BIRTH, WEANING, CARCASS, AND MEAT TRAITS IN *Bos indicus-Bos taurus* RECIPROCAL BACKCROSS CALVES PRODUCED THROUGH EMBRYO TRANSFER

A Thesis

by

TONYA SUE AMEN

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 2004

Major Subject: Animal Science

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December 2004

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ABSTRACT

Birth, Weaning, Carcass, and Meat Traits in *Bos indicus-Bos taurus*
Reciprocal Backcross Calves Produced Through Embryo Transfer. (December 2004)

Tonya Sue Amen, B.S., Texas Tech University

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Angus - *Bos indicus* (Brahman or Nellore) reciprocal backcross embryo transfer calves belonging to 28 full-sib families were evaluated for differences in birth weight (BW), gestation length (GL), weaning weight (WW), carcass weight (HCW), longissimus muscle area (REA), fat thickness (adjusted (ADJFAT) and actual(ACTFAT)), intramuscular fat (MARB), and Warner-Bratzler shear force tenderness (WBSF).

Family types with a greater proportion of *Bos indicus* in the sire in relation to the amount in the dam (F_1 x A and B x F_1) averaged longer GL and heavier BW than their respective reciprocal crosses (A x F_1 and F_1 x B). Calves had longer GL when the F_1 parent was BA as opposed to AB. Small differences (statistically insignificant) were detected for BW, but no consistent difference was found between offspring of AB and BA parental types, with the exception of male F_1-sired calves.

F_1 x A and B x F_1 crosses also showed a large BW difference between males and females (about 5.0 kg), while A x F_1 and F_1 x B crosses showed no BW difference between males and females. Further examination within each sex showed a difference between male reciprocals that was two times that of females.

Calves with a higher percentage of *Bos indicus* in the sire compared to the proportion in the dam showed the same trend, as they were still heavier at weaning, and produced heavier carcasses than the reciprocal crosses, though these differences were not significant.

As a whole, A backcross calves had more ACTFAT, more ADJFAT, larger REA, more MARB, and lower WBSF than B backcross calves, though no significant differences were detected between reciprocal crosses for any of these traits.

These results suggest that for weight related traits, especially BW, both the breed constitution of the calf and the cross that produces the calf play an important role in its ultimate performance for *Bos indicus* crossbred calves. For carcass and meat related traits, it appears that the breed make-up of the calf itself is more significant in influencing performance than the cross used to produce the calf.

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TABLE OF CONTENTS

LIST OF TABLES

TABLE Page

TABLE Page

TABLE Page

LIST OF FIGURES

INTRODUCTION

Accurate selection of breeding stock is an ongoing challenge for beef cattle producers. The respective breed advantages brought about by British, Continental, and Brahman cattle have been studied at length, as has the benefit of crossing *Bos indicus* and *Bos taurus* cattle. Insight into potential breed and sex effects and their interactions on calf performance can greatly assist producers in making selection decisions.

Adaptation characteristics of *Bos indicus* cattle make their inclusion in breeding programs imperative, especially in the southern United States and other tropical and sub-tropical regions. Plus, higher levels of heterosis exist in *Bos indicus*-*Bos taurus* crosses than in crosses that only involve *Bos indicus* or *Bos taurus* breeds. Research has shown that the manner in which *Bos indicus*-*Bos taurus* crossbreeding programs are designed is extremely important (Roberson et al., 1986; Baker et al., 1989; Thallman et al., 1993). Specifically, there is a noticeable difference in the performance of reciprocal cross (*Bos indicus* bulls bred to *Bos taurus* cows, versus *Bos taurus* bulls on *Bos indicus* cows) calves for several size and growth traits.

Current methods used in the selection and evaluation of quantitative traits in livestock are based on additive effects of genes at multiple loci. It is assumed that these additive effects adequately account for genetic differences among animals that are subject to selection. Because of presumed traditional maternal influence, or lack thereof, the observation of disproportionate performance in reciprocal *Bos indicus*-*Bos taurus*

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crosses seems to indicate that factors such as genomic imprinting may be involved. Additionally, research that has been carried out in this area with cattle has focused primarily on pre-weaning traits, likely due to the fact that reciprocal cross performance differences in non-embryo transfer calves were assumed to be caused my maternal effects. Consequently, little emphasis has been placed on post-weaning growth, reproductive and carcass traits; however, considering their economic importance, further study is warranted.

The objective of this research is to verify and expound on studies previously done concerning the performance of *Bos indicus – Bos taurus* reciprocal cross calves. Using data collected from the Texas A&M University Angleton project, the aim is to better characterize differences in reciprocal cross performance for birth, weaning, post-weaning and carcass traits of cattle that have been produced through embryo transfer.

LITERATURE REVIEW

The purpose in reviewing previous research is to gain perspective into knowledge that has been gained thus far concerning the phenomenon involving reciprocal differences in performance among crosses of *Bos indicus* and *Bos taurus* cattle. A review of historic research involving crosses of these two genetic types and the findings in regards to reciprocal performance differences for crossbred progeny, sires, and dams will be presented. Following, will be a review of literature related to possible causes of reciprocal cross performance differences as observed in other species.

Performance Differences in Reciprocal Cross Cattle

In 1965, Ellis et al. evaluated birth weight (BW) in Brahman (B) and Hereford (H) cattle and crosses involving the two breeds. Research was carried out at the Texas Agricultural Experiment Station in McGregor, TX. Crosses involved were (sire breed first): Pure bred HH and BB, F_1 BH and F_1 HB, as well as backcrosses H x BH, B x BH, BH x H, and BH x B. Mean birth weight for all calves was 30.1 kg. Birth weight for HH, BB, HB, and BH calves differed from the mean by 0.6 kg, -3.6 kg, -2.9 kg, and +5.8 kg, respectively. In this case, 8.9 kg separated the reciprocal F_1 calves at birth. Further analysis carried out on the backcrosses showed deviation from the mean ranging from -3.5 kg for BH x B calves to +4.7 for BH x H calves; H x BH and B x BH were intermediate with -1.1 kg and +0.7 kg deviation from the mean, respectively. Birth weight difference between reciprocal backcrosses was approximately half as large as the difference between F_1 reciprocal crosses. Quarter-blood calves had a 5.8 kg difference in birth weight, and 4.2 kg separated the 3/4 blood calves. Researchers suggested that both the genotype of the dam and the genotype of the calf influenced BW.

Notter et al. (1978) reported results from a study on birth and survival traits in calves from young crossbred cows (two and three year olds) of various *Bos taurus* breeds. Calves from two-year-old dams were sired by Angus, Hereford, Brahman, Holstein, and Devon sires. Of these matings, Brahman-sired calves had the heaviest birth weight and the longest gestation length. Among these dams, the average sex difference for birth weight (male minus female) across all sire breeds was 2.1 kg; but, the average sex difference among Brahman-sired progeny was 4.4 kg.

Similarly, Bailey and Moore (1980) found these same trends in F_1 calves of various crosses at the Main Station Field Lab in Reno, Nevada. When compared to *Bos taurus* F_1 crosses, Brahman x Hereford F_1's had the heaviest BW (38.4 kg compared to 35.6 kg average over all crosses). Also, Brahman-sired calves had the largest difference between sexes of all the crosses studied.

As a follow up to this study, in 1988, Bailey et al. examined maternal characteristics of purebred *Bos taurus*, *Bos taurus* cross, and *Bos indicus* - *Bos taurus* dams. Hereford (H), Red Poll (R), H x R, R x H, Angus (A) x H, A x Charolais, Brahman (B) x H, and B x A dams were represented. Red Angus sires were used on first-calf heifers, while Santa Gertrudis bulls were used in subsequent breeding seasons. In this study, calves from B cross dams had the lightest BW, with calves from BH and BA dams being 2.5 kg and 5 kg lighter, respectively, than the AH average; BA dams also produced calves with the lightest weaning weight (Bailey et al., 1988).

Lemos et al. (1984) studied birth weight and gestation length on six different crosses of Holstein-Friesian (Hf) and Guzera (G). One-quarter Hf 3/4G, 1/2 Hf 1/2 G, 5/8 Hf 3/8 G, 3/4 Hf 1/4 G, 7/8 Hf 1/8 G, and Hf calves were born and raised at Santa Monica Experiment Station in Valenca, Rio De Janeiro, Brazil, with the breeding strategies show in Table 1.

Table 1. Lemos et al. (1984) breeding scheme

Calf Breed Type	Sire Type	Dam Type
1/4 Hf 3/4 G	G	Hf G
1/2 Hf 1/2 G	Hf	G
5/8 Hf 3/8 G	5/8 Hf 3/8 G	5/8 Hf 3/8 G
3/4 Hf 1/4 G	Hf	Hf G
7/8 Hf 1/8 G	Hf	3/4 Hf 1/4 G
H	H	H

Calves with the longest GL were 1/4 Hf 3/4 G and 5/8 Hf 3/8 G (290.0 and 285.3 days for males, respectively, and 287.5 and 285.3 days for females, respectively). Distinguishing characteristics of these crosses were 3/4 G calves represented the highest percentage *Bos indicus*, while 5/8 Hf calves showed no difference in the proportion of *Bos indicus* in the dam in relation to the proportion of *Bos indicus* in the sire. Little difference was observed in GL for the other crosses in which there was either a low percentage G or the amount of G in the dam was greater than the amount of G in the sire. Results for BW were also reported. The difference in BW between male and female calves was 0.8 kg among H-sired calves, but was 4.7 kg for G-sired calves (Lemos et al., 1984).

In order to rationalize these differences, direct and maternal additive effects have been considered. Direct additive effect (calculated as the deviation of the Holstein from the Guzera) on BW was negative for males but positive for females. Also, the maternal additive effect on BW was positive for both sexes, but was nearly twice as large in males as females (Table 2). Birth weight direct heterosis showed the same trend as the direct additive effect for BW, with the male estimate being negative and the female estimate positive. The maternal heterosis estimate for BW, however, was two times as large for female calves as male calves (the opposite of maternal additive effect).

Table 2. Direct and maternal additive effects and heterosis*

Effect	Gestation Length Male (days)	Gestation Length Female (days)	Birth Weight Male (kg)	Birth Weight Female (kg)
Direct Additive	-21.5	-21.9	-3.5	4.7
Maternal Additive	10.6	14.6	7.1	4.1
Direct Heterosis	1.5	5.7	-0.6	2.8
Maternal Heterosis	-1.6	-1.5	1.0	2.0

* from the study of Lemos et al. (1984)

Peacock et al. (1978) studied differences in weaning weight for straight-bred and reciprocal cross calves from Brahman (B), Angus (A), and Charolais (C) cattle at the University of Florida Agricultural Research Center in Ona, FL. Sire breed and dam breed was found to have a significant effect on weaning weight. A significant breed of sire x breed of dam interaction was also detected. Weaning weight for AB, BA, CB, and BC calves was 202.8, 198.5, 229.7, and 216.3 kg, respectively. These reciprocal differences were attributed to the maternal ability of Brahman, Angus, and Charolais females.

Birth weight trends similar to those already discussed were further supported by the work of Roberson et al. (1986), who re-analyzed data discussed by Ellis et al. (1965) with the inclusion of nine additional years of data from McGregor, TX. Brahman-sired Brahman x Hereford (BH) F_1 calves were 7.4 kg heavier at birth than Hereford-sired Hereford x Brahman (HB) F_1 calves. Calves out of F_1 dams were intermediate for BW for each sire type (B, H, and F_1). Using a regression approach (similar to Lemos et al., 1984), a maternal additive effect of -7.5 kg, for the Brahman female as compared to Hereford, was estimated. On the contrary, BH calves showed 21 kg less pre-weaning gain than HB calves, while calves from F_1 dams had larger gains than calves out of Brahman or Hereford dams for each sire breed. These observations are significant because under traditional Mendelian genetics, we would expect both crosses to have the same genetic and phenotypic values (if the maternal influences were similar). Differences in pre-weaning growth were statistically attributed to greater direct effect (17.7 kg) shown by the Hereford breed, in addition to the strong, positive maternal effect (20 kg) contributed by the Brahman female (Roberson et al., 1986). Though the exact cause of the maternal effect of the Brahman female was unknown, uterine environment, milk production and passive immunity were all stated as speculative potential sources.

Comerford et al. (1987) studied birth weight (BW) on calves from the Wilkens Unit of the University of Georgia Experiment Station in Lexington. Calves were from a four breed diallel involving Simmental (S), Limousin (L), Brahman (B), and Hereford (H). Variables of year, sex of calf, dam breed, sire breed, sire breed x dam breed, year x sex, dam breed x sex, and sire breed x sex were all significant sources of variation for BW.

Brahman-sired calves averaged the heaviest at birth (36.5 kg). This was significantly heavier than the BW averages of calves from S, L, and H sires which were 35.5, 34.0, and 33.0 kg, respectively. Brahman dams, on the other hand, had calves with the lightest BW, 29.9 kg, on average. This too was significantly different from the 36.8, 36.9, and 35.3 kg average BW recorded for calves of S, L, and H dams, respectively (Comerford et al., 1987).

The individual breed effects contributed by these Brahman sires and dams became apparent in the evaluation of the reciprocal crosses in which they were involved. SB, BS, LB, BL, HB, and BH calves had BW of 30.9, 38.3, 29.6, 39.2, 29.3, and 39.0 kg, respectively. In each case, the reciprocal involving a B sire was heavier than the cross with a B dam. These authors attributed the reciprocal differences to a negative maternal effect of the B female (Comerford et al., 1987).

Further results from this study were discussed in the 1988 article by Comerford et al. Here, preweaning and post weaning growth were evaluated, though weaning weight (WW) will be the focus of this discussion. Year, calf sex, dam breed, and sire breed x dam breed were all significant sources of variation for WW. Calves from B-dams had the heaviest WW (237.8 kg), which differed from the H dam average of 206.2, but was not significantly different from the average of calves with S and L dams (230.5 and 224.0 kg, respectively). Brahman-sired calves averaged 229.9 kg at weaning which was greater than the L and H average of 222.5 and 219.6 kg, respectively (Comerford et al., 1988).

Weaning weight heterosis estimates for breed pairs of SB, LB, and HB combinations were 20.4, 16.9, and 20.3, respectively. These values were nearly twice as large as estimates for breed pairs consisting of only *Bos taurus* breeds. BW heterosis values were 0.78, 1.35, and 2.59 kg for SB, LB, and HB. These positive values are in contrast to all negative heterosis estimates for *Bos taurus* breed pairs. It was concluded that crosses involving B have significant heterosis for traits related to weight (Comerford et al., 1987 and 1988). It was also hypothesized that the large negative maternal effect of the B dam for BW may have suppressed the expression of some growth genes until after birth, and that the WW results for calves with B dams were simply a function of compensatory gain (Comerford et al., 1988). Quite possibly though, the WW of calves from B-dams was simply an effect of superb heterosis between the *Bos indicus* dam and *Bos taurus* sires, or higher milk production of the Brahman dams.

Baker et al. (1989) attempted to account for the maternal difference observed in Brahman versus Hereford females by utilizing embryo transfer technology. A small number of purebred Brahman and Hereford embryos and reciprocal F_1 cross embryos were placed in Brahman and Hereford recipients (Table 3). Differences in birth weight, cannon bone length, and gestation length were evaluated. For birth weight, significant sources of variation included sire breed, donor breed, and sire breed x donor breed interaction. Recipient breed, however, was significant only for gestation length differences. For each fetus type (BB, BH, HB, HH), the Brahman recipient had a longer gestation length than the Hereford (1.5, 4.2, 2.2, and 5.7 days, respectively).

Table 3. Baker et al. (1989) breeding scheme

	Brahman Recipients			**Hereford Recipients**		
Fetus breed type[a]	n	BW (kg)	GL (days)	n	BW (kg)	GL (days)
HB	8	34.8	287	9	37.4	284
BH	3	42.2	297	5	49.3	292
BB	6	32.0	293	11	34.0	291
HH	3	39.2	289	8	37.0	284

[a] Sire breed is listed first.

The significance of this study is that by using embryo transfer, the effect of the Brahman donor female could be evaluated strictly by source of inheritance, as the effect of uterine environment, milk production, and passive immunity should have been equalized through the use of the recipient females. Still, the birth weight and gestation length differences in reciprocal cross calves and the longer gestation length of Brahman recipients were apparent.

Thallman et al. (1993) examined interactions involving calf sex and *Bos indicus*-*Bos taurus* reciprocal crosses produced by using embryo transfer. Brahman (B) and Simmental (S) cattle were used as sires and donors, with Holstein cows used as recipients. Reciprocal cross effects as well as the effect of the sex of the calf and interactions on birth weight, gestation length, weaning weight, yearling weight, and scrotal circumference were evaluated.

Brahman-sired calves had larger values than the Simmental-sired calves for all evaluated traits, for both sexes; however, more pronounced differences were typically expressed between the two types of male calves (BS bull calves were 13.7 kg heavier than SB bull calves for birth weight) than between the two types of female calves (BS heifer calves were 7.7 kg heavier than SB heifer calves). Also, Simmental-sired male calves were not different from Simmental-sired female calves for birth weight, but Brahman-sired male calves were approximately 5 kg heavier than Brahman-sired female calves. This study reaffirms that differences do exist in the performance of *Bos indicus-Bos taurus* reciprocal cross calves even when embryo transfer is used, and that there are differences in the performance of calves depending on the sex and breed combination of genetic parents (a cross x sex interaction) for *Bos indicus – Bos taurus* crosses.

Possible reasons for differences in performance among reciprocal crosses were proposed by Thallman et al. (1993), and included mitochondrial inheritance, genomic imprinting, X-linked inheritance with non-random X-inactivation, Y linked inheritance, maternal transmission of non-genetic components, as well as the maternal effect of oviduct and uterus of donor cow on embryo prior to collection. To date in cattle, none of these potential sources has been disproved. Herein, genomic imprinting, non-random X-inactivation, and Y-linked inheritance will be the main focus of this discussion.

Genomic Imprinting

Though little research has been done on the cause of performance differences in reciprocal cross calves, cross-species investigation reveals fascinating evidence pointing to genomic imprinting as the cause for reciprocal cross performance differences in mice (Zechner et al., 1996; Hemberger et al., 1999; 2001) and sheep (Cockett et al., 1996). Genomic imprinting occurs when a gene is expressed differently depending on from which parent it was inherited.

In sheep, non-equivalent reciprocal cross performance attributed to genomic imprinting was documented in the muscle structure of sheep (Cockett et al., 1996). Animals expressing the *callipyge* phenotype exhibit muscle hypertrophy in the loin and hind leg. This phenotype is controlled by the *callipyge* locus, located on ovine chromosome 18 (Cockett et al., 1996). Inheritance of the *callipyge* phenotype has been termed polar over-dominance because the gene is only active in heterozygous individuals (*CLPG*/*clpg*) when *CLPG* is inherited from the sire, while *CLPG*/*CLPG*, *clpg*/*CLPG* and *clpg*/*clpg* animals exhibit normal muscularity.

Further study by Charlier et al. (2001a; 2001b) revealed four imprinted genes that are expressed in skeletal muscle residing at the *callipyge* locus; *DLK1* and *PEG11* are both paternally expressed protein-coding genes, while *GTL2* and *MEG8* are maternally expressed and seem to code for RNA. Evaluation of the skeletal muscle of the four possible *callipyge* genotypes shows that *clpg*/*clpg* and *clpg*/*CLPG* muscle express a very low concentration of *DLK1*, and *PEG11 i*s absent. Muscle from C*LPG*/*CLPG* and *CLPG*/*clpg* individuals, on the other hand, has very high concentrations of these paternally expressed transcripts. Further, *clpg*/*clpg*, *clpg*/*CLPG*, and *CLPG*/*clpg* individuals show presence of only the paternal *DLK1* allele no matter what phenotype they express (Charlier et al., 2001a).

These findings led Georges et al. (2003) to propose a three-part model explaining the expression of the *callipyge* phenotype. Likely, there is a paternal effector acting in *cis* (*DLK1* and/or *PEG11*), a maternal repressor acting in *trans (GTL2* and/or *MEG8),* and finally the *callipyge* mutation (an A to G transition) acts as a gain-of-function mutation that enhances the expression of both the effectors and repressors.

Advances have also been made in the understanding of imprinting effects in mice. DeChira et al. (1991) studied mutations in the insulin-like growth factor II (IGF-II) gene in mice. Specifically, mutant mice carried a targeted disruption of IGF-II. When inherited through the male germ line, progeny heterozygous (P-het) for the mutation were born growth deficient and remained 60% smaller than non-mutant mice throughout their lifetime. Progeny with this genotype were viable and fertile. Progeny heterozygous for the maternally inherited mutation (M-het) are normal. Homozygous mutants were not distinguishable from P-het offspring. Individuals heterozygous for the paternally and maternally inherited mutation were then mated to wild type mice, and the phenotype of resulting progeny was consistent with earlier results with only individuals paternally inheriting the mutation expressing deficient growth. This mode of inheritance was continued in subsequent generations. From these results, it is apparent that only the paternal allele is expressed; while, the maternal allele is silent. Thus, the inheritance of IGF-II is subject to genomic imprinting (DeChira et al., 1991).

In a mouse cross that could prove somewhat analogous to *Bos indicus* - *Bos taurus* matings, hypotrophic placentas were observed in crossbred *Mus spretus* (*spretus*) x *Mus musculus* (*mus*) mice when the *spretus* male was mated to *mus* female. Obtaining pregnancy in the reciprocal cross is extremely difficult, but in the two that were acquired, progeny displayed the opposite phenotype (Zechner et al., 1996). Gene mapping in the same study revealed one of the major loci affecting placental size (*Ihpd* – Interspecific hybrid placental dysplasia) is located on the X chromosome. Upon determining the sex of the fetuses, Zechner et al. showed that, in both *spretus* x *mu*s and *spretus* x F_1 crosses, male fetuses were significantly lighter than females, suggesting that the sex of the fetus may play a role in placental development. In *mus* x F_1 crosses male fetuses were heavier than females.

As a continuation, Hemberger et al. (1999) created F_1 hybrids by crossbreeding *mus* and *spretus* mice. Congenic strains were then developed by backcrossing F_1 offspring repeatedly to one of the parental strains. In these congenic strains, a significant positive correlation ($r = 0.93$) existed between placental weight and length of the spretus portion of the X-chromosome (Hemberger et al., 1999). Next, Hemberger et al. (2001) analyzed the sex difference observed in the placental development of male and female fetuses. Results from this study showed that the difference between male and female placental weights is not found in matings involving only *mus*, thus signifying that the sex dependence is a feature of *mus* – *spretus* interspecific matings. It was concluded that these differences were caused by interactions between the X and Y chromosome.

X Chromosome Inactivation (XCI)

Though discussed separately, it appears that in some cases XCI and genomic imprinting are not mutually exclusive events. In mice, non-random X-inactivation plays a significant role in genomic imprinting, as paternal X chromosomes seem to be preferentially inactivated (Latham, 1996).

In cats and humans, it appears that XCI may be random (Travis, 2000). All calico cats are female, and sweat glands are absent from portions of some women's bodies. Though it is not known what triggers these phenomena, both are due to the fact that early in development individual cells randomly inactivate one X-chromosome. In fact, all female mammals possess this ability, which is referred to as mosaicism (Travis, 2000).

X-chromosome inactivation is not absolute, as it appears that many genes on the inactive X may escape inactivation. Borsani et al. (1991) showed that *XIST* is one such gene, and its transcript (*Xist*) seems to play an important role in XCI. In a study reviewed by Travis (2000), it was shown that a large number (34 out of 224) of genes escaped inactivation in mouse-human hybrid chromosomes. Interestingly, 31 of the 34 were located on the short arm of the X chromosome.

Both studies seem to agree that genes in close proximity to *XIST* are the first to be repressed (Latham, 1996; Travis, 2000) while genes farther from *XIST* are not repressed until later in development. This is supported by studies in which dosage compensation was shown to occur at different times of development for different genes (Latham, 1996).

Researchers attempting to answer what it is about the X chromosome that makes it prone to inactivation went in search of a DNA sequence prevalent on the human X chromosome, and discovered LINE-1 elements (L1s) (Travis, 2000). About 26% of the human X chromosome is comprised of L1s, which is about two times the amount on other chromosomes. Also, there appears to be non-random distribution of these L1 elements, as most appear to be in close proximity to *XIST*.   Previously thought to be "junk" DNA, it now appears that L1s may have a role in XCI as areas that are prone to inactivation are rich in L1s, and those escaping inactivation had L1 concentrations lower than the autosomes (Travis, 2000).

Y-Linked Inheritance

Wilken et al. (1992) studied performance for growth and carcass traits in Duroc (D) and Landrace (L) reciprocal cross pigs produced naturally and through embryo transfer (ET). Four genotype-treatment combinations were developed. The first treatment produced non-ET pigs developed by mating of Duroc boars to Landrace sows (DL-L), or Landrace boars to Duroc sows (LD-D). The pigs were farrowed and reared by their natural dam. The second treatment produced pigs by ET, where DL embryos were placed in Duroc recipients (DL-D), and LD embryos were place in L recipients (LD-L). In this case, litters were born to and reared by females that were the opposite breed of their genetic dam.

Analysis for this study revealed no genotype-treatment x sex interaction for growth rate, carcass weight, or average back fat thickness, so the differences were averaged over both sexes. Still, no reciprocal cross differences were detected for these traits for ET or non-ET pigs. On the other hand, genotype-treatment x sex interactions were observed for carcass length, 10th rib back fat (BF), longissimus muscle area (LMA), estimated fat standardized lean, and estimated lean gain per day of age; so, means were compared within each sex. Reciprocal cross differences were observed in barrows only for BF and LMA. Gilts displayed no reciprocal cross effects.

For non-ET pigs, DL-L barrows had 3.9 cm^2 greater LMA and 5.8 mm less BF than LD-D barrows. Among ET barrows, DL-D pigs averaged 3.8 cm^2 greater LMA than LD-L barrows; however, no difference was detected in BF (Wilken et al., 1992). Because the barrows seemed to perform similarly to the sire breed and no reciprocal cross differences were detected among gilts, these researchers concluded their results were consistent with Y-linked inheritance.

The results from non-ET barrows certainly support this conclusion, as the D-sired progeny were leaner, and more muscular than L-sired progeny. However, no difference was detected in BF between D and L-sired ET barrows, which may suggest this trait is not Y-linked after all.

Reciprocal cross performance differences in *Bos indicus – Bos taurus* crossbred calves have been previously reported in non-embryo transfer calves, and in small numbers of embryo transfer calves. Reciprocal cross performance differences have been observed in various traits for sheep, mice, and pigs, with the cause of the phenotypic dissimilarity being attributed to genomic imprinting, X-chromosome inactivation, Y-linked inheritance.

MATERIALS AND METHODS

Data from embryo transfer calves belonging to 28 full-sib families raised and harvested between 1990 and 1996 were evaluated for differences in birth weight (BW, n = 511), gestation length (GL, n = 512), weaning weight (WW, n = 497), carcass weight (HCW, n = 493), longissimus muscle area (REA, n = 492), adjusted fat (ADJFAT, n = 489), actual fat (ACTFAT, n = 492), marbling score (MARB, n = 483), and Warner-Bratzler shear force tenderness (WBSF, n = 459).

The data collected were from Angus - *Bos indicus* (Brahman or Nellore) reciprocal backcross embryo transfer calves born in spring and fall seasons at the Texas A&M University Experiment Station at Angleton. All of the progeny were 3/4 Angus 1/4 *Bos indicus*, or 3/4 *Bos indicus* 1/4 Angus, with eight different family types being created through the use of purebred and F_1 sires and dams to produce a total of 32 families. To obtain each family type, four different breeding schemes were used: F_1 (AB or BA) bulls were mated to purebred (Angus or Brahman) cows; or, conversely, purebred (Angus or Brahman) bulls were mated to F_1 (AB or BA) females (Table 4). All calves were born to recipient dams that were approximately 1/2 Brahman and 1/2 British, and were 4 to 10 years old.

Embryo transfer procedures were carried out at Cross Country Genetics, Normangee, Texas, using industry-accepted protocols. After flushing, embryos were evaluated for quality and stage. Assigning each embryo a numerical grade from one to four indicated embryo quality[1], embryo stage was denoted by assigning a numerical value to each stage of development[2] (Selk, 2002).

All calves were weaned at approximately 7 months of age and backgrounded on pasture at Angleton for an average of 215 days. Calves were then shipped to the Texas A&M University Research Center at McGregor, Texas, where they were finished on a corn-based ration for an average of 150 days. Calves were harvested at the Rosenthal Meat Science and Technology Center on the Texas A&M campus in College Station.

Birth weight and gestation length data were studied through analysis of covariance through the mixed model procedure of SAS that included independent variables of sex, sire-type x dam-type interaction (ST x DT), family nested within ST x DT, sex x ST x DT, embryo quality (EQ), embryo stage (ES), and the regression on birth date within season-year combinations (JDAY (BY x Season)).

Table 4. Breeding scheme for Angleton project

Calf Breeding	**Sire Type**	**Dam Type**
Angus backcross (3/4 A 1/4 B)	A	AB
	A	BA
	AB	A
	BA	A
Bos indicus backcross (3/4 B 1/4 A)	B	AB
	B	BA
	AB	B
	BA	B

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[1] Grade 1 = Excellent; Grade 2 = Fair; Grade 3 = Poor; Grade 4 = Dead or degenerating

[2] Stage 4 = Morula; Stage 5 = Early Blastocyst; Stage 6 = Blastocyst; Stage 7 = Expanded Blastocyst.

Weaning weight data were analyzed through analysis of covariance using the mixed model procedure of SAS. Independent variables included sex, sire-type x dam-type interaction (ST x DT), family nested within ST x DT, sex x ST x DT, embryo quality (EQ), embryo stage (ES), and the regression on weaning age within season-year combination (WAGE (BY x Season)). Initial analysis also included EQ and ES; however, neither was statistically significant so both were excluded from subsequent analysis.

Carcass traits of carcass weight, longissmus muscle area, actual fat, adjusted fat, intramuscular fat, and Warner-Bratzler shear force (HCW, REA, ACTFAT, ADJFAT, MARB, and WBSF, respectively) were examined through analysis of covariance. Independent variables included sex, ST x DT, sex x ST x DT, family nested within ST x DT, and the regression on slaughter age (SLAGE) with in season-year combination.

For all traits, family nested with ST x DT was considered a random effect, and was the error term to test for differences due to ST x DT. When an F-test showed a significant difference for an effect, least squares means were separated by two-tailed t-tests.

Each trait was analyzed with two different methods. Though the independent variables were the same for each method, ST and DT were slightly different. Method I combined AB and BA parents into a single F_1 category, whereas Method II separated F_1 parents into AB or BA categories.

RESULTS AND DISCUSSION

Gestation Length (GL)

Gestation length was studied on 512 embryo transfer calves. Calf sex, embryo quality, the regression on Julian day of birth within birth year and season combinations, and the two-way interaction of sire type x dam type accounted for variation in GL for Method I and Method II (Tables 5 and 6).

Table 5. Method I gestation length fixed effects

Effect	F-Value	P-value
Julian date (Birth Year x Season)	19.05	<.0001
Sex	18.63	<.0001
Sire Type x Dam Type	4.97	.008
Sire Type x Dam Type x sex	0.43	.7330
Embryo Quality	2.73	.0436
Embryo Stage	1.49	.2166

Table 6. Method II gestation length fixed effects

Effect	F Value	P-value
Julian date (Birth Year x Season)	19.08	<.0001
Sex	19.19	<.0001
Sire Type x Dam Type	3.69	.0101
Sire Type x Dam Type x sex	0.23	.9771
Embryo Quality	2.91	.0340
Embryo Stage	1.53	.2057

Method I. Gestation length for male calves averaged 291.2 days and female calves averaged 288.5 days, a difference of 2.7 days. This is similar to Herring et al. (1996) who found that on average, F_1 male calves were carried 1.9 days longer than F_1 females in a cross of Brahman, Boran, and Tuli bulls on Angus and Hereford cows.

Embryo quality was responsible for significant differences in GL. Quality grades one through three represented excellent, good, and fair quality embryos, respectively. Grade six embryos were poor quality. Gestation length was longer for "good" quality (grade two) embryos than for excellent quality embryos (grade one), though no definite trend was established (Table 7).

Table 7. Gestation length least squares means for embryo quality

Embryo Qualtiy	n	Gestation Length (days)	Standard Error
1	224	289.3	0.93
2	273	290.9	0.95
3	13	287.6	2.03
6	2	291.5	4.81

For A backcross calves, GL averaged 286.8 days from A x F_1 matings, but averaged 289.3 days from F_1 x A matings. For B backcross calves GL averaged 293.8 days from B x F_1 matings, but averaged 289.5 days from F_1 x B matings. The differences in gestation length were only significant among B backcross calves, where B x F_1 calves were carried 4.2 days longer than F_1 x B. Among A backcross calves, F_1 x A were only carried 2.6 days longer than A x F_1 (Table 8).

Method II. Gestation length data confirmed more specific reciprocal cross differences involving F_1 sire and dam type when reciprocal cross parents were separated (AB vs. BA). Angus backcross calves sired by A bulls were carried for 289.6 days when BA was the dam type; however, calves with AB dams were carried for 284.5 days – a difference of 5.1 days. Calves sired by F_1 bulls out of A dams only differed in GL by 2.5

Table 8. Method I least squares means for gestation length

Calf Breeding	Sire Type	Dam Type	N	Gestation Length (days)	Difference
Angus backcross	A	F_1	140	286.8	-2.6
(3/4 A 1/4 B)	F_1	A	127	289.3	(P = .1901)
Bos indicus backcross	B	F_1	141	293.8	4.2
(3/4 B 1/4 A)	F_1	B	104	289.5	(P = .035)

days when the sire was BA as opposed to AB. For calves from B sires and F_1 dams, GL was 4 days longer in calves from BA dams (296.1) as compared to 292.4 for those from AB dams. For calves from F_1 sires and B dams, GL was 3 days longer in calves from BA sires (291.1) than calves from AB sires (288.3). In both the A and B backcross calves, the trend was to have a longer GL when the F_1 parent was BA as opposed to AB (Table 9).

Table 9. Method II least squares means for gestation length

Calf Breeding	Sire Type	Dam Type	n	Gestation Length (days)	Difference
Angus backcross (3/4 A 1/4 B)	A	AB	76	284.5	-5.1
	A	BA	64	289.6	(P=.0432)
	AB	A	68	288.4	-2.5
	BA	A	59	290.8	(P=.3475)
Bos indicus backcross (3/4 B 1/4 A)	B	AB	83	292.4	-3.7
	B	BA	58	296.1	(P=.1485)
	AB	B	48	288.3	-2.8
	BA	B	56	291.1	(P=.2736)

These data seem to indicate that GL was shorter for calves whose dams had a higher percentage B in relation to the amount of B in the sire. This is consistent with results from an embryo transfer study by Baker et al. (1989), where BH calves were carried for 10 days longer than HB calves in B recipients, and 8 days longer in H recipients. Also, in the current study, B-sired calves had the longest GL for both Methods (ranging from 292.4 to 296.1 while A-sired calves ranged from 284.5 to 289.6). This is consistent with results from Paschal et al. (1991) who found *Bos indicus* sired calves were carried 7-12 days longer than Angus sired calves when bred to Hereford cows.

Reynolds et al. (1980) also recognized a breed of sire x breed of dam effect. In reciprocal F_1 Angus-Brahman crosses, BA calves were carried 2.6 days longer than AB. Lemos et al. (1984) reported similar results in Holstein–Guzera cross calves. Males and females were analyzed separately; however, similar results were observed for both sexes. The longest GL for both sexes was seen in calves sired by Guzera bulls and out of F_1 Holstein x Guzera cows (290 and 288 days for male and female calves, respectively).

Reciprocal differences between sexes were analyzed by Thallman et al. (1993) in embryo transfer crosses involving Brahman and Simmental. Among females, Brahman x Simmental calves were carried 2.3 days longer than Simmental x Brahman; while BS male calves were carried 1.6 days longer than SB male calves.

Birth Weight (BW)

Birth weight was studied on 511 embryo transfer calves. Calf sex, the regression on Julian birth date within season and year combinations, the three-way interaction of sire type x dam type x sex, and embryo stage accounted for variation in BW for Method

I and Method II (Tables 10 and 11). Sire type x dam type also accounted for significant variation in Method I.

Table 10. Method I birth weight fixed effects

Effect	F Value	P-value
Julian date (Birth Year x Season)	2.24	.0148
Sex	34.57	<.0001
Sire Type x Dam Type	4.46	.0126
Sire Type x Dam Type x sex	4.07	.0072
Embryo Quality	0.18	.9130
Embryo Stage	3.08	.0270

Table 11. Method II birth weight fixed effects

Effect	F Value	P-value
Julian date (Birth Year x Season)	2.47	.0070
Sex	33.02	<.0001
Sire Type x Dam Type	1.98	.1093
Sire Type x Dam Type x sex	3.27	.0021
Embryo Quality	0.14	.9344
Embryo Stage	3.15	.0250

Method I. BW for male calves averaged 38.2 kg, and female calves averaged 35.2 kg. This is similar to results by Herring et al. (1996) who found male F_1 calves to average 4.4 kg heavier at birth than F_1 females in a cross of Brahman, Boran, and Tuli bulls on Angus and Hereford cows.

Embryo stage was responsible for significant differences in BW. Stage seven represented the blastocyst stage of development on day seven, stage six was the morula stage, and stage four and five were earlier stages of development. Calves that were transferred as stage six embryos were lighter at birth than calves transferred at other stages. (Table 12).

Table 12. Birth weight differences for embryo stage

Embryo Stage	n	Birth Weight (kg)	Standard Error
4	240	36.9	1.3
5	169	36.8	1.3
6	73	34.9	1.4
7	29	38.2	1.6

Reciprocal cross performance differences were observed for BW for A and B backcrosses. For A backcrosses, A x F_1 calves were 3.5 kg lighter than F_1 x A calves (34.9 vs. 38.4 kg). Among B backcrosses, B x F_1 calves averaged 39.1 kg, which was 4.7 kg heavier than the F_1 x B average of 34.4 (Table 13).

Table 13. Method I least squares means for birth weight

Calf Breeding	Sire Type	Dam Type	N	Birth Weight (kg)	Difference
Angus backcross	A	F_1	139	34.9	-3.5
(3/4 A 1/4 B)	F_1	A	141	38.4	(P=.0406)
Bos indicus backcross	B	F_1	127	39.1	4.7
(3/4 B 1/4 A)	F_1	B	104	34.4	(P=.0073)

A significant sex x ST x DT effect was observed for this method. Among A backcross calves from A sires and F_1 dams, the BW difference was 1.8 kg between male and female calves, but when A backcross calves were produced from F_1 sires and A dams the difference in male vs. female BW was 5.0 kg (40.9 vs. 35.9 kg, respectively).

For B backcross calves produced from B sires and F_1 dams, male calves averaged 4.6 kg heavier than females (41.4 vs. 36.8 kg), whereas when B backcross calves were produced from F_1 sires and B dams, the difference was only 1.2 kg (Table 14).

Divergent sex differences involving *Bos indicus* x *Bos taurus* crosses had been reported previously in natural service calves by Notter et al. (1978), Bailey and Moore (1980), and Lemos et al.(1984). In each of these studies, the average sex difference in BW was greater for *Bos indicus*-sired calves than for *Bos taurus*-sired calves. This is also consistent with results from Paschal et al. (1991) who reported a breed x sex interaction in a study of four different *Bos indicus* sire breeds. In that study, A-sired male calves averaged 2.6 kg heavier than females while *Bos indicus*-sired males ranged from 4.4 to 7.0 kg heavier than females, when these sire types were bred to Hereford cows.

Within sex analysis of reciprocal differences revealed more fascinating differences. First, F_1 x A male calves were 5.4 kg heavier than A x F_1 male calves, while the difference between female calves was only 1.6 kg (in the same direction). Among B-backcross individuals, the difference between male calves was 6.4 kg, though in this case the purebred-sired calves were heavier than F_1-sired calves. Again, female reciprocals exhibited less differentiation (again, this difference was in the same direction as the male calves), with only 3.0 kg separating the two (Table 15).

Similar trends were reported on Brahman – Simmental reciprocal cross ET calves by Thallman et al. (1993). In this study, BS male calves averaged 13.7 kg heavier than SB male calves, while BS female calves were only 7.7 kg heavier than SB females,

Table 14. Method I least squares means for birth weight for cross and calf sex combinations

Calf Breeding	Sire Type	Dam Type	Birth Weight males (kg)	N	Birth Weight females (kg)	n	Difference	P-Value
Angus backcross	A	F_1	35.5	76	34.3	63	1.2	.1877
(3/4 A 1/4 B)	F_1	A	40.9	63	35.9	64	5.0	<.0001
Bos indicus backcross	B	F_1	41.4	69	36.8	72	4.6	<.0001
(3/4 B 1/4 A)	F_1	B	35.0	54	33.8	50	1.2	.2630

Table 15. Method I birth weight least squares means for within sex reciprocal differences

Calf Breeding	Sire Type	Dam Type	Birth Weight males (kg)	Difference	Birth Weight females (kg)	Difference
Angus backcross	A	F_1	35.5	-5.4	34.3	-1.6
(3/4 A 1/4 B)	F_1	A	40.9	(P = .0022)	35.9	(P = .3581)
Bos indicus backcross	B	F_1	41.4	6.4	36.8	3.0
(3/4 B 1/4 A)	F_1	B	35.0	(P = .0004)	33.8	(P = .0883)

on average. Current results show a smaller difference within sex for each cross in these backcross calves, however the magnitude of the difference between males and females is the same as in Thallman's study with F_1 calves. In each case, the difference between reciprocal male calves is nearly twice as large as the difference between reciprocal female calves.

Method II. ST x DT x sex differences existed for Method II also. Among A backcross calves with F_1 sires, male calves with AB sires and A dams were 8.0 kg heavier than female calves of this cross, while BA-sired males calves out of A dams averaged only 1.6 kg heavier than females of that cross. Angus backcross calves with F_1 dams exhibited no significant difference in birth weight between male and female calves. Likewise, there was no significant difference between male and female B backcross calves from F_1 sires. However, 3/4 B male calves were 4.4 kg and 4.7 kg heavier than female calves when the dam was AB and BA, respectively (Table 16).

Within sex analysis of reciprocal crosses showed an 8.1 kg difference between A x AB and AB x A male calves (the F_1-sired calves were heavier). When BA was the F_1 parental type, only 2.6 kg separated 3/4 A male calves. Again, BA x A were larger than A x BA. Significant reciprocal differences also existed among 3/4 B male calves. *Bos indicus* x AB males averaged 8.4 kg heavier than AB x B males, and B x BA males averaged 5.8 kg heavier than BA x B. Among female calves, all reciprocal differences in BW were in the same direction as those in the male calves; however, none of the differences were of a significant magnitude (Table 17).

Table 16. Method II least squares means for birth weight for cross and calf sex combinations

Calf Breeding	Sire Type	Dam Type	Birth Weight males (kg)	n	Birth Weight females (kg)	n	Difference	P-Value
Angus backcross (3/4 A 1/4 B)	A	AB	35.7	46	34.3	30	1.4	.2837
	A	BA	35.1	30	34.0	33	1.1	.4285
	AB	A	43.8	34	35.8	34	8.0	<.0001
	BA	A	37.7	29	36.1	30	1.6	.2865
Bos indicus backcross (3/4 B 1/4 A)	B	AB	41.6	47	37.2	36	4.4	.0008
	B	BA	40.9	22	36.2	36	4.7	.0026
	AB	B	34.6	25	33.2	23	1.4	.3827
	BA	B	35.1	29	34.0	27	1.1	.4882

Table 17. Method II birth weight least squares means for within sex reciprocal differences

Calf Breeding	Sire Type	Dam Type	Birth Weight males (kg)	Difference	Birth Weight females (kg)	Difference
Angus backcross (3/4 A 1/4 B)	A	AB	35.7	-8.1	34.3	-1.5
	AB	A	43.8	(P = .0016)	35.8	(P = .5746)
	A	BA	35.1	-2.6	34.0	-2.1
	BA	A	37.7	(P = .3251)	36.1	(P = .4181)
Bos indicus backcross (3/4 B 1/4 A)	B	AB	41.6	8.4	37.2	4.0
	AB	B	33.2	(P = .0069)	33.2	(P = .1263)
	B	BA	40.9	5.8	36.2	2.2
	BA	B	35.1	(P = .0312)	34.0	(P = .4165)

No significant differences were observed among reciprocal F_1 parents except for in the case of 3/4 A male calves with F_1 sires. In this instance, male calves with AB F_1 sires averaged 6.1 kg heavier at birth than BA-sired male calves (Table 18). These results are in contrast to those observed for gestation length where, in all cases, calves with BA F_1 parents had a longer GL than calves with AB F_1 parents.

The *Bos indicus-Bos taurus* reciprocal differences documented here in embryo transfer calves have been widely reported in non-embryo transfer calves, and are also consistent with earlier reports in ET calves (with the exception of 3/4 A calves with BA F_1 sires). Reynolds et al. (1980) found AB natural service calves to average 5.0 kg lighter than BA calves. Roberson et al. (1986) found similar differences in Hereford (H) and Brahman backcross calves produced by natural service. Brahman backcross calves from B sires and F_1 dams were approximately 5.0 kg heavier than calves from F_1 sires and B dams. Hereford backcross calves from F_1 sires and H dams were about 5.1 kg heavier than H-sired calves.

Likewise, Baker et al. (1989) found that BH embryo transfer calves were 7.4 kg heavier than HB calves when both were produced from B recipients. When H recipients were used, BH calves were 11.9 kg heavier than their HB contemporaries. Also BH calves from B recipients were 15.7 lb lighter than BH calves from H recipients. Similarly, HB calves from B recipients were 5.7 lb lighter than HB calves from Hereford recipients (Baker et al., 1989). The trend for all of these findings seems to be that calves with higher percentage B dams (in relation to the amount of *Bos indicus* in the sire) have

Table 18. Method II birth weight least squares means for within sex reciprocal F_1 differences

Calf Breeding	Sire Type	Dam Type	Birth Weight males (kg)	Difference	Birth Weight females (kg)	Difference
Angus backcross (3/4 A 1/4 B)	A	AB	35.7	0.6	34.3	0.3
	A	BA	35.1	(P=.8077)	34.0	(P=.9064)
	AB	A	43.8	6.1	35.8	-0.3
	BA	A	37.7	(P=.0230)	36.1	(P=.9073)
Bos indicus backcross (3/4 B 1/4 A)	B	AB	41.6	0.7	37.2	1.0
	B	BA	40.9	(P=.7896)	36.2	(P=.6717)
	AB	B	33.2	-1.9	33.2	-0.8
	BA	B	35.1	(P=.8606)	34.0	(P=.7569)

lighter BW, even when produced through embryo transfer. As a result, this difference can not simply be due to a uterine maternal effect.

Kim (1999) used interval mapping with maximum likelihood (IM), composite interval mapping (CIM), and interval mapping with Restricted Maximum Likelihood (REML) to locate QTL for birth weight, weaning weight, hot carcass weight, adjusted fat thickness, and kidney, pelvic, and heart fat in the same population studied here. In unpublished results from this study significant QTL for BW were found on the X-chromosome using both IM and CIM methods. Interval mapping with maximum likelihood procedures revealed a QTL highly suggestive at the genome-wide level ($P < .10$), while CIM showed a highly significant QTL at the genome-wide level ($P < .01$). The additive[3] effect of this QTL was .987 kg and 1.853 kg for IM and CIM, respectively. The dominance[4] effect was -1.249 kg and -1.228 kg for the IM and CIM procedures, respectively.

Weaning Weight (WW)

Weaning weight was studied on 497 embryo transfer calves. The effects of the regression on weaning age within birth year and season combinations, and sex accounted for variation in WW for both Method I and Method II (Tables 19 and 20).

Method I. Weaning weight for male calves (n = 256) averaged 245.6 kg and female calves (n = 241) averaged 229.9 kg, a difference of 15.7 kg. These results are similar to Herring et al. (1996) who found F_1 male calves to average 14.7 kg heavier

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[3] QTL genotypic value of Angus homozygotes such that 2a=AA-BB (Kim, 1999).

[4] AB heterozygote deviation from QTL homozygote midpoint such that d=AB -.05(AA+BB) (Kim, 1999).

than F_1 females in crosses of Brahman, Boran, and Tuli bulls on Angus and Hereford cows.

Table 19. Method I weaning weight fixed effects

Effect	F-Value	P-Value
Weaning Age (Birth Year x Season)	30.28	<.0001
Sex	39.93	<.0001
Sire Type x Dam Type	0.82	.4942
Sex x Sire Type x Dam Type	0.83	.4752

Table 20. Method II weaning weight fixed effects

Effect	F-Value	P-Value
Weaning Age (Birth Year x Season)	29.94	<.0001
Sex	36.43	<.0001
Sire Type x Dam Type	0.78	.6102
Sex x Sire Type x Dam Type	0.82	.5711

Table 21. Method I least squares means for weaning weight

Calf Breeding	Sire Type	Dam Type	N	Weaning Weight (kg)	Difference
Angus backcross	A	F_1	132	235.5	-4.8
(3/4 A 1/4 B)	F_1	A	126	240.3	(P = .3629)
Bos indicus backcross	B	F_1	134	240.8	6.4
(3/4 B ¼ A)	F_1	B	104	234.4	(P = .2176)

No statistically significant variation was detected for ST x DT; however the observed reciprocal cross differences were in the same direction as those found in BW. Among A-backcross calves, F_1-sired calves were heavier than A-sired calves; and, among B-backcrosses, B-sired calves were heavier than F_1-sired calves (Table 21).

The sex x ST x DT interaction was not significant for this method. The differences between the sexes (male minus female) for A x F_1, F_1 x A, B x F_1, and F_1 x B was 9.4, 17.6, 19.1, and 16.5 kg, respectively. Similar to the BW results, less difference existed between the sexes when the dam had more *Bos indicus* (in relation to the amount in the sire).

Results from this study show an 8.9 kg difference between A x F_1 males and F1 x A males and a -0.7 kg difference between 3/4 A females at weaning. The B x F_1 male calves outweighed the F_1 x B males by 7.7 kg, while the difference between females was 5.1 kg. These numbers seemed to have changed very little from the time of birth. The difference in birth weight between 3/4 Angus male reciprocal crosses was 5.4 kg, while the difference between female reciprocal crosses averaged 1.6 kg. The difference among 3/4 Brahman reciprocal crosses for birth weight was 6.4 kg and 3.4 kg for males and females, respectively.

Method II. WW for male calves (n = 256) averaged 244.5 kg, while females averaged 229.4, a difference of 15.1 kg ($P < .0001$). As with method I, no statistically significant differences were observed in the ST x DT interaction for method II. Again, the small differences that were observed followed the trend of lighter calves from crosses with more *Bos indicus* influence from the dam (Table 22). Also, in crosses where the dam had more B influence than the sire (A x AB, A x BA, AB x B, and BA x B), the BA F_1 parent produced calves with heavier WW on average than the AB F_1 parent. For crosses where the sire possessed more B-influence than the dam (AB x A, BA x A, B x AB, and B x BA), the AB parent tended to produce heavier weaning calves, though none of these differences were statistically significant (Table 22).

Table 22. Method II least squares means for weaning weight

Calf Breeding	Sire Type	Dam Type	n	Weaning Weight (kg)	Difference
Angus backcross (3/4 A 1/4 B)	A	AB	72	233.9	-2.0
	A	BA	60	235.9	(P = .7725)
	AB	A	67	243.4	6.9
	BA	A	59	236.5	(P = .3587)
Bos indicus backcross (3/4 B 1/4 A)	B	AB	79	244.4	10.6
	B	BA	55	233.8	(P = .1550)
	AB	B	53	233.7	-0.3
	BA	B	51	234.0	(P = .9672)

Thallman et al. (1993) studied WW in reciprocal F_1 Brahman-Simmental embryo transfer calves. These calves, born to Holstein recipients, showed a significant reciprocal difference when analyzed within sex. Brahman x Simmental bull calves averaged 46.5 kg heavier than SB bull calves. While BS heifers were only 23.7 kg heavier than SB heifers.

In a study of F_1 reciprocal calves, Comerford et al. (1988) showed a significant sire breed x dam breed interaction. In crosses involving Simmental (S), Brahman (B), Polled Hereford (H) and Limousin (L), calves with B dams outweighed their reciprocal for each breed combination (SB 250.3 kg vs. BS 249.5 kg, LB 241.4 kg vs. BL 232.0kg, HB 237.0 kg vs. BH 215.5 kg). This is consistent with results from Peacock et al. (1978) involving Angus, Brahman and Charolais. In this study, F_1 calves from B dams outweighed their reciprocals at weaning (202.8, 198.5, 229.7, and 216.3 kg for AB, BA, CB, and BC, respectively). Bailey et al. (1988) showed that F_1 BA dams produced calves with lighter weaning weights than AH dams when bred to Red Angus and Santa Gertrudis sires.

Summary of Body Weight Traits

Evaluation of calf weight at various stages of life revealed a very consistent trend for Method I. As discussed previously, F_1 x A calves were heavier at birth and weaning than A x F_1 calves and B x F_1 calves were heavier at these same weights than F_1 x B calves. This difference continued both as the calves were weighed upon entering and leaving the feedlot (Table 23). It seems then, that calves with a greater proportion of *Bos indicus* in the sire in relation to the amount in the dam tended to be heavier throughout life.

No consistent performance differences dependant upon AB vs. BA F_1 parental type were detected for Method II. At birth, calves with AB F_1 parents were heavier for all family types, with the exception of B backcross calves with F_1 sires; here, BA-sired calves were heavier at birth than AB-sired calves. Weights taken at weaning and upon leaving the feed yard showed that the advantage of AB vs. BA F_1 parental types depended on the proportion of *Bos indicus* in the sire when compared to the dam. While when calves entered the feedlot, those with AB F_1 parents where heavier than calves BA F_1 parents for all family types (Table 24).

Table 23. Method I least squares means for weight at different production stages

Calf Breeding	Sire Type	Dam Type	Birth Weight (kg)	Weaning Weight (kg)	Feed Yard In-Weight (kg)	Feed Yard Out-Weight (kg)
Angus backcross (3/4 A 1/4 B)	A	F1	34.9	235.5	335.5	528.4
	F1	A	38.4	240.3	347.1	549.0
Bos indicus backcross (3/4 B 1/4 A)	B	F1	39.1	240.8	330.3	510.8
	F1	B	34.4	234.4	322.4	487.5

Table 24. Method II least squares means for weight at different production stages

Calf Breeding	Sire Type	Dam Type	Birth Weight (kg)	Weaning Weight (kg)	Feed Yard In-Weight (kg)	Feed Yard Out-Weight (kg)
Angus backcross (3/4 A 1/4 B)	A	AB	35.0	233.9	334.6	523.8
	A	BA	34.6	235.9	333.8	530.4
	AB	A	39.8	243.4	359.1	561.0
	BA	A	36.9	236.5	332.9	536.6
Bos indicus backcross (3/4 B 1/4 A)	B	AB	39.4	244.4	336.9	518.6
	B	BA	38.5	233.8	318.4	496.4
	AB	B	33.9	233.7	325.1	486.8
	BA	B	34.6	234.0	317.3	487.3

Carcass Traits

Carcass Weight (HCW). Carcass weight was studied on 493 calves. The regression on slaughter age within birth year and season combinations, sex, and sire type x dam type were responsible for significant variation in HCW for Method I and Method II (Tables 25 and 26).

On average, male calves had an 18.3 kg heavier carcass than female calves for Method I and were 17.7 kg heavier than female calves for Method II.

Table 25. Method I carcass weight fixed effects

Effect	F-Value	P-Value
Slaughter age (Birth Year x Season)	15.23	<.0001
Sex	37.03	<.0001
Sire Type x Dam Type	5.75	.0041
Sex x Sire Type x Dam Type	1.52	.2098

Table 26. Method II carcass weight fixed effects

Effect	F-Value	P-Value
Slaughter age (Birth Year x Season)	14.58	<.0001
Sex	34.47	<.0001
Sire Type x Dam Type	2.54	.0484
Sex x Sire Type x Dam Type	0.94	.4762

The two-way interaction of ST x DT was a significant source of variation for both methods. Method I differences between B-backcross calves approached significance (Table 27). Carcasses from B x F_1 calves averaged 17.6 kg heavier than carcasses from F_1 x B carcasses. The difference between 3/4 A reciprocal crosses was 10.4 kg, on average, with F_1-sired calves producing a heavier carcass than A-sired.

Table 27. Method I least squares means for carcass weight

Calf Breeding	Sire Type	Dam Type	n	Carcass Weight (kg)	Difference
Angus Backcross	A	F_1	128	323.7	-10.4
(3/4 A 1/4 B)	F_1	A	130	334.1	(P = .2615)
Bos indicus backcross	B	F_1	133	314.9	17.6
(3/4 B 1/4 A)	F_1	B	102	297.3	(P = .0608)

Though no significant differences existed between AB vs. BA reciprocal F_1's for Method II, trends seem to exist for HCW. In crosses where there is more B in the dam in relation to the sire (A x AB, A x BA, AB x B, and BA x B), the BA F_1 parents produced calves with heavier carcasses, on average, than the AB F_1 parent. In crosses where the sire possessed more B influence than the dam (AB x A, BA x A, B x AB, and B x BA), the AB F_1 parent produced calves with heavier carcasses than the BA F_1 parent (Table 28).

Table 28. Method II least squares means for carcass weight

Calf Breeding	Sire Type	Dam Type	n	Carcass Weight (kg)	Difference
Angus Backcross (3/4 A 1/4 B)	A	AB	69	321.2	-3.7
	A	BA	59	324.9	(P = .7712)
	AB	A	67	340.3	12.7
	BA	A	63	327.6	(P = .3660)
Bos indicus backcross (3/4 B 1/4 A)	B	AB	77	318.9	11.7
	B	BA	56	307.2	(P = .3851)
	AB	B	53	294.0	-5.7
	BA	B	49	299.7	(P = .6773)

For both models, calves from 3/4 A families had heavier carcass weights than 3/4 B calves (Tables 27 and 28). This is consistent with known information on the phenotypic attributes of Angus and *Bos indicus* breeds. Cundiff et al. (2000) reported Angus-sired steers to have heavier carcass weights than B-sired steers when bred to Angus, Hereford, and MARC III cows. Also, Crouse et al. (1989) showed that as percent *Bos indicus* increased, carcass weight decreased; calves included in this study were by purebred Brahman and Sahiwal sires or F_1 sires comprised of these two breeds, and out F_1 dams comprised of Brahman, Sahiwal, Hereford, Angus, or Pinzgauer (AH, HA, PH, PA, BH, BA, SH, and SA, specifically). The resulting offspring of these reciprocal backcross and F_2 matings produced calves with *Bos indicus* to *Bos taurus* ratios of 0:100, 25:75, 50:50 and 75:25. Contrary to these findings, results from Paschal et al. (1995) found that in calves born and raised in Texas, those with B-sires had heavier carcasses than A-sired calves when both were bred to Hereford cows. This difference is likely attributable to the large amount of heterosis that exists between *Bos indicus* and *Bos taurus* breeds, or possibly a genotype x environment interaction.

Actual Fat (ACTFAT). Actual fat was evaluated on 492 calves. The regression on slaughter age within birth year and season combinations, sex and, sire type x dam type were significant sources of variation for ACTFAT for Method I (Table 29). For Method II, the regression on slaughter age and sex were the only significant contributors to variation (Table 30).

Table 29. Method I actual fat fixed effects

Effect	F-Value	P-Value
Slaughter age (Birth Year x Season)	6.43	<.0001
Sex	50.80	<.0001
Sire Type x Dam Type	5.07	.0074
Sex x Sire Type x Dam Type	0.43	.7338

It has been well documented that heifers tend to be fatten quicker than steers (Trenkle and Marple, 1983; Taylor and Field, 1999). Results from this study support previous research, as heifer carcasses possessed 0.28 cm more ACTFAT than steers for Method I and Method II.

Table 30. Method II actual fat fixed effects

Effect	F-Value	P-Value
Slaughter age (Birth Year x Season)	6.70	<.0001
Sex	53.97	<.0001
Sire Type x Dam Type	2.37	.0613
Sex x Sire Type x Dam Type	1.30	.2467

The two-way interaction of ST x DT accounted for significant variation in ACTFAT for Method I. Comparison of reciprocal crosses shows no significant difference between Ax F_1 vs. F_1 x A. But, the difference between B-backcrosses approached significance, as F_1-sired calves averaged 0.19 cm less fat than B-sired (Table 31). ST x DT approached significance for Method II; again, the difference between 3/4 B calves with F_1 sires approached significance (Table 32). AB F_1 sires produced calves with .18 cm less fat, on average, than BA sires. Additionally, as a whole, 3/4 A calves tended to possess more fat than 3/4 B.

The results for ST x DT for both methods are consistent with the findings of Cundiff et al. (2000), where B-sired calves possessed 0.24 cm less fat than A-sired calves. Crouse et al. (1989) also reported A-sired calves to have more 12th rib fat than B-sired calves. However, percent *Bos indicus* had no consistent effect on ACTFAT.

Paschal et al. (1995), on the other hand, found no difference in ACTFAT between A- and B-sired F_1 calves.

Table 31. Method I least squares means for actual fat

Calf Breeding	Sire Type	Dam Type	n	Actual Fat (cm)	Difference
Angus Backcross	A	F_1	127	1.15	-0.09
(3/4 A 1/4 B)	F_1	A	130	1.24	(P = .3716)
Bos indicus backcross	B	F_1	133	1.06	0.19
(3/4 B 1/4 A)	F_1	B	102	0.87	(P = .0554)

Table 32. Method II least squares means for actual fat

Calf Breeding	Sire Type	Dam Type	n	Actual Fat (cm)	Difference
Angus Backcross (3/4 A 1/4 B)	A	AB	68	1.07	-0.14
	A	BA	59	1.21	(P = .3134)
	AB	A	67	1.24	0.01
	BA	A	63	1.23	(P = .9433)
Bos indicus backcross (3/4 B 1/4 A)	B	AB	77	1.01	-0.07
	B	BA	56	1.08	(P = .6444)
	AB	B	53	0.77	-0.18
	BA	B	49	0.95	(P = .2526)

Adjusted Fat (ADJFAT). Adjusted fat was evaluated on 489 calves. The regression on slaughter age within birth year and season combinations, and sex were significant sources of variation in ADJFAT for Method I and Method II (Tables 33 and 34). Sire type x dam type was an additional significant source of variation under Method I. Females possessed 0.39 cm more ADJFAT than males for Method I and 0.40 cm more ADJFAT for Method II. This is consistent with the results found for ACTFAT.

Table 33. Method I adjusted fat fixed effects

Effect	F-Value	P-Value
Slaughter age (Birth Year x Season)	9.31	<.0001
Sex	107.89	<.0001
Sire Type x Dam Type	3.29	.0379
Sex x Sire Type x Dam Type	0.88	.4526

Table 34. Method II adjusted fat fixed effects

Effect	F-Value	P-Value
Slaughter age (Birth Year x Season)	9.71	<.0001
Sex	112.93	<.0001
Sire Type x Dam Type	1.89	.1251
Sex x Sire Type x Dam Type	1.94	.0620

Differences attributed to ST x DT for Method I are similar to those discussed for ACTFAT. Again, calves with more *Bos indicus* in the sire in relation to the amount in the dam, tended to possess more fat than their reciprocal cross. Also, 3/4 A calves averaged a greater amount of ADJFAT than 3/4 B calves. Differences between reciprocal B-backcrosses did approach significance, with F1-sired calves being leaner, on average, than B-sired individuals (Table 35).

Table 35. Method I least squares means for adjusted fat

Calf Breeding	Sire Type	Dam Type	n	Adjusted Fat (cm)	Difference
Angus Backcross	A	F_1	127	1.27	-0.05
(3/4 A 1/4 B)	F_1	A	130	1.32	(P = .6109)
Bos indicus backcross	B	F_1	132	1.19	0.18
(3/4 B 1/4 A)	F_1	B	100	1.01	(P = .0913)

Sex x ST x DT approached significance for Method II (P = .0620). Analyzing the differences between sexes for all 8 family types, it was observed that the 3/4 A calves had a much more consistent difference between males and females (.34 to .50 cm, P < .01 for all comparisons). *Bos indicus*-backcross calves varied much more widely in the difference between male and female, from virtually no difference (0.11 cm) in AB x B calves (P = .3219) to a highly significant difference of .61 cm (P < .0001) for B x BA calves (Table 36).

Longissimus Muscle Area (REA). Longissimus muscle area was evaluated on 492 calves. The regression on slaughter age within birth year and season combinations, and sire type x dam type were significant sources of variation in REA for Method I and Method II (Tables 37 and 38). Sex was also found to be significant for Method I.

Table 36. Method II least squares means for adjusted fat for cross and calf sex combinations

Calf Breeding	Sire Type	Dam Type	Adjusted Fat Males (cm)	n	Adjusted Fat Females (cm)	n	Difference	P-Value
Angus Backcross (3/4 A 1/4 B)	A	AB	0.97	41	1.37	27	-0.40	<.0001
	A	BA	1.10	29	1.60	30	-0.50	<.0001
	AB	A	1.11	33	1.45	34	-0.34	<.0010
	BA	A	1.12	32	1.55	31	-0.43	<.0001
Bos indicus backcross (3/4 B 1/4 A)	B	AB	0.97	42	1.27	35	-0.30	.0027
	B	BA	0.94	21	1.55	34	-0.61	<.0001
	AB	B	0.86	25	0.97	26	-0.11	.3219
	BA	B	0.84	26	1.35	23	-0.51	<.0001

Table 37. Method I longissimus muscle area fixed effects

Effect	F-Value	P-Value
Slaughter age (Birth Year x Season)	5.10	<.0001
Sex	4.12	.0430
Sire Type x Dam Type	6.90	.0016
Sex x Sire Type x Dam Type	1.22	.3029

Table 38. Method II longissimus muscle area fixed effects

Effect	F-Value	P-Value
Slaughter age (Birth Year x Season)	4.86	<.0001
Sex	3.75	.0534
Sire Type x Dam Type	2.91	.0287
Sex x Sire Type x Dam Type	0.92	.4910

On average, male carcasses possessed 1.5 cm^2 larger REA than females for Method I. Also, A-backcross calves had larger REA than B-backcrosses for both methods (Tables 39 and 40), though differences between reciprocal crosses were not significant.

Paschal et al. (1995), and Cundiff et al. (2000) both reported larger REA for A-sired calves compared to B-sired calves. Crouse et al. (1989) found *Bos indicus* influence to have no consistent effect on REA.

Table 39. Method I least squares means for longissimus muscle area

Calf Breeding	Sire Type	Dam Type	n	Longissimus Muscle Area (cm^2)	Difference
Angus Backcross	A	F_1	127	79.9	-1.3
(3/4 A 1/4 B)	F_1	A	130	81.2	(P = .5765)
Bos indicus backcross	B	F_1	133	73.1	-0.5
(3/4 B 1/4 A)	F_1	B	102	73.6	(P = .8439)

Table 40. Method II least squares means for longissimus muscle area

Calf Breeding	Sire Type	Dam Type	n	Longissimus Muscle Area (cm^2)	Difference
Angus Backcross (3/4 A 1/4 B)	A	AB	68	81.4	2.9
	A	BA	59	78.5	(P = .3825)
	AB	A	67	82.6	2.6
	BA	A	63	80.0	(P = .4779)
Bos indicus backcross (3/4 B 1/4 A)	B	AB	77	74.0	2.3
	B	BA	56	71.7	(P = .5194)
	AB	B	53	74.2	1.3
	BA	B	49	72.9	(P = .7021)

Intramuscular Fat (MARB). Marbling score was evaluated on 483 calves. The regression on slaughter age within season and year combinations, and sire type x dam type accounted for significant variation in MARB for both Method I and Method II (Tables 41 and 42).

Table 41. Method I intramuscular fat fixed effects

Effect	F-Value	P-Value
Slaughter age (Birth Year x Season)	2.53	.0030
Sex	1.09	.2981
Sire Type x Dam Type	9.61	.0002
Sex x Sire Type x Dam Type	1.52	.2086

Table 42. Method II intramuscular fat fixed effects

Effect	F-Value	P-Value
Slaughter age (Birth Year x Season)	2.60	.0023
Sex	1.17	.2794
Sire Type x Dam Type	3.71	.0098
Sex x Sire Type x Dam Type	1.00	.4331

Both methods show a greater amount of marbling for 3/4 A calves in relation to 3/4 B, though no significant reciprocal cross differences were found for either method (Tables 43 and 44). These results are not unexpected, as it has been shown repeatedly that Angus cattle marble well, while Brahman cattle are often lower for marbling (Crouse et al., 1989; Paschal et al., 1995; Cundiff et al., 2000).

Table 43. Method I least squares means for intramuscular fat

Calf Breeding	Sire Type	Dam Type	n	Marbling Score	Difference
Angus Backcross	A	F_1	128	456.8	28.3
(3/4 A 1/4 B)	F_1	A	133	428.5	(P = .2778)
Bos indicus backcross	B	F_1	120	351.9	1.5
(3/4 B 1/4 A)	F_1	B	102	350.4	(P = .9543)

Table 44. Method II least squares means for intramuscular fat

Calf Breeding	Sire Type	Dam Type	n	Marbling Score	Difference
Angus Backcross (3/4 A 1/4 B)	A	AB	69	443.0	-27.5
	A	BA	59	470.5	(P = .4520)
	AB	A	57	423.2	-9.2
	BA	A	63	432.4	(P = .8240)
Bos indicus backcross (3/4 B 1/4 A)	B	AB	77	351.7	2.0
	B	BA	56	349.7	(P = .9595)
	AB	B	53	344.9	-10.0
	BA	B	49	354.9	(P = .7983)

Warner-Bratzler Shear Force (WBSF). WBSF was evaluated on 459 calves. The regression on slaughter age within season and year combinations was a significant source of variation for Method I and Method II. Method I analysis found ST x DT to have a significant effect on WBSF, while this interaction only approached significance for Method II (Tables 45 and 46).

Table 45. Method I Warner-Bratzler shear force fixed effects

Effect	F-Value	P-Value
Slaughter age (Birth Year x Season)	8.07	<.0001
Sex	1.99	.1586
Sire Type x Dam Type	6.50	.0022
Sex x Sire Type x Dam Type	0.65	.5843

Table 46. Method II Warner-Bratzler shear force fixed effects

Effect	F-Value	P-Value
Slaughter age (Birth Year x Season)	7.94	<.0001
Sex	1.92	.1668
Sire Type x Dam Type	2.41	.0583
Sex x Sire Type x Dam Type	0.99	.4359

Both methods agree that on average, 3/4 A calves produce carcasses with lower shear force values than 3/4 B calves. No reciprocal differences were detected for either method (Tables 47 and 48).

Cundiff et al. (2000) showed WBSF values for B-sired calves of 7.3 kg and 6.0 kg when aged 7 and 14 days, respectively. WBSF measurements for A-sired calves aged 7 and 14 days were 5.1 kg and 4.0 kg. Research of Crouse et al. (1989) showed both an increase in WBSF and more variability in tenderness were associated with an increase in *Bos indicus* influence.

Table 47. Method I least squares means for Warner-Bratzler shear force

Calf Breeding	Sire Type	Dam Type	n	Warner-Bratzler shear force (kg)	Difference
Angus Backcross	A	F_1	118	3.3	-0.2
(3/4 A 1/4 B)	F_1	A	123	3.5	(P = .2980)
Bos indicus backcross	B	F_1	127	3.8	-0.3
(3/4 B 1/4 A)	F_1	B	91	4.1	(P = .1643)

Table 48. Method II least squares means for Warner-Bratzler shear force

Calf Breeding	Sire Type	Dam Type	n	Warner-Bratzler shear force (kg)	Difference
Angus Backcross (3/4 A 1/4 B)	A	AB	64	3.21	-0.09
	A	BA	54	3.30	(P = .7565)
	AB	A	62	3.42	-0.08
	BA	A	61	3.50	(P = .8023)
Bos indicus backcross (3/4 B 1/4 A)	B	AB	74	3.73	-0.11
	B	BA	53	3.84	(P = .6998)
	AB	B	74	4.10	0.09
	BA	B	44	4.01	(P = .7670)

SUMMARY

Using the Mixed Model procedure of SAS, data collected from Angus - *Bos indicus* (Brahman or Nellore) reciprocal backcross embryo transfer calves belonging to 28 full-sib families were evaluated for differences in birth weight, gestation length, weaning weight, carcass weight, longissimus muscle area, fat thickness (adjusted and actual), intramuscular fat, and Warner-Bratzler shear force.

The regression on Julian birth date within birth year and season combinations, sex, the two-way interaction of sire type x dam type, and embryo quality all accounted for significant variation in gestation length. Analysis of data with F_1 parental types pooled (Method I) showed that family types with a greater proportion *Bos indicus* in the sire in relation to the amount in the dam (F_1 x A and B x F_1) averaged longer gestation lengths than their respective reciprocal crosses (A x F_1 and F_1 x B). Analysis of reciprocal F_1 parental types (Method II) revealed that in all cases, a longer gestation length was exhibited when the F_1 parent was BA as opposed to AB. It is important to note that BA F_1 parents had more Nellore influence than AB parents. Nellore-influenced calves typically have a longer gestation length than calves influenced by other Bos indicus breeds (Paschal et al., 1991; Thrift, 1997).

Significant birth weight differences for Method I were attributable to the regression on Julian birth date within birth year and season combinations, sex, the two-way interaction of sire type x dam type, the three-way interaction of sire type x dam type x sex, and embryo stage. Calves from family types with a greater proportion *Bos indicus* in the sire in relation to the amount in the dam (F_1 x A and B x F_1) had heavier BW than their respective reciprocal crosses (A x F_1 and F_1 x B). The former two crosses also showed a large BW difference between male and female calves (about 5.0 kg), while the latter two crosses showed no BW difference between male and female calves. Furthermore, examination of reciprocal differences within each sex showed a difference between male reciprocals that was two times the magnitude of the complementary female comparison.

The two-way interaction of sire type x dam type was not significant in Method II analysis of birth weight. Three-way interaction results were as expected for 3/4 B calves – for crosses with a greater proportion of B in the sire (in relation to proportion in the dam), the difference between male and female calves was about 5 kg, and male reciprocal crosses differed two times as much as female reciprocals. Results for 3/4 A calves followed suit, with the exception of those with F_1 sires. The difference between male and female calves with AB sires averaged 8 kg (two times as large a difference as any other family type), while no difference was detected between male and female calves with BA sires ($P > .25$). Also, when BA was the sire type no difference was detected between male reciprocals (A x BA vs. BA x A) ($P > .30$).

No difference in BW was detected through direct comparison of F_1 parental types, (AB x A vs. BA x A, etc) with the exception of male F_1-sired calves. In this case, male calves with AB sires averaged 6 kg heavier at birth than male calves with BA sires. In the small differences that were detected, no consistent difference between the AB and BA F_1 parental type was apparent.

The regression on weaning age within birth year and season combinations, and sex were the only fixed effects responsible for variation in weaning weight. The differences observed between reciprocal crosses followed a trend similar to BW, as calves with a higher percentage of *Bos indicus* in the sire compared to the proportion in the dam were still heavier, on average, at weaning. However, the difference between reciprocal crosses had not grown proportionately with the weight gain of the calves, so the differences detected were not statistically significant.

Differences associated with one F1 parent over the other were not apparent at this weight phase either. In crosses where the dam had more B influence than the sire (A x AB, A x BA, AB x B, and BA x B), the BA F_1 parent produced calves with heavier WW on average than the AB F_1 parent. For crosses where the sire possessed more B-influence than the dam (AB x A, BA x A, B x AB, and B x BA), the AB parent tended to produce heavier weaning calves, though none of these differences were statistically significant.

In order to track reciprocal differences in weight throughout the life of the calf, weight upon entering and leaving the feed yard was analyzed. For Method I (F_1 parental types pooled), reciprocal differences were detected for both 3/4 Angus and 3/4 *Bos indicus* calves. For each weight phase, the cross that involved a larger proportion of *Bos indicus* in the sire in relation to the amount in the dam had heavier weights than its reciprocal (Figure 1).

For carcass weight, the regression on slaughter age within birth year and season combinations, sex, and the two-way interaction of sire type x dam type were all statistically significant sources of variation. Calves with a larger proportion of *Bos indicus* in their sire in relation to their dam (F_1 x A and B x F_1) produced heavier carcasses than their reciprocals (A x F_1 and F_1 x B).

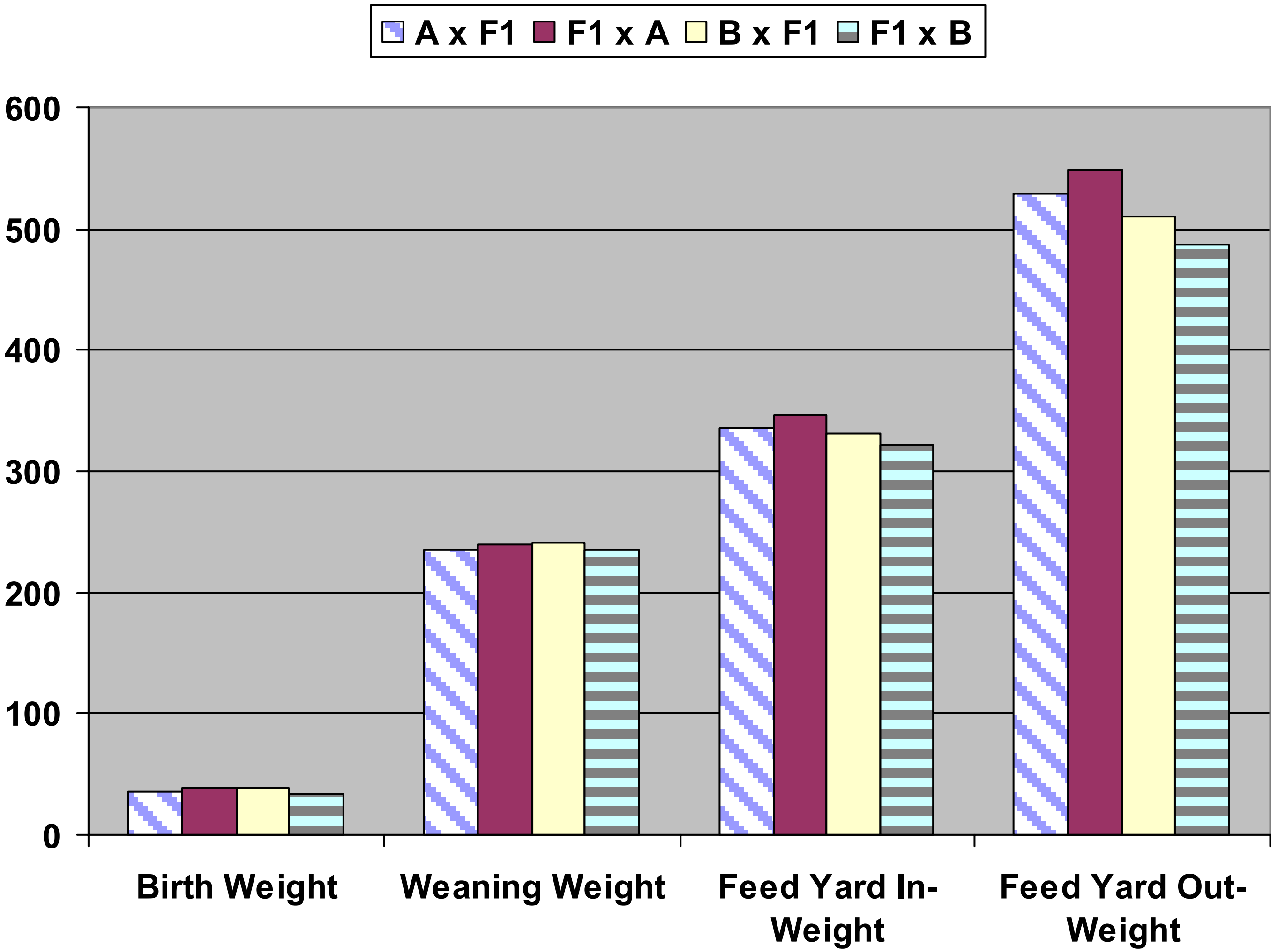

Figure 1. Method I body weight at different production phases

The trend in F_1 parental type for carcass weight was similar to weaning weight. In calves whose dam had more *Bos indicus* influence than their sire (A x AB, A x BA, AB x B, and BA x B), the BA F_1 parent produced calves with heavier carcasses than the AB F_1 parent. For crosses where the sire possessed more B-influence than the dam (AB x A, BA x A, B x AB, and B x BA), calves from the AB parent tended to produce a heavier carcass.

Method I showed the regression on slaughter age within birth year and season combinations, sex, and the two-way interaction of sire type x dam type to all be responsible for variation in actual and adjusted fat thickness. The regression on slaughter age and sex were the only significant effects in Method II for actual and adjusted fat. For both traits, calves from crosses with more B in the sire than the dam produced fatter carcasses. The difference detected between reciprocal A-backcross calves was not significant, but the difference between B reciprocals approached significance.

The regression on slaughter age within season and year combinations, sex, and sire type x dam type were responsible for significant variation in longissimus muscle area for Method I and Method II. As a whole, A backcross calves had larger REA than B backcross calves. Differences were not detected between 3/4 A or 3/4 B reciprocal crosses.

The regression on slaughter age within season and year combinations, and sire type x dam type were responsible for significant variation in intramuscular fat and Warner-Bratzler shear force. No significant differences were detected between reciprocal crosses for either trait. On average, A backcross calves produced carcasses with higher marbling scores and lower values for WBSF than B backcross calves.

These results suggest that for weight related traits, both the breed constitution of the calf and the cross that produces the calf play an important role in its ultimate performance. For carcass related traits, it appears that the breed make-up of the calf itself is more significant in influencing performance than the cross used to produce the calf.

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