Carcass Traits and Merit

Utilization of Bos indicus Cattle in Florida Beef Enterprises

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Introduction

Bos indicus cattle, especially the American Brahman, have had high utility in the Southern United States cow herd. The F_1 Brahman (crossed with basically any other breed) cow is the most productive cow type for this region, both in terms of reproduction (calving and weaning rate) and maternal ability. Among the opportunities for improvement for the breed, and for *B. indicus* in general, are those related to the beef traits, especially quality, of *B. indicus* carcasses. Although first reported almost 50 years ago, research in the 1980s solidified the reputation for substandard quality, especially tenderness, of *B. indicus* beef in the United States. Brahman background in calves is easily distinguishable by most people, and this became an economic problem as research results on carcass quality issues were probably used as justification for the lower prices being offered for Brahman crossbred calves. The F_1 Brahman cross cow is so valuable that it was necessary to investigate a variety of methods for improvement of carcass traits in Brahman cattle. The objective of this paper is to examine and discuss the genetic opportunities for improvement of carcass traits in *B. indicus* cattle.

Selection

For a given trait, differences between individuals are either due to genetic or environmental causes. If a reasonably high proportion of these differences is due to genetic causes (this is referred to as the heritability of the trait, that is, this proportion of the trait variation that is due to additive genetic control), then it can be possible to select animals to be parents using these trait values, and thereby change trait performance in their offspring. This is exactly what has been done in beef cattle for traits like weaning or yearling weight and in dairy cattle for milk production. These traits have moderate levels of genetic control (heritabilities from 0.20 to 0.45). If the heritabilities of carcass traits in Brahman cattle were high enough, then selection could be undertaken to improve those traits in the same manner, and in the 1990s, several studies were conducted to that end.

The largest of these studies was begun at Brooksville in 1994 as a progeny test of Brahman bulls for beef carcass and palatability attributes. The project was originally designed to last five years, but was continued for two additional years at the request of the American Brahman Breeders Association to include some Brahman bulls in the Carcass Merit Project (CMP) of the National Cattlemen's Beef Association. The experimental design was detailed previously (Riley et al., 2002; 2003a). In brief, Brahman cows at the SubTropical Agricultural Research Station (STARS) were exposed to five or six Brahman bulls in single-sire breeding herds each year. After the first year, a bull that sired calves in the previous year was again used. In the 1999 and 2000 breeding seasons, some cows were bred by AI to achieve target numbers of progeny from the CMP sires. The breeding season began on approximately March 20 of each year and lasted for 105 days. Calves were born from late December through early May of each year. Shortly after birth, calves were weighed and tagged, and bull calves were castrated. Calves were weaned in September of each year at approximately 7 months of age. Calves were maintained in a dry lot for two to three weeks after weaning, before beginning the post-weaning evaluation phase of the project.

Calves were sorted into feedlot pens by gender and body weight; pen capacity was about 13 calves. Calves started the feeding period on a diet that consisted of approximately 55% corn, 25% cottonseed hulls and/or ground hay, 15% supplement (which contained melengestrol acetate for heifers, and monensin, vitamin A, and microminerals for all calves), and 5% molasses. The diet was gradually changed over 28 days to the final diet, which consisted of 72.5% corn, 15% cottonseed hulls and/or ground hay, 7.5% supplement, and 5% molasses. Steers and heifers were implanted with Synovex-S or Synovex-H at 0 and 112 days of feeding. After 140 days of feeding, external fat cover was estimated using real-time ultrasound. When the median fat over the 12th rib of the animals in a pen was about 0.4 inches, the entire pen was slaughtered at a commercial facility.

The evaluated traits and simple statistics are presented in Table 1. Slaughter weight was the final (shrunk) weight. Fat thickness was measured on the carcass at the 12th rib and adjusted based upon overall carcass fatness according to the United States Department of Agriculture (USDA) guidelines. Marbling score was evaluated numerically: Devoid = 100 to 199; Traces = 200 to 299; Slight = 300 to 399; Small = 400 to 499; Modest = 500 to 599; Moderate = 600 to 699. In similar manner, USDA quality grade was evaluated numerically: Standard = 400 to 499; Select = 500 to 599; Choice = 600 to 699; and Prime = 700 to 799.

Estimates of heritability from this study (Table 1) indicated moderate to high genetic control over many of these traits in Brahman cattle. With one exception, these results were very similar to recent Brahman work from Louisiana (Smith et al., 2007). These are of about the same magnitude or larger than those reported for weight traits in beef cattle or milk traits in dairy cattle. This means that trait improvement using selection should be very accomplishable in reasonable amounts of time. This would seem to be especially important with regards to marbling score and USDA Quality Grade. Since at least one of the negative perceptions regarding *B. indicus* carcasses is insufficient marbling, the large estimates of heritability from both the Florida and Louisiana work indicate that there is potential to change the population average with selection. Very noteworthy are the low estimates of heritability for traits related to tenderness. This does not mean that these traits cannot be improved by selection, just that their improvement would be expected to be much slower.

Brahman data from STARS were combined with those from Louisiana State University and steer data from tests set up by the American Brahman Breeders Association in order to generate Expected Progeny Differences (Franke et al., 2003, 2005, 2006). The 2006 evaluation included 230 sires and 1,719 records. Florida records comprise a large part of this evaluation (over 700 records and 30 sires). Estimates of heritability from these combined analyses were 0.78, 0.66, 0.44, 0.41, and 0.16 for hot carcass weight, ribeye area, 12th rib fat thickness, marbling score, and Warner-Bratzler shear force, respectively (Franke et al., 2006).

Calpain activity (two types called μ- [“mu”] and m-calpains) in postmortem muscle has been shown to be responsible for the physical degradation associated with tenderization. A third enzyme called calpastatin acts as an inhibitor in that it restricts the activities of these calpains. Although the details related to specific timing and actions of the proteolytic enzyme activity in the postmortem cellular environment are still being clarified, it is accepted that increased calpastatin activity is responsible for reduced proteolysis and less change in tenderness with time in beef from *B. indicus* (Johnson et al., 1990). Furthermore, higher levels of calpastatin activity have been associated with higher percentages of Brahman in cattle (Pringle et al., 1997). Although calpastatin activity levels after slaughter are known to be higher in Brahman carcasses and, therefore, explain tenderness differences between breeds, they did not appear to be especially helpful in explaining tenderness differences within the Brahman breed because of its low (0.07, Table 1) estimate of heritability (Riley et al., 2003a). In contrast, Louisiana researchers reported a very high estimate of heritability (0.45) for calpastatin activity (Smith et al., 2007). Such a high heritability indicates that selective improvement of calpastatin activity is quite possible.

Genetic Effects on Tenderization that Occurs with Aging

A subset of the Florida Brahman calves (n = 87), sired by nine bulls, was evaluated in additional investigations of aspects of tenderness (Riley et al., 2003b). Myofibril fragmentation index (MFI) is an assessment of the physical deterioration of the muscle fibers. Higher values of this trait are associated with more tender meat. In addition to evaluating MFI after 1, 7, 14, and 21 days of refrigerated aging, other traits in this study were μ- and m-calpain activities, calpastatin activity, Warner-Bratzler shear force values after 7, 14, and 21 days of aging, and sensory panel rating of tenderness, juiciness, and connective tissue amount after 14 days of aging. This sample was too small to get reliable estimates of heritability for any of the traits, but an assessment of sire effects could be calculated as an indication of genetic control of these traits. Sires significantly affected μ-calpain activity, but sire influence was not detected for m-calpain activity.

Knowledge of the genetic control of the tenderization process, including the rate and extent of proteolysis, is limited. There appears to be evidence for breed differences in postmortem tenderization, but less evidence for animal variation within a breed. We used this subset of data to evaluate the progression of tenderization using MFI after the different aging periods (Riley et al., 2003b). We assumed that tenderization (MFI values) typically would increase with aging until a certain point at which additional aging would not result in MFI increases. Three aspects of physical tenderness were considered: 1) tenderness at the beginning of the aging period, 2) tenderness at the end of the aging period, and 3) the rate of change. Sires appeared to differ greatly in how steaks from their progeny fit into these three components and the curves associated with the three sires in Figure 1 represent how MFI changed in steaks from their progeny. For example steaks from some sires' progeny increased in tenderness rapidly (Sire 3 in Figure 1), and aging after 10 to 12 days produced no further increase in tenderness. Steaks from the progeny of other sires steadily increased in tenderness throughout the 21-days aging period (Sire 2 in Figure 1). At the other extreme, steaks from other sires' calves started with low MFI and ended with low MFI (Sire 1 in Figure 1); in other words, aging was of little benefit. Even though this was a small data set, it isn't hard to envision a system that directs steaks from different sires' calves to different product groups that require differential aging. This is a novel combination of genetic and environmental management that should be considered further. These results appeared to be consistent with earlier results (Riley et al., 2000) from a study that fitted curves to serial WBSF data (based on the premise that shear force decreases to a level and then stops) in half blood Brahman-British steers (Figure 2). These may be indicative of additive genetic control of tenderization associated with aging of beef, and verification should be initiated with larger data sets. These findings could be important as a unique avenue for investigation for improvement of beef tenderness, especially in breeds of cattle with a reputation for inadequate tenderness. This could facilitate the appropriate feeding, product designation, and value assignment for cattle and their carcasses from different genetic lines. Use of a combination of such estimated parameters in a selection/carcass sorting program represents an alternative consideration for tenderization improvement programs.

Role of Collagen

We used a large subset from this Brahman evaluation to examine tenderness and conducted statistical tests commonly used to choose the most important influences from a large group of possible explanatory variables on a given trait (Riley et al., 2005). Fifteen different carcass attributes were evaluated for their relative influence on seven different measures of tenderness in these data. These measures of tenderness of strip loin steaks from each carcass were assessed: MFI and Warner-Bratzler shear force (both of these after 7, 14, and 21 days of refrigerated storage) and overall tenderness after 14 days of aging as rated by a trained sensory panel.

There were three important findings from this work. First, the information that is available at the time carcasses are given quality and yield grades poorly accounts for tenderness variation in Brahman beef. For example, the traits that influence USDA Quality (marbling score) and Yield Grade (12th rib fat thickness, ribeye area, carcass weight) had almost no association with measures of tenderness. Secondly, although calpastatin activity may effectively explain tenderness differences among breeds or breedtypes of cattle (e.g., Brahman as compared to British or European breeds), it was not effective for explanation of within-Brahman tenderness differences. Perhaps the key result was that collagen content was among the most important (often the most important) explanatory variables for almost all of these assessments of tenderness after all aging periods. This appears to be a result unique to the Brahman breed and warrants additional investigation. This confirms the importance of the connective tissue component (collagen) in purebred Brahman cattle, and may be an appropriate focus for future research into improvement of Brahman tenderness.

Marker Assisted Selection for Beef Quality and Palatability

There will continue to be much research effort directed toward finding genes (or markers apparently associated with genes) that are responsible for observed differences in important cattle traits. There have been studies that have identified associations between DNA markers and beef carcass and palatability traits in cattle; some have resulted in commercial tests (examples include GeneSTAR® Tenderness and Quality Grade). Data and DNA from the cattle at STARS have been used in collaborative studies with USDA scientists in Nebraska. All of this work focused on segments on two chromosomes of DNA that were previously identified as functional genes, that is, they produced known products involved in the life activities of cells in cattle. Researchers determined the sequence (basic molecular structure) of these genes and subsequently looked for different versions (known as alleles) of the gene within various populations. These alleles (different versions) often differ only in a minor way, for example at one base pair (basic structural unit) within the gene; large changes might make this gene not produce its intended product and be detrimental to the organism. These single base changes are known as single nucleotide polymorphisms (SNPs) and were the markers distinguishing the analyzed versions of the gene.

There are two recently identified genes on bovine chromosome 14 (chromosomes are numbered from largest to smallest) with potential influence on beef quality and palatability. The *DGAT1* gene is involved in formation of important cell molecules in cattle; SNPs were identified recently in this gene that were associated with increased milk yield and fat content of milk in Holsteins. There also has been a SNP identified that appeared to be responsible for fat deposition in *B. taurus* cattle. The *TG* (thyroglobulin) gene makes a protein that is involved in production of thyroid hormones; alleles within this gene have been associated with marbling differences in *B. taurus* cattle. Casas et al. (2005) reported no association of any of these alleles (indicated by SNP markers) with any beef quality or tenderness trait in our Brahman data.

The *CAPN1* gene is located on chromosome 29 and produces the m-calpain protein. Work in *B. taurus* cattle demonstrated associations of two SNP markers with tenderness. Casas et al. (2005) showed that the two alleles in *CAPN1* that were associated with improved tenderness in *B. taurus* cattle were almost not present in our Brahman population, and therefore not useful. However, White et al. (2005) reported one SNP that had alleles that appeared to associate with tenderness differences in our Brahman data; the difference between shear forces of two genotypes (CT versus TT) was almost 1 lb. This marker also associated with similar differences in *B. taurus* crossbreds and *B. indicus* and other tropically-adapted crossbreds. These were pretty important results, as it was possible to identify animals using this marker that would have steaks with better tenderness. Casas et al. (2006) followed this by assessing the presence of the *CAST* gene and its alleles in our Brahman data. This gene encodes the calpastatin protein, and the SNP evaluated associated with about a one pound shear force differences in *B. taurus* cattle. This SNP was not associated with tenderness differences in our Brahman population; however, within one of the SNP genotypes (CC in Marker 4751) reported by White et al. (2005), Casas et al. (2006) reported over a two pound difference in shear force between each of the three *CAST* genotypes. This resulted in these markers within these genes being used in commercial tests for tenderness. Franke et al. (2007) reported about 0.25 lb difference between shear force of steaks from Brahman steers (n = 430) with the most and least favorable combinations of marker alleles within these genes.

Crossbreeding Results

Most of the cattle with *B. indicus* genetics that are fed and slaughtered for beef in the United States are crossbreds. It is therefore important to study carcass and palatability traits of crossbred Brahman cattle under conventional production systems. Our current crossbreeding project at STARS was designed to compare the performance of purebreds and crossbreds for traits at every phase of beef production and to estimate heterosis, that is, for a given trait, the superiority of crossbred animals as compared to the purebred average. Crossbred F_1 females represent a high value primary product as commercial females, but production of these females results in about an equal number of males that usually enter the stocker and feeder phases. All steer progeny in this project were transported to the USDA, ARS, Grazinglands Research Laboratory in north-central Oklahoma where they grazed wheat for a period of time and then entered the feedlot. At the conclusion of the feeding period (three groups ranging from 100 to 157 days on feed), steers were slaughtered commercially and data were collected from each carcass that contribute to USDA Quality and Yield Grades, and steaks were sent to the University of Florida Meats Laboratory, where Warner-Bratzler shear force and sensory panel tenderness were measured on steaks from each carcass.

Preliminary analyses indicated that F_1 Brahman-Angus steers had greater carcass weights, dressing percentages, 12^{th} rib fat thicknesses, and ribeye areas than most purebred steer groups (Table 2). Angus steers had the greatest marbling score and had steaks with the best tenderness values (measured both by Warner-Bratzler shear force and sensory panel tenderness values). Brahman steers had superior USDA Yield Grades than those of all other breed groups. Significant estimates of heterosis were detected for carcass traits related to quantity of meat (Table 3). The direct effect of Brahman breeding in a steer (Table 3) was to increase carcass weight 68 lb, and decrease yield grade and marbling score (0.59 and 157.8, respectively). The effect of Angus was to increase 12^{th} rib fat by 0.13 inches, ribeye area by 0.6 inches, and marbling score by 215. We detected a favorable Angus direct effect on shear force and sensory panel overall tenderness. The effect of having a Brahman dam was to improve dressing percentage, 12^{th} rib fat thickness, and USDA Yield Grade, but to decrease ribeye area and overall tenderness. The effect of having an Angus dam was to decrease dressing percentage, and increase 12^{th} rib fat thickness and therefore USDA Yield Grade.

A threshold of acceptability of ten pounds of Warner-Bratzler shear force has been publicized as necessary for steaks. The percentages of acceptable (according to this guideline) steaks were 84% and 58% for purebred Angus and Brahman, respectively. These acceptability percentages were 71% for F_1 steers sired by Angus and out of Brahman cows and 53% for F_1 steers sired by Brahman bulls and out of Angus cows, respectively. Electrical stimulation of carcasses was not employed in this study, but may result in higher percentages of acceptable tenderness.

Summary

There may be real opportunities to use our knowledge of genetics to influence beef traits in Brahman cattle. Selection for improvement of marbling score or quality grade would probably be successful. The non-genetic variation in tenderness in steaks from Brahman cattle is large (around 80% of the total variation) and therefore, improvement of tenderness may be more effective if other aspects of carcass management or other non-genetic means are employed in addition to genetic selection. There may be exploitable genetic control of tenderness that occurs with aging steaks. Collagen appears to be especially important as an influence on tenderness in Brahman steaks; additional knowledge of the genetic control of collagen amounts might offer another selection opportunity. We now have limited knowledge of the use of DNA markers to select parents for improvement of various carcass characteristics; it appears that this area of research will progress rapidly. It is mostly unknown how strong selection of parents for product tenderness (or many other carcass traits) will affect other production traits in Brahman and other *B. indicus* cattle. The high value of the Brahman breed is to produce crossbred cows that excel in both reproductive and maternal abilities. We must be careful that any selection for improvement of carcass traits does not compromise or sacrifice excellence in those areas.

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- Edwards Brahman Ranch, Starke, FL
- Felton Ranch, Maryville, MO
- Mrs. Wyatt Flowers, Lithia, FL
- J.D. Hudgins-Forgason Div., Hungerford, TX
- Husfeld Brahmans, Washington, TX
- Partin and Partin Heart Bar Ranch, Kissimmee, FL, and Montalba, TX
- Rock Hollow Farms, Alachua, FL
- Rocking S Ranch, Wauchula, FL
- Stardust Ranch, Micanopy, FL
- Tice Ranch, Bartow, FL
- TA Brahmans, Rockledge, FL
- Three Trees Ranch, Sharpsburg, GA
- W. W. Tilton, Jr., East Palatka, FL
- Treasure Hammock Ranch, Vero Beach, FL
- V-8 Ranch, Boling, TX

References

Casas, E., S. N. White, D. G. Riley, T. P. L. Smith, R. A. Brenneman, T. A. Olson, D. D. Johnson, S. W. Coleman, G. L. Bennett, and C. C. Chase, Jr. 2005. Assessment of single nucleotide polymorphisms in genes residing on chromosomes 14 and 29 for association with carcass composition traits in *Bos indicus* cattle. J. Anim. Sci. 83:13–15.

Casas, E., S. N. White, T. L. Wheeler, S. D. Shackelford, M. Koohmaraie, D. G. Riley, C. C. Chase, Jr., D. D. Johnson, and T. P. L. Smith. 2006. Effects of *calpastatin* and μ-*calpain* markers in beef cattle on tenderness traits. J. Anim. Sci. 84:520–525.

Franke, D. E., D. G. Riley, J. C. Paschal, and C. C.Chase, Jr. 2003. American Brahman Breeders Association, 2003 Brahman Performance Special, Carcass Sire Summary.

Franke, D. E., D. G. Riley, J. C. Paschal, and C. C.Chase, Jr. 2005. American Brahman Breeders Association, 2005 Brahman Performance Special, Carcass Sire Summary.

Franke, D. E., D. G. Riley, J. C. Paschal, and C. C.Chase, Jr. 2006. American Brahman Breeders Association, 2006 Brahman Performance Special, Carcass Sire Summary.

Franke, D. E., D. H. Fischer, M. G. Thomas, and T. D. Bidner. 2007. Calpastatin and calpain marker influences on shear force in Brahman steers. J. Anim. Sci. 85(Suppl. 2):1(Abstr.).

Johnson, D. D., R. D. Huffman, S. E. Williams, and D. D. Hargrove. 1990. Effects of percentage Brahman and Angus breeding, age-season of feeding and slaughter end point on meat palatability and muscle characteristics. J. Anim. Sci. 68:1980-1986.

Pringle, T. D., S. E. Williams, B. S. Lamb, D. D. Johnson, and R. L. West. 1997. Carcass characteristics, the calpain proteinase system, and aged tenderness of Angus and Brahman crossbred steers. J. Anim. Sci. 75:2955–2961.

Riley, D. G., L. B. Hager, J. O. Sanders, R. K. Miller, and D. K. Lunt. 2000. Comparison of Warner-Bratzler shears of F_1 *Bos indicus*-British steers produced by one Nellore and 15 Brahman bulls. J. Anim. Sci. 78(Suppl. 1):59 (Abstr.).

Riley, D. G., C. C. Chase, Jr., A. C. Hammond, R. L. West, D. D. Johnson, T. A. Olson, and S. W. Coleman. 2002. Estimated genetic parameters for carcass traits of Brahman cattle. J. Anim. Sci. 80:955-962.

Riley, D. G., C. C. Chase, Jr., A. C. Hammond, R. L. West, D. D. Johnson, T. A. Olson, and S. W. Coleman. 2003a. Estimated genetic parameters for palatability traits of Brahman cattle. J. Anim. Sci. 81:54-60.

Riley, D. G., C. C. Chase, Jr., T. D. Pringle, R. L. West, D. D. Johnson, T. A. Olson, A. C. Hammond, and S. W. Coleman. 2003b. Effect of sire on μ- and m-calpain activity and rate of tenderization as indicated by myofibril fragmentation indices of steaks from Brahman cattle. J. Anim. Sci. 81: 2440–2447.

Riley, D. G., D. D. Johnson, C. C. Chase, Jr., R. L. West, S. W. Coleman, T. A. Olson, and A. C. Hammond. 2005. Factors affecting tenderness in steaks from Brahman cattle. Meat Sci. 70:347-356.

Smith, T., J. D. Domingue, J. C. Paschal, D. E. Franke, T. D. Bidner, and G. Whipple. 2007. Genetic parameters for growth and carcass traits of Brahman steers. J. Anim. Sci. (In press).

White, S. N., E. Casas, T. L. Wheeler, S. D. Shackelford, M. Koohmaraie, D. G. Riley, C. C. Chase, Jr., D. D. Johnson, J. W. Keele, and T. P. L. Smith. 2005. A new SNP in CAPN1 extends the current tenderness marker test to include cattle of *Bos indicus*, *Bos taurus*, and crossbred descent. J. Anim. Sci. 83:2001–2008.

Table 1. Means, standard deviations, and estimates of heritability for carcass traits of Florida Brahman cattle.

Trait	Mean	SD	h^2
Slaughter wt, lb	978	121	0.47
Adj. fat thickness, in	0.52	0.2	0.63
Hot carcass wt, lb	625	83	0.55
Loin muscle area, in^2	11.3	1.2	0.44
KPH fat, %	2.3	0.7	0.46
Yield grade	3.1	0.6	0.71
Marbling score[a]	323.8	57.2	0.44
Quality grade[b]	526.0	42.9	0.47
Hump height, in	6.2	1.4	0.54
Shear force, day 7, lb	12.3	4.3	0.14
Shear force, day 14, lb	11.6	3.8	0.14
Shear force, day 21, lb	10.6	3.6	0.06
Panel tenderness[a]	4.9	0.7	0.11
Connective tissue amount[a]	5.3	0.7	0.12
Calpastatin activity, mg/g muscle	2.7	1.2	0.07

[a]200 to 299=Traces; 300 to 399=Slight; 400 to 499=Small.
[b]400 to 499=Standard; 500 to 599=Select; 600 to 699=Choice.
[c]Panel tenderness and detectable amount of connective tissue measured on scales from 1 to 8: 1=extremely tough, abundant amount, extremely dry, extremely bland; 4=slightly tough, moderate amount; 5=slightly tender, slight amount; 8=extremely tender, none detected.

Table 2. Carcass traits of 2002, 2003, and 2004-born steers[a] (n=163).

Breed[b]	n	Carcass wt, lb	Dressing %	12th rib fat thickness, in	Yield grade	Ribeye area, in²	Marbling score[c]	SF (lb)[d]	OT[e]
AA	38	699	61.6	0.65	3.33	12.0	571	8.1	5.9
BB	46	652	61.6	0.43	2.92	11.0	304	9.8	5.3
BA	34	825	63.4	0.75	4.00	12.5	440	9.9	5.4
AB	45	746	62.5	0.54	3.19	12.4	415	9.3	5.5
LSD(0.05)[f]		26	1.0	0.06	0.21	0.4	32	0.9	0.23

[a]Steers were randomly assigned to one of three slaughter dates after 101, 129, and 157 days (averaged across years) on feed.
[b]The first of the two letters of the calf breed group indicates the breed of the calf's sire, and the second the breed of the calf's dam: A=Angus, B=Brahman.
[c]Marbling scores: 300 to 399=Slight; 400 to 499=Small; 500-599=Modest.
[d]SF=Warner-Bratzler shear force after 7 days aging
[e]OT=Overall sensory panel tenderness scores from 1 to 8 (average of all panelists' scores): 1=extremely tough, 4=slightly tough, 5=slightly tender, 8=extremely tender.
[f]LSD=least significant difference ($P < 0.05$).

Table 3. Estimates of heterosis (and percentages of purebred average) for pairs of breeds, and direct and maternal breed effects for Brahman and Angus carcass traits.[a]

	Carcass wt, lb	Dressing %	12th rib fat, in	Yield grade	Ribeye area, in²	Marbling score[b]	Shear force[c]	Overall tenderness[d]
Heterosis								
BA	110 ± 16 (16.2%)	1.36 ± 0.50 (2.2%)	0.11 ± 0.03 (31.4%)	0.47 ± 0.10 (15.0%)	0.9 ± 0.2 (7.9%)			
Direct breed effects								
B	68 ± 23			0.59 ± 0.15		-157.8 ± 23.9		
A			0.13 ± 0.04		0.6 ± 0.3	215.0 ± 24.1	-1.5 ± 0.8	0.6 ± 0.2
Maternal breed effects								
B		15.2 ± 2.9	-0.17 ± 0.03	-0.67 ± 0.10	-0.4 ± 0.2			-0.4 ± 0.2
A		-25.1 ± 2.8	0.09 ± 0.02	0.27 ± 0.09				

[a]A=Angus, B=Brahman.
[b]Marbling scores were measured on a scale in which: 300 to 399=Slight; 400 to 499=Small; 500-599=Modest.
[c]Warner-Bratzler shear force after 7 days aging.
[d]Overall sensory panel tenderness scores from 1 to 8 (average of all panelists' scores): 1=extremely tough, 4=slightly tough, 5=slightly tender, 8=extremely tender.

Figure 1. Change with aging in myofibril fragmentation indices (MFI) as indication of tenderness in steaks from progeny of three Brahman sires.

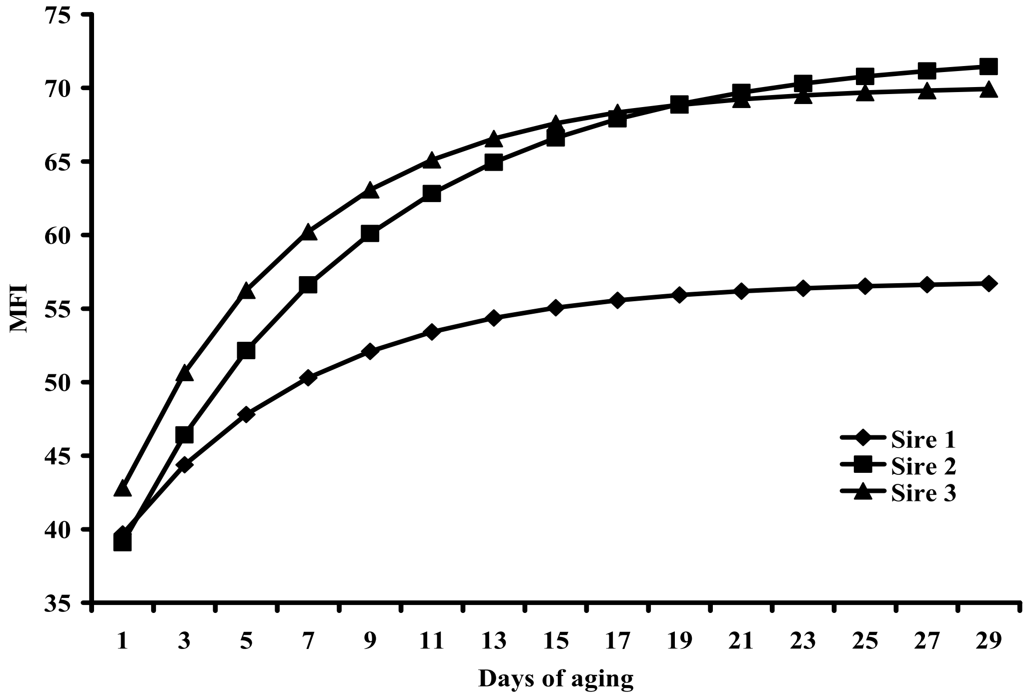
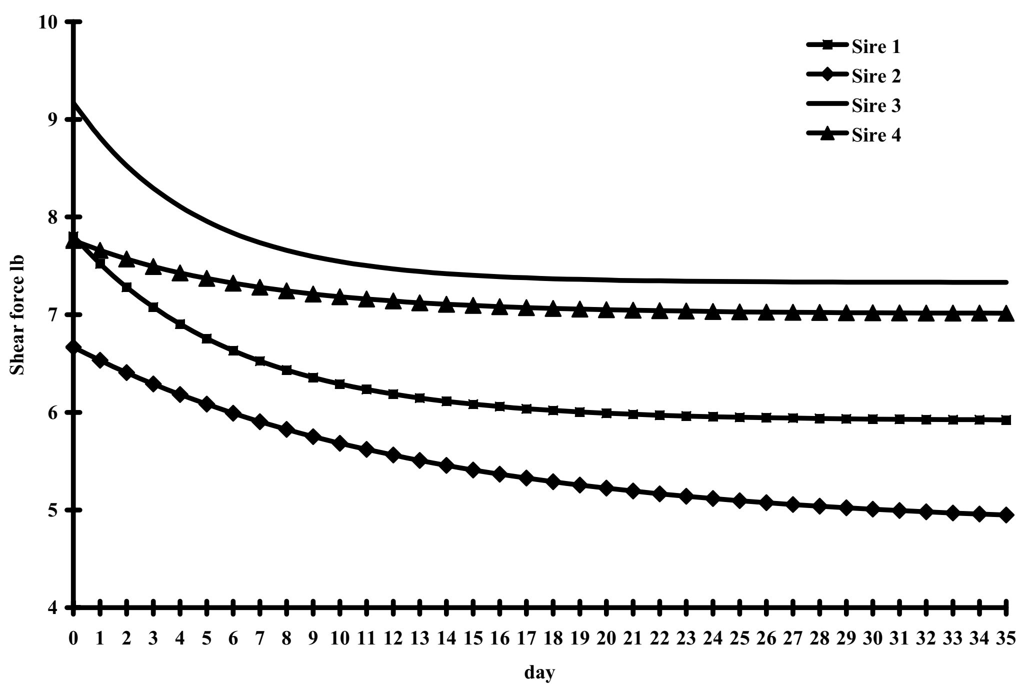


Figure 2. Change in Warner-Bratzler shear force with aging of steaks from F_1 progeny of four Brahman sires.



Notes: