 yrs	**3 yrs**	**4 yrs**	**5 yrs**	**Overall**
A	31.66 $\pm$ 0.83	33.78 $\pm$ 0.88	36.55 $\pm$ 0.91	37.81 $\pm$ 0.97	34.85 $\pm$ 0.79
B	31.80 $\pm$ 1.73	32.51 $\pm$ 0.81	34.39 $\pm$ 0.92	33.54 $\pm$ 0.80	33.07 $\pm$ 0.93
H	28.70 $\pm$ 0.83	32.91 $\pm$ 1.00	34.76 $\pm$ 0.97	37.12 $\pm$ 0.95	33.29 $\pm$ 0.89
N	28.48 $\pm$ 3.68	30.06 $\pm$ 0.87	32.20 $\pm$ 1.09	30.44 $\pm$ 1.20	30.19 $\pm$ 1.63
F_1 NA	28.72 $\pm$ 0.77	32.25 $\pm$ 0.80	33.93 $\pm$ 0.75	33.53 $\pm$ 0.76	32.12 $\pm$ 1.03
3/8N 5/8A[a]	31.36 $\pm$ 0.60	33.60 $\pm$ 0.62	34.37 $\pm$ 0.77	36.45 $\pm$ 1.08	33.87 $\pm$ 0.84
BANH[b]	31.13 $\pm$ 0.72	34.04 $\pm$ 0.77	35.69 $\pm$ 0.77	38.17 $\pm$ 0.88	34.74 $\pm$ 0.86

[a]Includes 3/8N 5/8A a, b and c
[b]Includes BANH a, b, c and $BANH_2$

Table 40. Birth weight (kg) contrasts and standard errors (SE) by cow breed group[a] for 2 to 5 year old dams

L	**Contrast ± SE**
F_1 NA vs Mp[b]	-0.34 ± 0.58
BANH[c] vs MP	1.85 ± 0.59*
3/8N 5/8A[d] vs WMP[e]	0.08 ± 0.68

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]Includes 3/8N 5/8A a, b and c
[d]Includes BANH a, b, c and $BANH_2$
[e]WMP – weighted midparent value (3/8N 5/8A)
* P < 0.01

Table 41. Birth weight contrasts and standard errors (SE) by cow breed group for 2, 3, 4, and 5 year old dams

L	**2 yrs**	**3 yrs**	**4 yrs**	**5 yrs**
F_1 NA vs Mp[a]	-1.54 ± 2.09	0.35 ± 1.02	-0.37 ± 0.96	-0.47 ± 1.03
BANH[b] vs MP	1.05 ± 1.32	1.86 ± 0.90[o]	1.36 ± 0.84	3.59 ± 0.96**
3/8N 5/8A[c] vs WMP[d]	0.77 ± 1.63	1.24 ± 0.90	0.48 ± 0.96	1.55 ± 1.26

[a]See Table 1 for breed designations

[b]MP - midparent average for the purebreds in the cross

[c]Includes 3/8N 5/8A a, b and c

[d]Includes BANH a, b, c and $BANH_2$

[e]WMP - weighted midparent value (3/8N 5/8A)

[o] $P < 0.10$

** $P < 0.001$

Weaning Weight

Least squares means for weaning weight by dam breed and dam breed group are presented in Tables 42 and 43, respectively. Note that sire breed of calf is partially confounded with breed of cow. The F_1 NA dams weaned the heaviest calves at 239.37 kg. Among straightbred dams the Brahman dams weaned the heaviest calves at 220.68 kg. The calves weaned by Hereford dams had the lowest weaning weight at 184.19 kg. Although all were similar, among BANH dams the $BANH_2$ dams weaned the heaviest calves at 229.12 kg. The 3/8N $5/8A_b$ dams weaned the heaviest calves at 219.97 kg among the 3/8N 5/8A dams. Adjusted means for weaning weight by dam age for dam breed and dam breed group are presented in Tables 44 and 45, respectively. At two years of age, the Hereford dams weaned the lightest calves at 137.27 kg, and the $BANH_c$ dams weaned the heaviest calves at 232.38 kg. The $BANH_2$ dams weaned the heaviest calves at 6 years of age (281.75 kg).

Table 42. Least squares means and standard errors (SE) for weaning weight (kg) by cow breed[a]

Cow breed	LS means $\pm$ SE
A	210.42 $\pm$ 3.26
B	220.68 $\pm$ 2.60
H	184.19 $\pm$ 3.18
N	197.57 $\pm$ 3.94
F_1 NA	239.37 $\pm$ 2.94
3/8N 5/8A(a)	209.11 $\pm$ 4.19
3/8N 5/8A(b)	219.97 $\pm$ 5.90
3/8N 5/8A(c)	219.70 $\pm$ 7.72
BANH(a)	223.24 $\pm$ 4.81
BANH(b)	227.82 $\pm$ 4.40
BANH(c)	220.03 $\pm$ 8.14
$BANH_2$	229.12 $\pm$ 6.22

[a]See Table 1 for breed designations

Table 43. Least squares means and standard errors (SE) for weaning weight (kg) by cow breed group

Cow breed group	LS means ± SE
A	209.86 ± 3.24
B	220.48 ± 2.60
H	183.84 ± 3.14
N	198.09 ± 3.89
F_1 NA	238.83 ± 2.92
3/8N 5/8A[a]	212.77 ± 3.40
BANH[b]	226.16 ± 3.03

[a]Includes 3/8N 5/8A a, b and c
[b]Includes BANH a, b, c and $BANH_2$

Table 44. Least squares means and standard errors (SE) for weaning weight (kg) by cow breed[a] by cow age

	2 yrs	**3 yrs**	**4 yrs**	**5 yrs**
A	165.64 $\pm$ 4.80	172.51 $\pm$ 4.54	209.11 $\pm$ 4.50	233.54 $\pm$ 4.70
B	187.81 $\pm$ 8.59	203.62 $\pm$ 4.04	207.79 $\pm$ 4.82	222.77$\pm$ 4.10
H	137.27 + 4.54	142.96 $\pm$ 5.12	164.88 $\pm$ 5.07	192.17$\pm$ 4.81
N	185.61 $\pm$ 24.57	197.16 $\pm$ 4.81	210.17 $\pm$ 7.26	205.80 $\pm$ 6.54
F_1 NA	210.65 $\pm$ 3.95	227.90 $\pm$ 3.95	240.03 $\pm$ 4.00	239.85 $\pm$ 3.88
3/8N 5/8A(a)	207.74 $\pm$ 3.85	208.85 $\pm$ 3.60	223.8 $\pm$ 4.37	226.36 $\pm$ 6.77
3/8N 5/8A(b)	197.64 $\pm$ 8.93	198.19 $\pm$ 9.48	229.11 $\pm$ 11.03	237.73 $\pm$ 10.16
3/8N 5/8A(c)	194.13 $\pm$ 11.18	233.72 $\pm$ 10.40	227.02 $\pm$ 12.45	245.36 $\pm$ 23.90
BANH(a)	180.12 $\pm$ 8.75	227.18 $\pm$ 7.58	216.97 $\pm$ 7.93	219.18 $\pm$ 7.60
BANH(b)	227.16 $\pm$ 5.41	215.76 $\pm$ 6.59	223.39 $\pm$ 6.05	242.28 $\pm$ 6.01
BANH(c)	232.38 $\pm$ 12.53	218.61 $\pm$ 11.30	231.71 $\pm$ 11.30	243.38 $\pm$ 17.20
$BANH_2$	194.40 $\pm$ 9.51	225.29 $\pm$ 9.50	233.99 $\pm$ 8.92	232.73 $\pm$ 12.27

[a]See Table 1 for breed designations

Table 44. Continued

	6 yrs	7 yrs	8 yrs	9 yrs	10 yrs
A	235.63 ± 4.85	225.87 ± 5.87	228.99 ± 7.91	—	—
B	229.18 ± 4.96	246.90 ± 5.60	237.71 ± 7.49	242.48 ± 12.11	252.25 ± 16.07
H	212.34 ± 4.84	217.17 ± 5.01	229.43 ± 9.58	224.31 ± 13.76	—
N	196.25 ± 8.78	213.07 ± 10.74	227.02 ± 17.37	—	—
F_1 NA	252.78 ± 3.92	257.27 ± 4.73	270.76 ± 7.85	—	—
3/8N 5/8A(a)	—	—	—	—	—
3/8N 5/8A(b)	235.31 ± 16.96	246.95 ± 13.99	194.87 ± 16.83	—	—
3/8N 5/8A(c)	245.98 ± 23.88	—	—	—	—
BANH(a)	233.09 ± 8.31	252.61 ± 16.62	257.53 ± 23.47	251.94 ± 23.47	—
BANH(b)	251.14 ± 13.83	—	—	—	—
BANH(c)	—	—	—	—	—
$BANH_2$	281.75 ± 23.82	—	—	—	—

Table 45. Least squares means and standard errors (SE) for weaning weight (kg) by cow breed group[a] by cow age

	2 yrs	**3 yrs**	**4 yrs**	**5 yrs**
A	165.64 ± 4.80	171.65 ± 4.47	208.74 ± 4.55	233.92 ± 4.77
B	187.81 ± 8.59	203.5 ± 4.10	208.3 ± 4.88	222.47 ± 4.15
H	137.27 + 4.54	142.93 ± 5.19	163.41 ± 4.95	195.25 ± 4.72
N	185.61 ± 24.57	198.03 ± 4.72	211.49 ± 7.23	202.02 ± 6.50
F_1 NA	210.65 ± 3.95	227.58 ± 3.98	239.27 ± 3.98	239.88 ± 3.92
3/8N 5/8A[b]	204.20 ± 3.42	210.64 ± 3.25	225.57 ± 3.91	231.28 ± 5.53
BANH[c]	212.42 ± 3.97	221.49 ± 4.16	224.83 ± 4.00	234.15 ± 4.32

Table 45. Continued

	6 yrs	7 yrs	8 yrs	9 yrs	10 yrs
A	234.48 ± 4.93	225.42 ± 5.97	228.67 ± 8.01	—	—
B	227.37 ± 4.98	246.38 ± 5.70	236.95 ± 7.32	243.64 ± 9.09	239.95 ± 11.95
H	215.06 ± 4.77	217.19 ± 5.10	228.00 ± 9.73	222.85 ± 13.61	—
N	192.04 ± 8.74	211.56 ± 10.90	227.23 ± 17.00	—	—
F_1 NA	252.78 ± 3.96	257.32 ± 4.79	270.81 ± 7.96	—	—
3/8N 5/8A[b]	239.15 ± 13.80	249.17 ± 13.81	196.37 ± 16.75	—	—
BANH[c]	244.76 ± 6.76	260.58 ± 16.65	261.38 ± 23.68	256.1 ± 23.69	—

[a]See Table 1 for breed designations

[b]Includes 3/8N 5/8A a, b and c

[c]Includes BANH a, b, c and $BANH_2$

All crosses expressed higher weaning weights than their weighted midparent value. F_1 NA dams expressed significant ($P < 0.0001$) heterosis for weaning weight of 35.38 kg. The $BANH_a$, $BANH_b$, and $BANH_2$ dams also expressed significant ($P < 0.0001$) heterosis for weaning weight. The 3/8N $5/8A_a$ dams weaned calves that had higher weaning weights than their weighted midparent value by 3.51 kg, but the difference was not significant. Significantly heavier weaning weights were observed in calves out of 3/8N $5/8A_b$ ($P < 0.01$) and 3/8N $5/8A_c$ ($P < 0.05$) dams at 14.31 kg and 14.10 kg, respectively, compared to the weighted midparent value. Based on these results and those reported by Key (2004), estimations can be made based on the dominance model.

For the 3/8N 5/8A dams, it can be expected based on the dominance model that the 3/8N $5/8A_a$ and 3/8N $5/8A_c$ dams should express heterosis levels of 17.7 kg and the 3/8N $5/8A_b$ dams should express heterosis levels of about 26.5 kg for maternal effects on weaning weight. The 3/8N $5/8A_a$ ($P < 0.01$) and the 3/8N $5/8A_c$ ($P > 0.10$) dams expressed less heterosis than predicted from the dominance model by 14.2 kg and 3.6 kg, respectively. Also, the 3/8N $5/8A_b$ dams ($P < 0.05$) expressed less heterosis than predicted from the dominance model by 12.2 kg.

It can be expected, based on the dominance model, that the $BANH_a$ dams would express about 20.55 kg of heterosis, and that the $BANH_b$, $BANH_c$, and $BANH_2$ crosses would express about 15.65 kg of heterosis. Comparing these estimates to those obtained in this study the heterosis estimate for $BANH_a$ (20.03 kg) crosses is slightly lower than predicted from the dominance model (20.55 kg). The heterosis estimates for $BANH_b$ (24.60 kg) and $BANH_2$ (25.91 kg) crosses are higher than those predicted from the dominance model (15.65 kg). For the $BANH_c$ crosses, resulting from mating 1/2N 1/2A bulls to 1/2H 1/2B dams, significant heterosis was expressed at 16.18 kg which is similar to expectations based on the dominance model (15.65 kg) . Weaning weight contrasts by cow breed and cow breed group are presented in Tables 46 and 47, respectively.

The regression coefficients for weaning weight on age of calf at weaning within year/age of dam ranged from 0.02 $\pm$ 0.14 kg/day for calves out of two year old heifers in 2000 to 1.29 $\pm$ 0.19 kg/day for calves out of six year old cows in 2005.

Table 46. Weaning weight (kg) contrasts and standard errors (SE) by cow breed[a]

L	**Contrast + SE**
F_1 NA vs MP[b]	35.38 + 3.31***
3/8N 5/8A(a) vs WMP[c]	3.51 + 4.60
3/8N 5/8A(b) vs WMP[c]	14.31 + 6.16º
3/8N 5/8A(c) vs WMP[c]	14.10 + 7.91§
3/8N 5/8A(a) vs EPV[e]	-14.17 + 4.77*
3/8N 5/8A(b) vs EPV[f]	-12.25 + 6.15º
3/8N 5/8A(c) vs EPV[e]	-3.59 + 7.98
BANH(a) vs MP	20.03 + 5.01***
BANH(b) vs MP	24.60 + 4.66***
BANH(c) vs MP	16.18 + 8.30º
$BANH_2$ vs MP	25.91 + 6.25***
$BANH_2$ vs F_1 BANH[d]	10.54 + 6.24§

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]WMP – weighted midparent value (3/8N 5/8A)
[d]F_1 BANH average calf crop born for BANH a, b, and c
[e]EPV – Expected performance value (WMP + 1/2 F_1 NA heterosis)
[f]EPV – Expected performance value (WMP + 3/4 F_1 NA heterosis)
§ P < 0.10
º P < 0.05
* P < 0.01

Table 47. Weaning weight (kg) contrasts and standard errors (SE) by cow breed group[a]

L	**Contrast ± SE**
F_1 NA vs Mp[b]	34.85 ± 3.27***
BANH[c] vs MP	23.05 ± 3.37***
3/8N 5/8A[d] vs WMP[e]	7.32 ± 3.88°

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]Includes BANH a, b, c and $BANH_2$
[d]Includes 3/8N 5/8A a, b and c
[e]WMP – weighted midparent value (3/8N 5/8A)
° P < 0.05
*** P < 0.0001

Least squares means for weaning weights for two, three, four and five year old dams are presented in Table 48. Weaning weight contrasts for two to five year old dams are presented in Table 49, and weaning weight contrasts for two, three, four, and five year old dams are presented in Table 50. Averaging over four years the F_1 NA dams weaned the heaviest calves at 229.77 kg. F_1 NA and BANH dams expressed significant (P < 0.0001) heterosis for weaning weight from two to five years of age of 31.98 kg and 33.36 kg, respectively. The 3/8N 5/8A dams expressed significant (P < 0.01) heterosis for weaning weight with 21.38 kg.

The regression coefficients for weaning weight on age of calf at weaning were 0.49 ± 0.08, 0.65 ± 0.07, 0.68 ± 0.09, 0.90 ± 0.09 kg/day for two, three, four, and five year old dams, respectively.

Table 48. Least squares means and standard errors (SE) for weaning weight (kg) by cow breed group for 2, 3, 4, and 5 year old dams

	2 yrs	**3 yrs**	**4 yrs**	**5 yrs**	**Overall**
A	165.38 ± 4.81	173.15 ± 4.54	209.46 ± 4.52	233.74 ± 4.71	195.43 ± 3.02
B	188.42 ± 8.70	204.24 ± 4.07	207.98 ± 4.87	223.57 ± 4.13	206.05 ± 3.33
H	137.33 ± 4.55	144.51 ± 5.16	163.93 ± 5.09	193.22 ± 4.81	159.75 ± 3.04
N	186.21 ± 24.58	197.18 ± 4.84	211.79 ± 7.31	205.37 ± 6.57	200.14 ± 7.02
F_1 NA	210.69 ± 3.97	228.26 ± 3.97	240.54 ± 4.02	239.59 ± 3.89	229.77 ± 2.62
3/8N 5/8A[a]	205.08 ± 3.39	209.76 ± 3.43	225.47 ± 3.99	234.03 ± 5.57	218.58 ± 2.52
BANH[b]	213.46 ± 3.93	221.16 ± 4.11	224.39 ± 3.95	235.79 ± 4.32	223.70 ± 2.58

[a]Includes 3/8N 5/8A a, b and c

[b]Includes BANH a, b, c and $BANH_2$

Table 49. Weaning weight (kg) contrasts and standard errors (SE) by cow breed group[a] for 2 to 5 year old dams

L	**Contrast ± SE**
F_1 NA vs Mp[b]	31.98 ± 4.62***
BANH[c] vs MP	33.36 ± 3.40***
3/8N 5/8A[d] vs WMP[e]	21.38 ± 4.07***

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]Includes 3/8N 5/8A a, b and c
[d]Includes BANH a, b, c and $BANH_2$
[e]WMP – weighted midparent value (3/8N 5/8A)
*** P < 0.0001

Table 50. Weaning weight contrasts and standard errors (SE) by cow breed group[a] for 2, 3, 4, and 5 year old dams

L	**2 yrs**	**3 yrs**	**4 yrs**	**5 yrs**
F_1 NA vs Mp[b]	33.06 ± 14.76°	43.08 ± 5.06***	29.52 ± 5.98***	21.28 ± 5.58**
BANH[c] vs MP	42.15 ± 8.77***	42.74 ± 4.75***	29.65 ± 4.79***	25.52 ± 4.99***
3/8N 5/8A[d] vs WMP[e]	29.69 ± 11.54°	27.87 ± 4.76***	13.49 ± 5.50°	9.05 ± 6.78[§]

[a]See Table 1 for breed designations
[b]MP - midparent average for the purebreds in the cross
[c]Includes 3/8N 5/8A a, b and c
[d]Includes BANH a, b, c and $BANH_2$
[e]WMP - weighted midparent value (3/8N 5/8A)
[§] P < 0.10
° P < 0.05
** P < 0.001
*** P < 0.0001

Cow Weight at Palpation

Least squares means for cow weight at palpation are presented in Tables 51 and 52. Note that these means include weights of females ranging from yearlings to mature cows. Among straightbred dams the Nellore cows had the highest cow weights at palpation at 504.94 kg. The Hereford cows were the lightest among all cow breeds with 479.49 kg. The $BANH_c$ cows produced by mating 1/2N 1/2A bulls to 1/2H 1/2B dams were the heaviest among all cow breeds at 553.01 kg. The 3/8N 5/8A breed group was lighter (511.68 kg) than the BANH breed group (521.30 kg). Adjusted means for cow weight at palpation by dam age by cow breed and cow breed group are presented in Tables 53 and 54, respectively. At 1.5 year of age the $BANH_c$ cows were heavier than any other dam breed at 429.97 kg, while the Nellore cows were the lightest at 327.83 kg. Arango (2004) reported cow weights for 1/2Nellore 1/2Angus dams, which are in agreement with the weights observed in this study.

Tables 55 and 56 show the adjusted means for cow weight at palpation by lactation status. Among all dam breeds and dam breed groups, dry cows were heavier than cows that were lactating.

Table 51. Least squares means and standard errors (SE) for cow weight (kg) at palpation by cow breed[a]

Cow breed	LS means ± SE
A	500.54 ± 7.19
B	491.03 ± 5.76
H	479.49 ± 7.01
N	504.94 ± 7.88
F_1 NA	543.99 ± 7.12
3/8N 5/8A(a)	524.75 ± 8.81
3/8N 5/8A(b)	497.90 ± 13.16
3/8N 5/8A(c)	528.30 ± 15.13
BANH(a)	495.84 ± 10.71
BANH(b)	550.04 + 9.80
BANH(c)	553.01+ 17.56
$BANH_2$	505.42 + 13.26

[a]See Table 1 for breed designations

Table 52. Least squares means and standard errors (SE) for cow weight (kg) at palpation by cow breed group

Cow breed group	LS means ± SE
A	500.22 ± 7.30
B	491.83 ± 5.86
H	483.20 ± 7.06
N	505.25 ± 7.87
F_1 NA	546.11 ± 7.23
3/8N 5/8A[a]	511.68 ± 7.50
BANH[b]	521.30 ± 7.03

[a]Includes 3/8N 5/8A a, b and c
[b]Includes BANH a, b, c and $BANH_2$

Table 53. Least squares means and standard errors for cow weight (kg) at palpation by cow breed[a] by cow age

	1yr	2 yrs	3 yrs	4 yrs	5 yrs
A	369.74 ± 7.51	406.39 ± 7.92	429.15 ± 8.29	492.43 ± 8.54	534.96 ± 8.91
B	351.92 ± 7.11	434.14 ± 7.11	446.95 ± 7.25	520.4 ± 7.52	502.36 ± 7.63
H	358.08 ± 7.59	370.39 ± 7.72	423.17 ± 7.91	476.47 ± 8.19	497.13 ± 8.99
N	327.83 ± 10.48	444.03 ± 8.95	465.28 ± 8.35	522.19 ± 9.55	553.24 ± 11.24
F_1 NA	407.91 ± 7.59	441.04 ± 7.64	494.09 ± 7.55	529.65 ± 7.64	551.63 ± 7.76
3/8N 5/8A(a)	394.46 ± 7.71	430.26 ± 6.87	476.67 ± 6.91	516.64 ± 8.43	534.85 ± 12.74
3/8N 5/8A(b)	388.90 ± 28.14	396.17 ± 17.76	441.68 ± 17.76	505.69 ± 17.76	504.97 ± 18.57
3/8N 5/8A(c)	403.70 ± 18.72	420.41 ± 19.76	489.51 ± 18.79	517.28 ± 20.99	531.43 ± 46.56
BANH(a)	361.37 ± 14.07	388.20 ± 13.78	477.16 ± 14.15	486.52 ± 14.55	480.49 ± 14.99
BANH(b)	407.17 ± 17.03	464.58 ± 10.25	501.19 ± 11.23	540.63 ± 11.43	569.46 ± 12.39
BANH(c)	429.97 ± 25.55	444.22 ± 21.91	522.62 ± 21.91	562.67 ± 23.43	575.93 ± 34.24
$BANH_2$	367.58 ± 19.09	401.21 ± 14.34	475.57 ± 17.33	505.96 ± 17.33	544.41 ± 24.10

[a]See Table 1 for breed designations

Table 53. Continued

6 yrs	7 yrs	8 yrs	9 yrs	10 yrs
546.86 ± 9.49	540.81 ± 11.06	561.32 ± 13.43	—	—
530.84 ± 8.93	538.19 ± 9.92	571.72 ± 11.70	590.34 ± 14.38	554.14 ± 19.77
543.52 ± 9.46	536.79 ± 9.88	565.13 ± 16.06	537.41 ± 25.42	—
575.34 ± 12.96	587.32 ± 17.43	582.43 ± 31.44	—	—
575.92 ± 7.82	596.11 ± 9.40	615.88 ± 14.45	—	—
—	—	—	—	—
545.22 ± 24.33	540.00 ± 27.43	528.74 ± 32.80	—	—
547.31 ± 46.56	—	—	—	—
531.61 ± 16.70	552.08 ± 21.18	581.69 ± 31.85	619.11 ± 31.85	—
592.20 ± 26.28	—	—	—	—
—	—	—	—	—
551.66 ± 32.64	—	—	—	—

[a]See Table 1 for breed designations

Table 54. Least squares means and standard errors for cow weight (kg) at palpation by cow breed group[a] by cow age

	1 yr	2 yrs	3 yrs	4 yrs	5 yrs
A	369.74 ± 7.65	406.39 ± 8.05	429.12 ± 8.42	492.42 ± 8.67	534.99 ± 9.04
B	351.92 ± 7.23	434.14 ± 7.23	446.9 ± 7.38	520.34 ± 7.64	502.29 ± 7.75
H	358.08 ± 7.72	370.34 ± 7.85	423.17 ± 8.04	476.44 ± 8.32	497.11 ± 9.11
N	327.74 ± 10.61	443.96 ± 9.09	465.30 ± 8.50	522.16 ± 9.69	553.31 ± 11.37
F_1 NA	407.91 ± 7.72	441.05 ± 7.77	494.08 ± 7.68	529.65 ± 7.77	551.64 ± 7.88
3/8N 5/8A[b]	394.00 ± 6.97	425.45 ± 6.20	473.99 ± 6.20	515.93 ± 7.24	528.73 ± 10.11
BANH[c]	389.4 ± 8.82	429.86 ± 6.90	492.25 ± 7.49	521.71 ± 7.66	537.23 ± 8.63

Table 54. Continued

6 yrs	7 yrs	8 yrs	9 yrs	10 yrs
546.92 ± 9.60	540.96 ± 11.16	561.53 ± 13.51	—	—
530.74 ± 9.03	538.04 ± 10.01	571.61 ± 11.78	590.15 ± 14.45	553.99 ± 19.83
543.44 ± 9.57	536.72 ± 9.99	565.03 ± 16.13	537.38 ± 25.46	—
575.58 ± 13.07	587.68 ± 17.52	582.9 ± 31.49	—	—
575.95 ± 7.94	596.04 ± 9.51	615.74 ± 14.53	—	—
558.86 ± 20.32	557.45 ± 25.89	547.08 ± 3153	—	—
563.40 ± 12.58	581.03 ± 20.10	610.57 ± 31.14	647.99 ± 31.14	—

[a]See Table 1 for breed designations

[b]Includes 3/8N 5/8A a, b and c

[c]Includes BANH a, b, c and $BANH_2$

Table 55. Least squares means and standard errors for cow weight (kg) at palpation by cow breed[a] by lactation status

Cow breed	Lactation Status	
	dry	wet
A	538.26 ± 12.60	469.59 ± 6.92
B	553.90 ± 8.64	480.38 ± 6.50
H	498.71 ± 10.90	452.55 ± 6.76
N	506.48 ± 11.26	497.4 ± 8.46
F_1 NA	557.52 ± 12.90	523.63 ± 6.05
3/8N 5/8A(a)	496.38 ± 15.37	468.18 ± 6.55
3/8N 5/8A(b)	542.42 ± 30.73	461.91 ± 14.86
3/8N 5/8A(c)	549.73 ± 34.69	461.64 ± 18.35
BANH(a)	497.70 ± 17.28	469.18 ± 12.24
BANH(b)	519.57 ± 17.12	517.45 ± 9.74
BANH(c)	562.38 ± 65.85	534.02 ± 21.70
$BANH_2$	504.27 ± 30.42	470.51 ± 14.94

[a]See Table 1 for breed designations

Table 56. Least squares means and standard errors for cow weight (kg) at palpation by cow breed group[a] by lactation status

Cow breed	Lactation Status	
	dry	wet
A	538.23 ± 12.57	469.50 ± 6.95
B	555.99 ± 8.67	480.39 ± 6.53
H	498.70 ± 10.87	452.36 ± 6.79
N	506.49 ± 11.25	498.27 ± 8.46
F_1 NA	557.49 ± 12.86	523.61 ± 6.09
3/8N 5/8A[b]	511.74 ± 12.72	466.63 ± 5.71
BANH[c]	512.25 ± 11.03	496.78 ± 6.50

[a]See Table 1 for breed designations
[b]Includes 3/8N 5/8A a, b and c
[c]Includes BANH a, b, c and $BANH_2$

Cow weight at palpation for four year old cows by cow breed and cow breed group are presented in Tables 57 and 58, respectively. Cow weight at palpation was evaluated for four year old cows because it was the highest age with the largest number of observations available. The $BANH_c$ and the F_1 NA cows were among the heaviest at four years of age at 576.45 kg and 571.21 kg, respectively; while the Hereford cows were the lightest at 507.36 kg.

Table 59 presents cow weight contrasts for four year old cows by dam breed. Cow weight contrasts by dam breed group for four year old cows are shown in Table 60. The F_1 NA cows expressed significant ($P < 0.001$) heterosis for cow weight at palpation at 32.29 kg. All of the 3/8N 5/8A cow groups expressed lower cow weight at palpation than their weighted midparent value. Both, the $BANH_b$ and $BANH_c$ cows expressed significant ($P < 0.05$) heterosis for cow weight at palpation (30.32 kg and 49.87 kg, respectively). The $BANH_a$ cows produced by mating 1/2B 1/2H bulls to 1/2N 1/2A dams expressed negative heterosis of -12.78 kg, although not significantly different from zero. $BANH_2$ cows expressed almost no heterosis for cow weight at palpation at 0.27 kg.

Based on the dominance model the 3/8N $5/8A_a$ and 3/8N $5/8A_c$ cows should express heterosis levels of 16.2 kg for cow weight at palpation, while the 3/8N $5/8A_b$ cows should express heterosis levels of about 24.2 kg for cow weight at palpation. The heterosis levels for all 3/8N 5/8A cows were lower than those expected from the dominance model, although the differences were not significant.

Table 57. Least squares means and standard errors (SE) for cow weight (kg) at palpation for 4 year old cows by cow breed[a]

Cow breed	**LS means ± SE**
A	535.81 ± 9.79
B	521.10 ± 7.15
H	507.36 ± 9.10
N	542.05 ± 9.79
F_1 NA	571.21 ± 9.12
3/8N 5/8A(a)	530.88 ± 11.64
3/8N 5/8A(b)	519.66 ± 16.49
3/8N 5/8A(c)	514.60 ± 21.29
BANH(a)	513.80 ± 13.94
BANH(b)	556.90 ± 12.53
BANH(c)	576.45 ± 23.00
$BANH_2$	526.31 ± 17.38

[a]See Table 1 for breed designations

Table 58. Least squares means and standard errors (SE) for cow weight at palpation (kg) by cow breed group for 4 year old cows

Cow breed group	LS means ± SE
A	537.36 ± 9.78
B	522.06 ± 7.16
H	510.29 ± 9.00
N	539.47 ± 9.75
F_1 NA	572.71 ± 9.13
3/8N 5/8A[a]	519.80 ± 9.17
BANH[b]	536.94 ± 8.36

[a]Includes 3/8N 5/8A a, b and c
[b]Includes BANH a, b, c and $BANH_2$

Table 59. Cow weight at palpation contrasts and standard errors (SE) by cow breed[a] for 4 year old cows

L	Contrast ± SE
F_1 NA vs MP[b]	32.29 ± 9.47**
3/8N 5/8A(a) vs WMP[c]	-7.27 ± 13.43
3/8N 5/8A(b) vs WMP[c]	-18.49 ± 17.40
3/8N 5/8A(c) vs WMP[c]	-23.55 ± 22.44
3/8N 5/8A(a) vs EPV[e]	-23.41 ± 13.75
3/8N 5/8A(b) vs EPV[f]	-42.70 ± 17.68
3/8N 5/8A(c) vs EPV[e]	-39.69 ± 22.66
BANH(a) vs MP	-12.78 ± 14.46
BANH(b) vs MP	30.32 ± 13.46°
BANH(c) vs MP	49.87 ± 23.60°
$BANH_2$ vs MP	0.27 ± 18.07
$BANH_2$ vs F_1 BANH[d]	-17.12 ± 17.84

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]WMP – weighted midparent value (3/8N 5/8A)
[d]F_1 BANH average calf crop born for BANH a, b, and c
[e]EPV – Expected performance value (WMP + 1/2 F_1 NA heterosis)
[f]EPV – Expected performance value (WMP + 3/4 F_1 NA heterosis)
° $P < 0.05$
** $P < 0.001$

Table 60. Cow weight at palpation contrasts and standard errors (SE) by cow breed group[a] for 4 year old cows

L	**Contrast $\pm$ SE**
F_1 NA vs Mp[b]	34.29 $\pm$ 9.48**
BANH[c] vs MP	9.65 $\pm$ 9.48
3/8N 5/8A[d] vs WMP[e]	-18.35 $\pm$ 11.24

[a]See Table 1 for breed designations
[b]MP – midparent average for the purebreds in the cross
[c]Includes 3/8N 5/8A a, b and c
[d]Includes BANH a, b, c and $BANH_2$
[e]WMP – weighted midparent value (3/8N 5/8A)
* P < 0.01
*** P < 0.0001

SUMMARY AND CONCLUSIONS

Calf Crop Born and Weaned

Heterosis estimates for calf crop born and calf crop weaned were estimated by linear contrasts of least squares means. All types of crossbred dams expressed higher calf crop born and weaned than their weighted midparent values.

The F_1 NA and BANH breed groups expressed significant ($P < 0.0001$) heterosis for calf crop born and calf crop weaned. The $BANH_c$ dams resulting from mating 1/2N 1/2A bulls to 1/2H 1/2B dams expressed significant heterosis for calf crop born ($P < 0.001$) and calf crop weaned ($P < 0.10$). The 3/8N $5/8A_a$ and 3/8N $5/8A_b$ dams had significantly higher calf crop born than the weighted midparent value by 0.15. The 3/8N $5/8A_a$ dams expressed significantly ($P < 0.01$) higher calf crop weaned than the weighted midparent value by 0.16. The amount of heterosis expressed by all types of BANH dams for calf crop born was higher than the amount predicted by expectations from the dominance model. For the $BANH_b$ and $BANH_c$ dams the heterosis estimates for calf crop weaned were higher than expectations from the dominance model, but the estimates were lower than the expectations for $BANH_a$ and $BANH_2$ dams.

The 3/8N $5/8A_a$ dams expressed significantly more heterosis for calf crop born ($P < 0.0001$) and calf crop weaned ($P < 0.01$) than predicted from the dominance model. The 3/8N $5/8A_c$ dams expressed less heterosis ($P > 0.10$) than expectations for both traits. The 3/8N $5/8A_b$ dams expressed more heterosis for calf crop born ($P < 0.05$), but less heterosis for calf crop weaned than expectations from the dominance model.

Among straightbred dams, Brahman and Nellore dams had the lowest calf crop born and calf crop weaned due to later onset of puberty. Note that all heifers, including Nellore and Brahman, were assigned values of zero for calf crop if they did not calve at two years of age. Contrasts for calf crop born and calf crop weaned were estimated by linear contrast of least squares means for two to five year old dams. Heterosis estimates for two year old dams was significant ($P < 0.0001$) for all cow breed groups.

Calf Survival

Among straightbreds Hereford dams had the highest calf survival rate at 0.90, while among crossbred dams the $BANH_b$ dams had the highest calf survival rates at 0.916. Heterosis for calf survival was estimated by linear contrasts of least squares means. Most estimates for calf survival were negative or close to zero. The only heterosis estimates that were significantly higher than zero were for the F_1 NA dams ($P < 0.01$) and for $BANH_b$ dams ($P < 0.10$).

The 3/8N $5/8A_a$ cows expressed the same amount of heterosis as predicted from the dominance model for calf survival of 0.05. Both, the 3/8N $5/8A_b$ and 3/8N $5/8A_c$ dams expressed less heterosis than predictions based on the dominance model.
The $BANH_b$ females expressed significantly ($P < 0.10$) more heterosis (0.08) than predicted from the dominance model (0.04). $BANH_a$ dams resulting from matings of 1/2B 1/2H bulls to 1/2N 1/2A dams expressed significantly lower ($P < 0.10$) heterosis for calf survival (-0.08) than predicted from the dominance model (0.05).

Birth and Weaning Weight

Among calves out of straightbred cows, those out of Angus dams were heaviest at birth at 36.22 kg, while calves out of Nellore dams were lightest at birth at 30.16 kg. Heterosis estimates for maternal effects on birth weight were obtained through linear contrasts of least squares means. For both birth weight and weaning weight the heterosis estimates for maternal effects are partially confounded with heterosis for direct effects. Calves out of $BANH_c$ were significantly heavier at birth ($P < 0.10$) by 2.84 kg than the midparent average of dam breeds. Calves out of $BANH_2$ dams were significantly lighter ($P < 0.05$) than their average midparent value by 0.96 kg. The BANH cow breed group expressed significant heterosis ($P < 0.001$) for maternal effects on birth weight of 3.59 kg.

The F_1 NA dams weaned the heaviest calves at 239.37 kg. Among straightbreds the Brahman dams weaned the heaviest calves at 220.68 kg, while the calves weaned by Hereford dams had the lowest weaning weight at 184.19 kg.

Heterosis for maternal effects on weaning weight was also estimated by linear contrast of least squares means. All cow breed groups expressed significant heterosis for maternal effects on weaning weight. All cow breed groups also expressed significant heterosis for maternal effects on weaning weight in the model that only included cows from two to five years of age. All groups of 3/8N 5/8A dams expressed less heterosis for maternal effects weaning weight than predictions based on the dominance model. All groups of BANH dams expressed significant heterosis ($P < 0.0001$) for maternal effects on weaning weight except the $BANH_c$ dams. Heterosis estimates were similar to the expectations from the dominance model for the $BANH_c$ dams. The heterosis estimates for $BANH_b$ and $BANH_2$ crosses were higher than those predicted from the dominance model, while for $BANH_a$ dams the heterosis estimates were slightly lower than those predicted from the dominance model.

Cow Weight at Palpation

Nellore cows were heavier at palpation at four years of age than any other straightbred group (542.05 kg), while the Hereford cows were the lightest among all cow breeds (507.36 kg). Heterosis estimates for four year old cow weight at palpation were estimated by linear contrast of least squares means. All groups of 3/8N 5/8A cows expressed lower four year old cow weight at palpation than their weighted midparent value. The $BANH_b$ and $BANH_c$ cows expressed significant ($P < 0.05$) heterosis for cow weight at palpation. The $BANH_a$ cows produced by matings of 1/2B 1/2H bulls to 1/2N 1/2A dams expressed negative heterosis (-12.78 kg), while the $BANH_2$ cows expressed almost no heterosis for cow weight at palpation.

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VITA

Name: Rodney Oliver Neufeld Arce

Place of Birth: Asunción, Paraguay.

Permanent Address: Coronel Moreno, 1341. Asunción, Paraguay.

Education: National University of Asunción, 1998-2004.
College of Veterinary Science.
DVM, 2004.

Texas A&M University, 2005-2006.
M.S., Animal Breeding. 2006.