Southern Cooperative Series Bulletin

A COMPILATION OF RESEARCH RESULTS INVOLVING TROPICALLY ADAPTED BEEF CATTLE BREEDS

S-243 and S-277 Multistate Research Projects

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Preface

The Southern region of the U.S. contains approximately 42% of the nation's beef cows and nearly 50% of its cow-calf producers. The region's environment generally can be characterized as subtropical, i.e. hot, humid summers with ample rainfall supporting good forage production. Efficient cow-calf production in the humid South is dependent on heat and parasite tolerance and good forage utilization ability. Brahman and Brahman-derivative breeds generally possess these characteristics and excel in maternal traits. Consequently, they have been used extensively throughout the Southern Region in crossbreeding systems with *Bos taurus* breeds in order to exploit both breed complementarity and heterosis effects. However, several characteristics of Brahman and Brahman crossbred cattle, such as poor feedlot performance, lower carcass quality including meat tenderness, and poor temperament, whether real or perceived can result in economic discounts of these cattle. Therefore, determining genetic variation for economically important traits among Brahman and Brahman-derivative breeds and identifying tropically adapted breeds of cattle from other countries that may excel in their performance of economically important traits in Southern U.S. environments have been greatly needed.

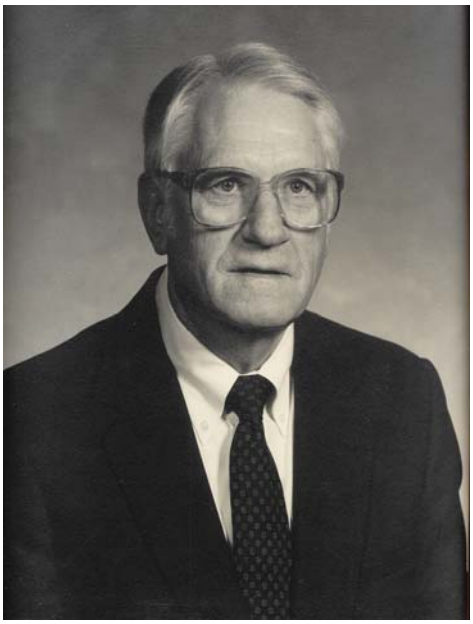
The S-243 and S-277 multistate research projects have focused on these research problem areas and this publication is a compilation of those research results. The 24 scientific papers contained herein emanate from 50 contributing scientists from seven Southern Region states (AR, FL, GA, KY, LA, OK, TX) plus Nebraska. The research was conducted both at land-grant university experiment stations and at USDA-ARS facilities. This bulletin was developed from a day-long tropically adapted breeds symposium held in Little Rock, AR on February 8, 2005, during the annual meeting of the Southern Section of the American Society of Animal Science. The symposium was hosted by the S-1013 multistate project technical committee.

Special acknowledgement is expressed to Dr. Larry Cundiff of the U.S. Meat Animal Research Center (USMARC), Clay Center, NE, who spawned the idea for the symposium and served ably as its organizer. Sincere appreciation is also expressed to Ms. Jan Watts at USMARC who converted all 24 papers to Journal of Animal Science style, incorporated peer review changes, and transmitted the entire document to the LSU AgCenter's Communications Department. Further acknowledgement and thanks are expressed to two LSU AgCenter faculty; Ms. Jane Honeycutt, Publications Editor, for conducting the final bulletin editing and to Dr. Frankie Gould, Director of Public Relations and Communications, for posting it to the institution's web site.

It has been my privilege to work with this productive group of scientists during S-277 and currently with the S-1013 multistate research project. Their dedication to animal breeding and genetics in support of the U.S. cattle industry has been exemplary. It is the collective desire of this group that the reports contained in this bulletin will be useful both to animal scientists and beef cattle producers. In addition, it is quite fitting that this bulletin be dedicated to Dr. Keith Gregory, who contributed so much to the science of animal breeding.

David G. Morrison
S-1013 Administrative Advisor

Dedication



Dr. Keith E. Gregory
1924-2005

Proceedings of this symposium on tropically adapted breeds are dedicated to the memory of Dr. Keith E. Gregory. Dr. Gregory was born October 27, 1924, in Macon County, NC. During World War II, he served in the U.S. Navy. He received his B.S. degree from North Carolina State University in 1947, the M.S. degree from the University of Nebraska in 1949 where he worked with Dr. Marvel Baker, and the Ph.D. degree from the University of Missouri in 1951 under the direction of Dr. Gordon E. Dickerson. Dr. Gregory began his teaching and research career in 1951 as an associate professor at Auburn University. In 1955, he joined the Agricultural Research Service, U.S. Department of Agriculture, as Investigations Leader for Beef Cattle Breeding Research in the North Central Region located at the University of Nebraska, Lincoln. In 1957, Dr. Gregory initiated a long-term crossbreeding project to evaluate heterosis effects on major bioeconomic traits at the Fort Robinson Beef Cattle Research Station, Crawford, NE. Results of this project had a major impact on the adoption of crossbreeding systems to use heterosis in the beef cattle industry.

In 1966, Dr. Gregory was appointed as the first Director of the U.S. Meat Animal Research Center, ARS, USDA, Clay Center, NE. His vision, focus, and total commitment to development of the 35,000-acre land resource, physical plant, and organization of scientific and support staff have had a great and lasting impact on multidisciplinary research programs at MARC. Dr. Gregory maintained an active personal research program during the time he served as Director at MARC. He conceived, initiated, and provided leadership for a comprehensive Germplasm Evaluation Program to characterize breeds of cattle representing diverse biological types for rate and efficiency of growth, carcass composition, and meat quality, reproduction and maternal performance, cow size, and herd life. Results from the project have affected breeding programs used for beef production in the United States and all major beef-producing areas of the world.

After completing his role as Director in 1977, he committed his full time and effort to leadership of two major beef cattle breeding projects. In 1978, he initiated a comprehensive project on Germplasm Utilization in beef cattle. Results from this program demonstrated that significant heterosis was maintained in composite populations, proportional to the number of breeds used in foundation of the population. Also, composite populations could be used to optimize performance levels and match genetic potential with the climatic environment, feed resources, and consumer preferences with greater precision and uniformity than possible with alternative crossbreeding systems. As a result, a significant number of composite populations have been developed by cattle breeders in diverse geographic regions of the United States and the world.

Dr. Gregory also served as leader of the project, Twinning in Beef Cattle, from 1981 to 1998. Twinning frequency has increased significantly in the population in response to innovative selection criteria and an effective breeding program. Today more than 55% of the calvings in the herd are multiple births.

Dr. Gregory was an author or co-author of more than 200 papers published in refereed scientific journal and author of more than 150 other publications including book chapters, bulletins, and proceedings of national and international scientific or beef industry meetings. He has consulted on research and development programs and presented invited papers to national at international audiences in Uganda, Kenya, Republic of South Africa, Colombia, Brazil, Argentina, Chili, Turkey, New Zealand, Republic of Korea, India, Paraguay, United Kingdom, Spain, Australia, and Canada.

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Rationale for Evaluating Alternative Sources of Subtropically Adapted Beef Cattle Germplasm[1,2]

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ABSTRACT: Considerable effort has been directed to evaluating the Brahman breed, primarily for crossbreeding, in a wide array of environments. Results indicate that in the hot/humid Southeast and Gulf Coast areas and even in more temperate areas of the United States, weaning productivity of Brahman x *Bos taurus* cows is virtually unequaled. These crossbred cows express longevity because of calving ease and resistance to ectoparasites (horn flies, mosquitoes, ticks), endoparasites (gastrointestinal helminths), eye disorders (infectious bovine keratoconjunctivitis, ocular squamous cell carcinoma), metabolic disorders (grass tetany), and dentition deterioration; however, problems are associated with production and management of these crossbred cows. Specifically, 1) subpar reproductive performance of Brahman bulls, 2) increased dystocia/reduced survival rate expressed by Brahman-sired calves, 3) price discounts for Brahman-sired steers and surplus heifers contemporary to the Brahman x *Bos taurus* cows, and 4) older age at puberty, udder/teat abnormalities, vaginal/uterine prolapses, and non-docile temperament expressed by Brahman x *Bos taurus* cows are problems associated with the Brahman breed that have served as a major impetus to evaluate alternative sources of subtropically adapted beef cattle germplasm.

Key Words: Beef Cattle, Brahman, Subtropical Adaptation.

Introduction

Weaning productivity of Brahman x *Bos taurus* cows in the southeastern and Gulf Coast (Brown et al., 1989; Brown et al., 1997; Chase et al., 2004; Cundiff, 1970; Franke, 1980; Kincaid, 1962; Koger, 1980; Long, 1980; McCarter et al., 1990a,b,c; McCarter et al., 1991; Olson et al., 1991; Riley et al., 2001a,b; Rohrer et al., 1988a,b) and even in temperate areas of the United States that receive small (Bailey, 1991) and more conventional amounts of rainfall (Green et al., 1991; Jenkins and Ferrell, 2004; Olson et al., 1991) is well documented. Also, contribution of Brahman x *Bos taurus* cows to sustained crossbreeding programs has been documented at locations in Florida (Belle Glade: Crockett et al., 1978a,b; Ona: Peacock and Koger, 1980; Peacock et al., 1981; Peacock et al., 1982; Peacock et al., 1986; Gainesville: Koger, 1973; Restle et al., 1986), Louisiana (DeRouen and Franke, 1989; DeRouen et al., 1992a,b; Franke et al., 2001; Williams et al., 1990; Williams et al., 1991) and Georgia (Chapman et al., 1970; Neville et al., 1984a,b,c). Production and management of these Brahman x *Bos taurus* cows is not without problems, however. The purpose of this contribution to the Symposium on Characterization and Utilization of Tropically Adapted Breeds in U.S. Beef Production is to identify problems associated with production and management of Brahman x *Bos taurus* cows which have served as an impetus to evaluate alternative sources of subtropically adapted beef cattle germplasm.

Materials and Methods

Thrift and Thrift (2003) indicated that Brahman x *Bos taurus* cows express longevity due to calving ease and resistance to ectoparasites (horn flies, mosquitoes, ticks), endoparasites (gastrointestinal helminths), eye disorders (infectious bovine keratoconjunctivitis, ocular squamous cell carcinoma), metabolic disorders (grass tetany) and dentition deterioration; however, problems are associated with production and management of these crossbred cows. Specifically, the following production and management issues are

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addressed: 1) subpar reproductive performance of Brahman bulls, 2) increased dystocia/reduced survival rate expressed by Brahman-sired calves, 3) price discounts for Brahman-sired steers and surplus heifers contemporary to the Brahman x *Bos taurus* cows, and 4) older age at puberty, udder/teat abnormalities, vaginal/uterine prolapses, and non-docile temperament expressed by Brahman-sired females. These production and management issues associated with the Brahman breed have served as a major impetus to evaluate alternative sources of subtropically adapted beef cattle germplasm.

Results and Discussion

Production and Management Issues Associated with Brahman x Bos taurus Females.

Sub-Par Reproductive Performance of Brahman Bulls

Relative to *Bos taurus* bulls, Brahman bulls mature at a slower rate and have smaller testes that produce semen with lower sperm cell concentration, decreased motility, and increased number of abnormal sperm (Randel, 1994). Consequently, females exposed to Brahman bulls express lower calving and weaning rates than females exposed to *Bos taurus* bulls (Bailey and Moore, 1980; Chapman and England, 1965; Crockett et al., 1978a; Cundiff, 1970; Fields et al., 1979; Koger et al., 1962; Reynolds, 1967; Reynolds et al., 1965).

With one exception (Neville et al., 1988), most studies (Bailey, 1981; Crockett and Kidder, 1967; Franke et al., 2001; Gotti et al., 1985; McCormick and Southwell, 1957; Olson et al., 1990; Reynolds et al., 1982; Reynolds et al., 1979; Reynolds et al., 1980; Williams et al., 1990; Williams et al., 1991; Yilmaz and Franke, 2001) have indicated that, relative to *Bos taurus*-sired calves, Brahman-sired calves are born later in the calving season. Similar results have been observed for calves sired by Brahman-derivative sires (Neville et al., 1985).

Increased gestation length attributed to the Brahman breed (Thrift et al., 2002) and the fact that some Brahman sires express especially poor reproductive performance (Bailey, 1981; Bailey and Moore, 1980; Cartwright, 1980; Chase et al., 1997; Chenoweth, 1994a,b; Chenoweth et al., 1996; Fields et al., 1982; Galina et al., 1994; Larsen et al., 1990; McCormick and Southwell, 1957; Randel, 1994; Reynolds, 1967; Reynolds et al., 1982; Reynolds et al., 1979) by tending to clump together when used in multi-sire breeding units (Cartwright, 1980; Koch et al., 1994), by showing preferential mating habits for Brahman-type females when exposed to *Bos taurus* and Brahman-type cows (Chapman and England, 1965; Koch et al., 1994; Reynolds, 1967; Reynolds et al., 1979), and by being prone to sheath (Franke and Burns, 1985; Kriese et al., 1991) and preputial prolapse (Brinks, 1986; Donaldson and Aubrey, 1960; Hofmeyr, 1968; Lagos and Fitzhugh, 1970; Lenert, 1956; Roberts, 1956) problems all are potential contributing factors to the later birth date of Brahman-sired calves conceived during a restricted breeding season.

Increased Dystocia/Reduced Survival Rate Expressed by Brahman-sired Calves

In a study involving purebred and high percentage Brahman calves, Riley et al. (2004) indicated that calves with dystocia had 2.6 times greater odds of poor birth vigor and 12.9 times greater odds of death before weaning than calves born with no dystocia. Thrift et al. (2002) indicated that dystocia, with associated increased mortality, can be a problem when Brahman bulls are mated to *Bos taurus* females. Holloway et al. (2002) reported that the percentage of Brahman-sired calves born live and vigorous were 27 and 12% lower, respectively, than for Senepol- and Tuli-sired calves.

Texas workers (Riley et al., 2001a) observed that late-born spring calves tended to have larger birth weights than early-born calves. Thus, it is likely that later birth dates of Brahman-sired calves, due to subpar reproductive performance of Brahman bulls and fact that Brahman-sired calves are gestated longer (Browning et al., 1995; Gregory et al., 1979b; Herring et al., 1996; Paschal et al., 1991; Williamson and Humes, 1985), when combined with large direct additive (Brown et al., 1993; Elzo et al., 1990; Franke et al., 2001; Olson et al., 1993; Roberson et al., 1986; Wyatt and Franke, 1986) and heterotic (Brown et al., 1993; Comerford et al., 1987; Ellis et al., 1965; Franke, 1980; Franke et al., 2001; Roberson et al., 1986) effects for birth weight, and fact that Brahman-sired male calves have considerably heavier birth weights than female calves (Thrift et al., 1999; Thrift et al., 2002), all interact to contribute to the increased dystocia expressed by calves resulting from mating of Brahman bulls to *Bos taurus* females.

The fact that Brahman-sired calves are susceptible to cold, moist conditions within 24 hr after birth (Azzam et al., 1993; Cartwright, 1980; Godfrey et al., 1991; Josey et al., 1993; Martin et al., 1999; McElhenney et al., 1985; Notter et al., 1978a,b; Paschal et al., 1991; Reynolds, 1967; Reynolds et al., 1982; Reynolds et al., 1980; Riley et al., 2004; Stanko et al., 1991; Turner, 1980; Williamson and Humes, 1985) contributes to reduced survival rate.

Price Discounts for Steers and Heifers Contemporary to Brahman x Bos taurus Females

Contemporary steer and surplus heifer mates to Brahman x *Bos taurus* females are frequently price discounted at weaning and yearling stages, especially when numbers are small and marketing occurs through traditional channels. Several authors (Baker et al., 2001; Brown, 1995; Huffman et al., 1990; Jenkins and Ferrell, 2004; Morgan et al., 1991; Olson et al., 1991; Olson et al., 1993; Sherbeck et al., 1996) only alluded to these discounts, but four studies quantified discounts for Brahman-influenced cattle.

Two Kansas studies, involving cattle weighing 300 to 600 lb (Sartwelle et al., 1996a) and 601 to 900 lb (Sartwelle et al., 1996b) indicated discounts/cwt, relative to a Hereford base averaged across two time periods, of -$8.53 ($P$<0.05) and -$5.92 (P<0.05) and -$4.13 ($P$<0.05) and -$4.13 (P<0.05), respectively, for steers and heifers of the two weight groups that were > 1/4 Brahman inheritance. An Oklahoma study (Smith et al., 1999) indicated discounts per cwt relative to an Angus base of -$5.91 ($P$<0.05) and -$1.91 (P<0.05), respectively, for steers and heifers that were > 1/4 Brahman inheritance. For these three studies, discounts applied to cattle classified as < 1/4 Brahman inheritance were not significantly different from the base breed price.

Relative to an average for British (Angus, Hereford), Continental (Charolais, Limousin, Simmental), and various crosses between these two genetic types, an Arkansas study (Troxel et al., 2002) indicated premiums/discounts/cwt of $2.39 ($P$<0.05), $2.12 ($P$<0.05), $0.48, $0.45, -$1.12 (P<0.05), -$1.76 ($P$<0.05), and -$12.57 (P<0.01) for cattle weighing 300 to 800 lb and classified, respectively, as Hereford x Brahman x Angus, Angus x Brahman, Charolais x 1/4 Brahman, Brangus, Brahman x other crosses, 1/4 Brahman x other crosses, and Brahman.

In general, results from the Kansas and Oklahoma studies indicate that, when marketed through traditional channels, cattle with < 1/4 Brahman inheritance tend not to be discounted. Also, the Arkansas results indicate that price discounts for Brahman-influenced cattle would depend on the specific cross. For example, steers and heifers resulting from mating of Angus bulls with Brahman-influenced cows are not discounted, but due to expression of more prominent Brahman characteristics, steers and heifers resulting from mating of Brahman bulls with Angus-influenced cows are discounted.

The price discounts for Brahman-influenced steers and surplus heifers are based on the perception that phenotypic characteristics such as gray/striped/red color and excessive ear length, hump size, and sheath area are indicators of high percentage Brahman inheritance, which is associated with 1) cold stress when finished during the winter months (Boyles and Riley, 1991; Cartwright, 1980; Dikeman, 1995; Green et al., 1991; Koch et al., 1995; Neill, 1995; Rhodes, 1963; Rollins et al., 1964; Smith et al., 1999), 2) increased incidence of founder when finished on high energy diets (Cartwright, 1980; Elam, 1976; Turner, 1980), 3) unfavorable carcass attributes, especially tenderness (Thrift and Thrift, 2002; Voisinet et al., 1997a), 4) a non-docile temperament that results in decreased feedlot performance (Voisinet et al., 1997b) and increased injury/bruising during routine processing (Bryan, 1963; Fordyce et al., 1985; Fordyce et al., 1988b; Gonyou, 1986), and 5) the potential for an increased incidence of contaminated hides (potential problem with *E. coli 0157:H7* contamination in slaughter cattle: Hussein et al., 2001) and ears (potential problem with implant abscesses in stocker cattle: Anderson and Botts, 2002; Berry et al., 2000; Zollers et al., 2002), since cattle with a non-docile temperament tend to defecate more during routine processing.

Older Age at Puberty

Due to increased lifetime production for females calving first at two versus three years of age (Chapman et al., 1978; Morris, 1980; Nú ez-Dominquez et al., 1991; Nú ez-Dominquez et al., 1992; Pinney et al., 1972), a significant proportion of the beef cattle industry has shifted to calving females first at two years of age. To avoid problems associated with nonpuberal estrus (Nelsen et al., 1985; Rutter and Randel, 1986) and subfertile puberal estrus (Byerely et al., 1987; Perry et al., 1991), and since age at puberty is favorably related to percent of females calving during the first 25 days of the calving period (Laster et al., 1979), achieving puberty by 15 months of age is an important criterion if females are to be bred during a restricted breeding season to calve at two years of age (Ferrell, 1992; Patterson et al., 1992). Also, heifers that conceive earlier in their first breeding season calve earlier (Short and Bellows, 1971) and wean heavier calves (Lesmeister et al., 1973).

Most studies (Baker et al., 1989; Bolton et al., 1987; Dow et al., 1982; Gregory et al., 1979a; Morgan, 1981; Nelsen et al., 1982; Newman and Deland, 1991; Patterson et al., 1991; Peacock et al., 1976; Reynolds et al., 1963; Stewart et al., 1980) indicate older age at puberty for various Brahman x *Bos taurus* heifers, which can be a disadvantage when females are exposed to calve first at two years of age. Brahman x *Bos taurus* heifers tend to reach puberty at ages intermediate to Brahman and *Bos taurus* heifers,

but still reach puberty at ages considerably older than traditional *Bos taurus* heifers.

Udder/Teat Abnormalities

Studies with dairy cows have indicated a relationship between udder conformation and longevity. In general, high, wide and firmly attached udders with appropriate teat size and placement are favorably associated with longevity (Honnette et al., 1980a,b; White and Vinson, 1975). Udder/teat problems associated with some *Bos indicus* genetic types can be a major contributor to calf loss and decreased productivity. Frisch (1982) reported "bottle teat" (median teat diameter 35 mm) incidence values of 0, 15, 17, 29 and 55%, respectively, for Hereford, Hereford x Shorthorn, Brahman, Brahman-cross and Sahiwal-cross cows. Calf mortality was closely associated with the incidence of "bottle teats". Similarly, Reynolds (1967) indicated that calf mortality was associated with incidence of "bottle teats" expressed by Brahman-influenced cows.

Rohrer et al. (1988a) indicated that, relative to *Bos taurus* genetic types, nonfunctional udders were less frequent in Brahman and Brahman crossbred cows, but teat shape was a problem in these cows. Riley et al. (2001b) reported that Nellore-sired cows had smaller postpartum teat length and diameter than Indu-Brazil- and Red Brahman-sired cows. Also, Nellore-sired cows had larger postpartum udder support scores (more well-supported udders) than Gir-, Indu-Brazil- and Red Brahman-sired cows.

In situations where new-born calves have difficulty nursing due to udder/teat problems, increased calf mortality can occur. Also, udder/teat problems increase the chance females will be culled prior to reaching an economically optimum culling age.

Vaginal/Uterine Prolapses

Vaginal/uterine prolapses have been demonstrated to have a significant reduction on subsequent reproductive performance (Patterson et al., 1981). Texas workers (Rohrer et al., 1988a) indicated that 6.7, 9.4, 10.3, 3.7, 7.4 and 1.1%, respectively, of Brahman, Brahman-Angus, Brahman-Hereford, Brahman-Holstein, Brahman-Jersey (reciprocal crosses combined for the various 2-breed combinations), and non-Brahman cows were culled due to prolapses. Most of the prolapses occurred in cows older than eight years of age and since Brahman genetic types express greater longevity and their general physical condition should deteriorate with age, the authors concluded that the higher incidence values observed for these cows were expected.

Non-Docile Temperament

The likelihood of personnel injury (express aggressive behavior toward humans, especially when confined in working facilities) and increased labor/expense requirements (difficulty in processing cattle through working facilities, damage to working facilities and injury to cattle) are problems frequently encountered with cattle that express a non-docile temperament. Several studies have identified Brahman-influenced cattle as having a non-docile temperament (Burrow, 1997; Cartwright, 1980; Elder et al., 1980; Fordyce et al., 1988a; Fordyce et al., 1982; Gonyou, 1986; Grandin, 1993a,b; Grandin, 1997; Grandin, 1998; Hammond et al., 1996; Hammond et al., 1998; Hearnshaw and Morris, 1984; Paschal et al., 1991; Sutherst and Utech, 1981; Turner, 1980; Voisinet et al., 1997a,b).

Hammond et al. (1998) reported similar, but unfavorable, temperament scores for Brahman and Brahman x Angus heifers, indicating the non-docile temperament is not improved with crossbreeding. Heritability of temperament is moderate (Burrow, 1997; Grandin, 1998; Green et al., 1999), and some Brahman breeders have made major progress in improving temperament of their cattle; however, in general the beef cattle industry continues to associate Brahman-influenced cattle with a non-docile temperament. As was indicated for females that express udder/teat problems, a non-docile temperament increases the chance females will be culled prior to reaching an economically optimum culling age.

Implications

The Brahman is the most widely used subtropically adapted beef cattle breed, primarily because weaning productivity of the Brahman x *Bos taurus* cow is virtually unequaled in the Southeast and Gulf Coast areas of the United States; however, production and management problems associated with the Brahman x *Bos taurus* cow warrant evaluation of alternative sources of subtropically adapted beef cattle germplasm.

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Florida Crossbreeding Research[1]

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ABSTRACT: This review highlights the accomplishments of three University of Florida beef cattle research locations from the 1940s through the late 1980s. During that time, the Everglades Research and Education Center at Belle Glade, the Range Cattle Research and Education Center at Ona, and the Beef Research Unit at Gainesville conducted long-term crossbreeding research. These locations produced estimates of breed effects and heterosis for a variety of traits in Brahman and a number of other breeds. Most importantly, these facilities investigated the crossbred superiority (heterosis retained or expressed) in several crossbreeding systems, including terminal crosses, two- and three-breed rotations, and *inter se* matings (including F_1 and ⅜ - ⅝ parents). In most of these studies, formal tests were not conducted, but results generally supported the dominance model of heterosis expression for most reproductive and calf growth traits. However, there was large loss of heterosis for weaning rate (almost 40% of that expressed by F_1 cows with backcross calves) for ⅜ Brahman ⅝ Devon cows mated *inter se* at Belle Glade. There was almost a total loss of the heterosis expressed for 18-mo weight in ⅜ Brahman ⅝ Devon heifers at Belle Glade and for cow weight in F_2, backcross, and three-breed cross (Brahman, Charolais, and Angus) cows at Ona. Early work in Florida also emphasized the complex interaction of reproductive performance with lactation status, age of cow, and nutritional plane in Brahman and Brahman-cross cows. There appears to be a negative autocorrelation between successive reproductive events that correspond with the age of the cow; it seems that reproductive performance in a given year could be effectively predicted with knowledge of the cow's lactation status in the previous breeding season. This is especially important considering the high cost of heifer development, the late onset of puberty in Brahman heifers, and the longer gestation length of Brahman calves. This research has provided a framework for future investigations of Brahman crossbred superiority, especially for reproductive traits.

Key Words: Beef Cattle, Brahman, Crossbreeding, Florida, Reproductive Performance

Introduction

One of the most notable dilemmas in beef production in the southern United States is the conflict between cow adaptability and performance in other areas. The biological types of cattle that are adapted to the local forages, high temperatures, high pest loads, and humidity have some undesirable characteristics. Some of those include substandard disposition, inadequate beef quality, and, especially, poor reproductive performance as purebreds. The beginnings of beef cattle research in Florida were based on crossbreeding. Much of the early work was directed at cow reproductive performance and calf survival.

One of the major contributions of Florida beef research is the knowledge of heterosis expressed in different crossbreeding systems. Much of the beef cattle breeding work in the 1950s through the mid-1980s was related to expression of heterosis, especially in reproductive traits, and its proportionality to breed heterozygosity (the "dominance model") as described in the classic papers by Dickerson (1969, 1973). As such, the work served in part as an assessment of crossbreeding theory, as well as to provide practical assessment of crossbreeding systems for cow-calf producers in the region. The objective of this paper is to summarize the beef research accomplishments of Florida researchers at state facilities at Belle Glade, Gainesville, and Ona. Most of the estimates of heterosis and breed effects from this work have been

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reported in other reviews (Long, 1980; Wyatt and Franke, 1986). The reviewed work occurred from the early 1940s through the mid-1980s. It is appropriate to mention the team approach that was apparently encouraged by university leadership and the attitude of group discovery exhibited by investigators at all three locations that lasted for the duration of their scientific careers.

Research Locations

Belle Glade

The Agricultural Research and Education Center at Belle Glade was earlier known as the Everglades Experiment Station. Located in south Florida at 26º 42' latitude and an elevation of 12.5 ft, it is an area with high annual rainfall (> 55 in) and subtropical temperatures (averages range from 61 to 83°F). The predominant forage that cattle grazed during these projects was Roselawn St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntz).

A project initiated in the 1940s (Kidder et al., 1964; Crockett, 1973a) was begun to produce and evaluate ⅜ Brahman ⅝ Devon cattle, but the final design compared straightbreds, backcrosses (¾ Devon ¼ Brahman and ¾ Brahman ¼ Devon), a two-breed rotation of the two breeds ("crisscrossing"), and *inter se* mated ⅜ Brahman ⅝ Devon (some *inter se* matings of half bloods and also matings of F_1 bulls to ¾ Devon cows were included in this group). Almost a decade (1951 to 1959) of reproductive data (n = 1,388) and calf weaning weight (n = 933) and weights of replacement heifers (n = 415) was collected and analyzed.

From 1962 to 1971 at Belle Glade, three generations of three two-breed rotations (Brahman-Angus, Brahman-Hereford, and Hereford-Angus) and contemporary straightbreds of the three breeds were studied (Crockett, 1973b; Crockett et al., 1973, 1978a, b). The focus of this work was reproductive traits (n =3,327), including pregnancy rate, calf survival, and weaning rate.

From 1978 to 1983, reproductive and maternal performance (n = 751 for reproductive traits and n = 611 for traits of their calves) of Brangus cows mated to Brangus bulls was compared to that of F_1 and F_2 Brahman-Angus cows bred to F_1 Brahman-Angus bulls (Hargrove et al., 1991a, b).

Ona

The Range Cattle Research and Education Center at Ona (formerly Agricultural Research Center) is located in south-central Florida (27º 25' N latitude, 81º 55'W longitude) at an elevation of 85 ft. Average rainfall and temperatures are only slightly lower than those at Belle Glade. The predominant forages used were bahiagrass (*Paspalum notatum*), pangolagrass (*Digitaria decumbens* Stent.), coastal bermudagrass (*Cynodon dactylon*), and, to a lesser extent, native species *Aristida* and *Andropogon*, Dutch white clover (*Trifolium repens* L.), and hairy indigo (*Indigofera hirsute*).

Breeding research began at Ona in 1942 with the purchase of Brahman cows and a Shorthorn bull. In 1952 a crossbreeding study with these two breeds was begun (Peacock et al., 1973b). Five breed groups of cows were produced and evaluated; these included straightbred Shorthorn and Brahman, F_1 cows, and backcross cows (¾ Brahman ¼ Shorthorn and ¾ Shorthorn ¼ Brahman). All five groups were bred to Brahman and Shorthorn bulls. All breed groups were evaluated on low, medium, and high levels of nutrition. The objectives of this study were to estimate breed effects and heterosis on a variety of traits. The study continued for 10 years and was one of the most comprehensive crossbreeding studies of the era (Koger et al., 1975; Peacock et al., 1971, 1973a).

Evaluation of the Charolais breed began at Ona in 1959 using grade Charolais cows (Peacock et al., 1973b). From 1962 to 1974, a breeding project with Charolais, Brahman, and Angus was conducted using a diallel mating design as a base. Six breed groups of cows (three straightbred groups and three F_1 groups [reciprocals combined]) were mated to purebred bulls of all three breeds. Heterosis and breed effects were estimated for reproductive traits (n = 1,305), calf preweaning traits (n = 1,029) and steer growth and carcass traits (n = 351) using data from the project (Peacock and Koger, 1980; Peacock et al., 1978, 1979, 1981). Calf traits (weaning age, body condition score, and weight) of calves produced by F_1 bulls of all combinations mated to purebred and F_1 cows were compared to that of purebreds (Peacock et al., 1986). Cow reproductive and size traits of the second and third generations of two- and three-breed crosses (produced by rotational and *inter se* matings) of these breeds were subsequently compared for calf traits and cow reproduction and size (Olson et al., 1993).

Gainesville

The Beef Research Unit is near Gainesville in north-central Florida (latitude 29° 40' N) where cattle grazed bahiagrass (*Paspalum notatum*) and Dutch white clover (*Trifolium repens* L.). Average rainfall is slightly lower than at Ona and Belle Glade; average temperatures are substantially lower, with frequent frosts in winter.

From 1959 to 1970, the research herd at the Beef Research Unit (crossbred Brahman and criollo base) was bred to form five breed types: grade Hereford, grade Angus, and three two-breed rotations, including Hereford-Angus, Brahman-Angus, and Hereford-Santa Gertrudis (Koger, 1973a, b). Cow and calf performances of these five breed groups were evaluated (Restle et al., 1986).

From 1978 to 1980, a crossbreeding study was conducted with the Brown Swiss and Angus breeds in which straightbreds and F_1 cows were mated to Angus and F_1 bulls (Olson et al., 1985). Calf and cow performances were analyzed (n = 510) with estimation of breed effects and heterosis as objectives. Marshall et al. (1987) produced estimates of breed effects and heterosis for feedlot and carcass traits of steers produced in the study.

Heterosis Retained in Different Crossbreds

The F_1 *Bos indicus* cow is the most productive breed type in Florida and other sub- or semi-tropical areas but is expensive to purchase or produce. A common investigatory theme across four decades of Florida beef cattle research was the assessment of heterosis expressed for reproductive traits by other (non F_1) crossbred Brahman cows. Heterosis expression is generally expected to be proportional to heterozygosity (dominance effects), and substantial loss (half) of heterosis would be expected to occur from the F_1 to the F_2 generations. If dominance effects do not adequately account for heterosis expressed (Dickerson, 1969, 1973), then losses may be even greater for crossbreds other than F_1s.

Reproduction and Survival

Reproductive traits that were evaluated in the reviewed studies included various measures of cow efficiency. These included separate analyses of pregnancy rate, calving rate, and weaning rate, evaluated where cows that were exposed to bulls were assigned a value of 1 if they were pregnant, calved, or weaned a calf, or 0 if they failed in a given category. Calf survival rate was analyzed similarly, where calves that failed to survive to weaning were assigned 0; Crockett et al. (1978b) defined this trait as survival from pregnancy to weaning. In such analyses, least squares means represent proportions that "succeeded"; usually these were expressed as percentages. Annual production per cow was calculated as the product of pregnancy rate, calf survival rate, and calf weaning weight. Relative cow efficiency was evaluated as annual production per cow divided by cow weight.

Early work with the Brahman and Devon breeds demonstrated significant crossbred superiority for reproduction in all crossbred cow groups (Kidder et al., 1964; Crockett, 1973a), but the highest values for F_1 cows (Table 1). If it is assumed that the crossbred advantages of 5.4% for F_1 Brahman-Devon represents the direct (expressed by the calf) heterosis estimate for weaning rate, then it can be assumed that most of the crossbred advantage for the other mating systems in Table 1 is due to maternal heterosis. Using this reasoning, the ⅜ Brahman ⅝ Devon cows (a few were

Table 1. Performance of Brahman-Devon and Brahman-Angus crosses, 1950-59 (reproduced from Crockett, 1973a).

Breed[a]			Weaning data			Postweaning data			Level of heterosis[c]			
Sire	Dam	Progeny	Weaning rate[b] (%)	No. calves	205-Day wt. (lbs.)	No. heifers	12-Month wt. (lbs.)	18-Month wt. (lbs.)	Weaning rate (%)	205-Day wt. (%)	12-Month wt. (%)	18-Month wt. (%)
Purebreds												
A	× A	A	76.4	143	323	52	397	546	...	...	...	...
B	× B	B	50.0	67	330	33	455	584	...	...	...	...
D	× D	D	57.9	171	350	67	473	628	...	...	...	...
Purebred dams, F_1 progeny												
A or B	× B or A	AB	70.7	34	360	17	516	691	11.9	10.3	21.1	22.3
B or D	× D or B	BD	56.9	82	398	45	544	696	5.4	17.1	17.2	14.9
F_1 dams, backcross progeny												
A or B	× AB	$A_3B_1 + A_1B_3$	72.9	51	422	22	491	627	15.4	29.2	15.3	11.0
B or D	× BD	$B_3D_1 + B_1D_3$	83.9	106	400	48	515	651	55.4	17.6	11.1	7.4
3/4 Blood dams, backcrossed												
B or D	× or	B_1D_3 B_3D_1	$B_3D_5 + B_5D_3$	61.0	102	393	48	512	654	13.0	15.6	10.3	7.9
Inter se mating of crossbreds												
BD or B_3D_5	× or B_3D_5	B_1D_3 B_3D_5	60.0	177	375	83	468	610	11.1	10.3	0.9	0.7

a. A, B, and D represent Angus, Brahman, and Devon, respectively.
b. Reproductive performance was affected adversely by brucellosis and may have biased breed differences.
c. Heterosis expressed as the advantage of crossbreds over mean of purebreds.

¾ Devon ¼ Brahman, see Table 1) and ¾ (Brahman or Devon) - ¼ cows expressed approximately the same heterosis for weaning rate, which is consistent with expectation from the dominance model. However, if the huge advantage (> 50%) of the F_1 Brahman-Devon cows is considered, both groups (⅜ Brahman ⅝ Devon and ¾ Brahman or Devon - ¼ Brahman or Devon) appeared to deviate substantially below dominance expectation.

Crockett et al. (1978b) reported heterosis estimates for three generations in three separate two-breed rotations. Estimates of heterosis for pregnancy rate in Angus-Brahman first, second, and third generation cows (F_1, ¾ - ¼, and ⅜ - ⅝ cows) were 10.3, 7.0, and 2.7%, respectively, for pregnancy rate; 20.4, 12.4, and 8.9% for weaning rate (only those estimates for F_1 and ¾ - ¼ cows were significant for pregnancy and weaning rate); and 9.1, 5.1, and 6.7% for calf survival rate (only F_1 heterosis was significant). The first generation (F_1) of the Brahman-Hereford rotation had significant heterosis for weaning rate (12.7%) and the third generation (⅜ - ⅝) expressed significant heterosis for pregnancy rate (11.1%). No generation of the Hereford-Angus rotation expressed significant heterosis for any reproductive trait. Overall heterosis expression for all three generations for pregnancy rate (6.0, 3.7, and 5.9%, for generations one through three, respectively; only the estimate for the first generation was significant) and weaning rate (14.0, 6.1, and 4.6%) did not appear to differ from dominance model expectation. The authors realized one difficulty of analyses of lowly heritable, binomially distributed traits, that ". . . as a trait approaches an incidence of 100%, there is little opportunity for the expression of hybrid vigor in crossbreds. . .".

Brahman, Angus, and Charolais cows were compared with all combinations of backcross (¾ -¼) cows, F_1 and F_2 cows, and all combinations of ½ - ¼ - ¼ cows (Olson et al., 1993). Pregnancy rate heterosis ranged from 0.05 to 0.08 for the different breed combinations. Heterosis expressed for pregnancy rate in different mating systems were 0.071, 0.030, 0.063, and 0.072 for F_1, F_2, backcross dams, and three-breed cross dams—this does not appear to differ from dominance model expectation, but it should be noted that none of the contrasts used to estimate heterosis for the F_2, backcross, or three-breed cross cows were significant.

Brangus and F_2 cows had similar pregnancy and calving rates, annual cow production (weight), and cow efficiency (calf weaning weight/cow weight), but both groups had significantly lower performance for all of these traits than F_1 Brahman-Angus cows (Hargrove et al., 1991a). In this study, F_2 cows had a high stillbirth rate (11.0%), which resulted in a lower weaning rate (67.1%) than the Brangus and F_1 cows (80.8 and 90.7%, respectively). No cow breed group differences in calf mortality from birth to 4 d or from 4 d of age to weaning were detected, but the difference between the calf survival rate of F_2 cows (82.0%) and those of F_1 and Brangus cows (91.7 and 94.0%, respectively) approached significance ($P < 0.08$).

Peacock et al. (1981) reported productive efficiency rate as the product of cow efficiency (calf weight/cow weight) and weaning rate. The authors compared mating system means (combining all breed types) for this rate. In comparison to the purebred (Brahman, Angus, and Charolais) system mean of 0.34, the system mean purebred cows raising first cross calves of all combinations was 5.9% greater. The mean for F_1 cows raising backcross calves was 17.6% greater, and the mean for F_1 cows raising calves sired by the third breed was 26.5% greater than the purebred mean. Though not discussed by Peacock et al. (1981), results were presented for pairs of breeds in the study. Brahman-Angus F_1 cows expressed the largest crossbred advantage of any of the crossbred cow groups for productive efficiency rate when raising backcross calves (37.9%) or Charolais-sired calves (33.3%). Brahman-Charolais F_1 cows were intermediate, with 19.4% crossbred superiority when raising either backcross or Angus-sired calves. Angus-Charolais F_1 cows raising backcross calves had 4.5% higher productive efficiency rate compared to purebreds; it should be noted that when raising Brahman-sired calves, that advantage was 36.4%.

Subsequent data of the project detailed by Peacock et al. (1981) were analyzed and reported for different mating systems across all breeds (Olson et al., 1993). Pregnancy rates were 0.858, 0.929, 0.888, 0.921, and 0.93 for purebreds, F_1 cows, F_2 cows, backcross cows, and three-breed cross cows, with corresponding estimates of heterosis expressed (for the above crossbred systems) of 0.071, 0.030, 0.063, and 0.072. Only the estimates for backcross and three-breed cross cows approached significance, but the lower for F_2 cows appears to be consistent with dominance expectation.

Annual production per cow (Crockett et al., 1978a) was defined as the product of pregnancy rate, calf survival rate, and weaning weight. Cows were assigned values of either 0 or the weight of their calf. The authors then estimated heterosis for annual production divided by cow weight for the first three generations in three two-breed rotations (cows in the three generations were F_1, ¾ - ¼ , and ⅜ - ⅝, respectively) were 42, 23, and 24% in Brahman-Angus, and 32, 11 (not significant), and 14% in Brahman-Hereford. Estimates of heterosis for this trait in the three generations of Hereford-Angus data

were 10, 6, and 3% (none were significant). When all breed types were combined, the decline from generation one to three in heterosis expressed for annual production per cow weight appeared to conform to expectation. Authors believed this decline to be (consistent with thoughts for survival and weaning rate [Crockett et al., 1978b]) due to the higher survival rates of purebred calves in the second and third generations.

Cow and Heifer Weights

Heterosis for growth in heifers was significant for all except *inter se* groups at 12 and 18 mo of age and decreased up to 18 mo of age (Crockett, 1973a). Heterosis estimates for 12- and 18-mo weights in Brahman-Devon were 17.2 and 14.9% and in Brahman-Angus were over 21% for both traits. Estimates for backcross heifers were 11.1 and 7.4% in Brahman-Devon and 15.3 and 11.0% in Brahman-Angus. Estimates for these traits in ⅜ Brahman ⅝ Devon and ⅜ Devon ⅝ Brahman (out of pure bulls and ¾ dams) were 10.3 and 7.9%. Heifers from *inter se* mated ⅜ Brahman ⅝ Devon expressed almost no heterosis for 12- and 18-mo weight (0.9 and 0.7%, respectively). This would be a substantial departure from dominance expectation.

Heterosis effects were large for cow weight in Brahman-Angus and Brahman-Charolais, but not for Charolais-Angus (Olson et al., 1993). Essentially all of the cow weight heterosis expressed by F_1 cows was gone in F_2, backcross, and three-breed cross cows.

Calf Preweaning and Weaning Traits

Estimates of heterosis for 205-d weight were 10.3 and 17.1% for Brahman-Angus and Brahman-Devon crosses, respectively (Table 1; Crockett, 1973a). Backcross progeny/F_1dams expressed 29.2 and 17.6% heterosis for Brahman-Angus and Brahman-Devon crosses. Heterosis levels were only slightly reduced for ⅜ - ⅝ Brahman-Devon (both ways) at 15.6% and *inter se* mated ⅜ Brahman ⅝ Devon at 10.3%, which appears to be consistent with the dominance model for expression of heterosis.

Crockett et al. (1978a) reported these estimates (total) of heterosis for the first three generations of two-breed rotations: weaning weight, 19, 13, and 21% in Brahman-Angus rotation, and 15, 9, and 17% in Brahman-Hereford rotation, and 7, 1 (not significant), and 8% in Hereford-Angus rotation. Crockett et al. (1978a) reported total heterosis estimates for body condition score that ranged from 5 to 13% for the different generations in all three rotations evaluated (Brahman-Angus, Brahman-Hereford, and Hereford-Angus). This study also reported high levels of heterosis (11 to 19%) for birth weight in all three evaluated generations of Brahman-Hereford and Brahman-Angus rotations, but none in the Hereford-Angus rotation.

Heterosis estimates for weaning body condition score, weaning weight, and 205-d weight in *inter se* matings of F_1s (Brahman-Angus, Brahman-Charolais) were highly significant, while those for weaning body condition score and weaning weight were significant for F_1 Angus-Charolais (Peacock et al., 1986). Although these were estimates for the mating system (expectation of ½ direct heterosis + maternal heterosis), the direct heterosis expressed by F_2 calves did not appear to be substantially different from that predicted by the dominance model. Heterosis estimates expressed in backcross progeny for these traits (F_1 bulls mated to purebred cows) were significant only for weaning body condition score and 205-d weight in Brahman-Angus. Dominance model heterosis expectation for this system would be ½ of the direct heterosis; estimates appeared to be much lower than this expectation.

Total heterosis for weaning weight expressed by F_1, backcross, and three-breed cross cows (Brahman, Charolais, and Angus) did not appear to differ greatly (45 to 65 lb), but the estimate for F_2 dams was not different from 0 lb (Olson et al., 1993), which suggests dramatic loss of heterosis from the F_1 to the F_2 generations. No significant heterosis estimates for birth weight or survival rate were detected. Although heterosis estimates for weaning body condition score were highest for calves from F_1 cows, they were somewhat lower for backcross and three-breed cross cows, and the estimate for F_2 cows was slightly lower than half that of F_1 cows.

Preweaning average daily gain and weaning weight of calves from *inter se* mated Brangus cows and F_2 Brahman-Angus cows did not differ ($P > 0.05$), but both were less than calves from F_1 Brahman-Angus cows (Hargrove et al., 1991b). Birth weights did not differ for calves from the F_1 and F_2 cows; calves from both groups were heavier than Brangus calves.

Interdependence of Cow Age, Lactation Status, and Reproductive Success

Early research in Florida identified the difficulties and nuances associated with analyses of reproductive data. The influence of lactation on subsequent reproductive performance is detrimental (Koger et al., 1962; Crockett, 1973a). Lactation status and age of cow are tremendous influences on reproductive performance. Nonlactating cows had lower weaning rates in the following year (63 *versus* 84%) in a large study (1944 to 1958; n = 3,994 matings and 2,954

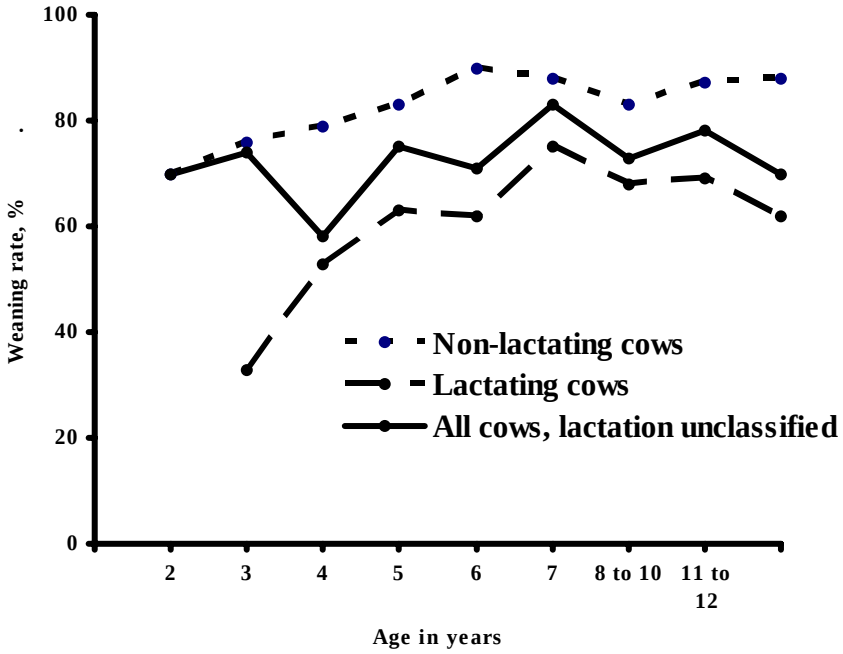


Figure 1. Age effects in lactating and non-lactating cows, compared to biased effects of when lactation status was unclassified (Reconstructed from Koger et al., 1962)

calvings) at Ona (Koger et al., 1962), and there was a significant interaction of lactation status with cow age, which is illustrated in Figure 1 (reproduced from Koger et al., 1962). The cyclical (with regard to cow age) weaning rate appeared to be due to the lower weaning rates of lactating cows, especially at young ages. This appears to be supported by results from two other Florida locations (Crockett, 1973a). In this study (Koger et al., 1962), the authors reported only the results of analyses of weaning rate, because calving rate results were similar. It may be that the reproductive status of a cow in a given year may be best predicted by her lactation status in the previous year, i.e., a negative autocorrelation exists between successive reproductive events. Koger et al. (1962) also reported differential response to lactation stress in different pasture programs, because they observed lower reproductive performance (weaning rate) for cows on lower nutritional plane; however, the authors noted a reduced weaning rate for non-lactating cows on improved pasture and a greater preweaning death loss (though not analyzed) in the highest nutritional plane. Breed effects appear to interact with lactation status and cow age to influence reproductive rates. Nonlactating cows of all breed groups performed at nearly the same level, but breed differences occurred when cows were lactating (Koger et al., 1962). Several breeds and breed types of both cows and bulls were included in this study, making analyses and interpretation difficult, but most of the positive effects on weaning rate appeared to be associated with heterotic effects in crossbred cows. Figures 2 and 3 (Crockett, 1967) illustrate the erratic pregnancy rates associated with age in British, crossbred, and Brahman cattle, particularly for Brahman cows at 2 through 6 yr of age. Results from a survey of reproduction traits (n = 15,204) from 14 cow-calf producers in southern states (Temple, 1967) indicated that *Bos indicus* breeds (Brahman, Brangus, Santa Gertrudis) had higher calving (3 to 8%) and weaning rates (4 to 5%) for nonlactating cows than lactating cows in the following year, but the opposite was the case for British breeds (Angus, Hereford, and Shorthorn); lactating cows had approximately 2% higher calving rates than nonlactating cows. Two states with large *Bos indicus* influence in the cow herd (Florida and Louisiana) had higher calving and weaning rates for nonlactating cows. Nonlactating cows tended to have higher calf mortality in the next year, which was consistent with the results of Koger et al. (1962). There appeared to be an interaction with cow age; 2-, 3-, and 4-yr and older nonlactating cows had 8.4, 11.6, and 5.3% death loss from 36 h to weaning in the next year, while lactating cows in the same categories had 4.3, 4.2, and 3.1% death loss in their next calves (Temple, 1967). Olson et al. (1985) also described an interaction of breed with cow age and lactation in which 2- and 3-yr-old Brown Swiss cows had much lower pregnancy rates (approximately

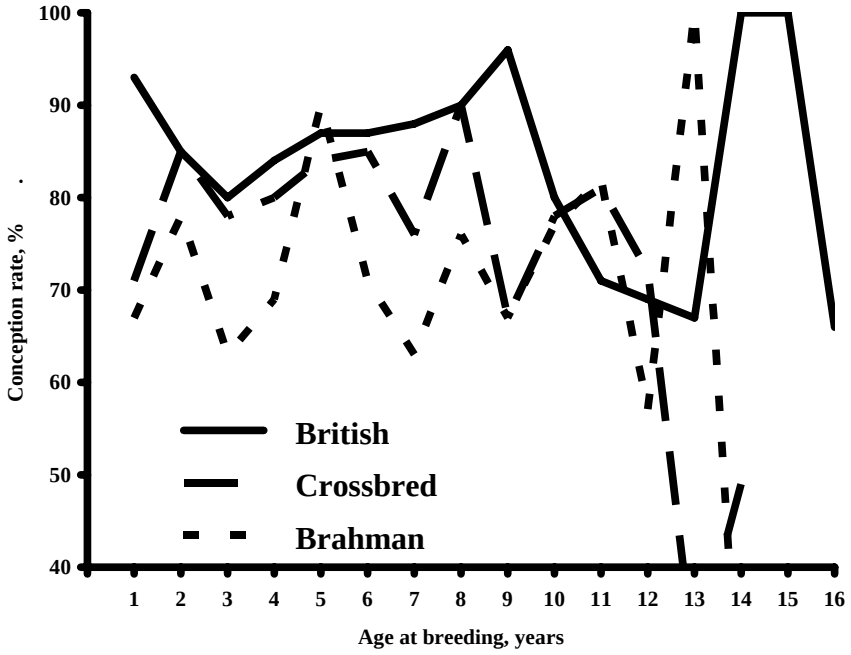


Figure 2. Age and breed interacting on reproductive rate (Reconstructed from Crockett, 1967)

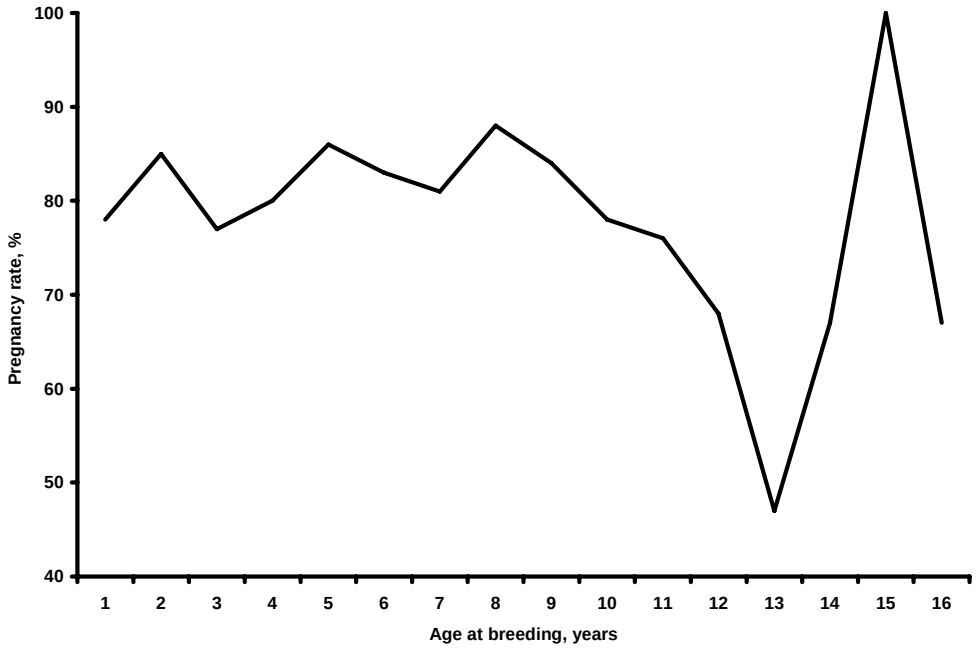


Figure 3. Effect of age in reproductive rate (recreated from Crockett, 1967)

20% lower) than the other breed types (Angus and Brown Swiss-Angus F_1s). Brown Swiss cows weaned calves (Angus-sired) that had 35 lb heavier 205-d weights than all other cows; this was likely responsible for the lower pregnancy rate (30% lower) for lactating Brown Swiss cows.

Historically in Florida, most cows (virtually all of the literature reviewed in this paper) were bred as 2-yr olds to calve as 3 yr olds. It has been generally accepted that because of lower replacement costs (BIF, 1996) and greater lifetime productivity (Chapman et al., 1978), heifers should be bred to calve first as 2 yr olds in the United States, and this standard has been promoted even among the later-maturing Brahman and Brahman cross heifers. Our own experience with Brahman cattle is that at best about 10% of heifers will calve as 2 yr olds. Among those (including crossbreds) that do calve at 2 yr, it again has been our experience (though not statistically demonstrated) that even the "best" cows eventually fail to get pregnant somewhere from 4 to 6 yr of age. There is an absence of experimental support for either the lifetime superiority (either from an economic or purely productive standpoint) of the system of breeding cows in the subtropical United States to first calve at 2 rather than 3 yr of age. Brahman cows mature later than other breeds; Plasse et al. (1967b) reported age at first corpus luteum (detected by palpation) for Brahman heifers to range from 18.9 to 21.3 mo, as compared to 15 to 20 mo in crossbred Brahman heifers. This is likely a consequence of *indicus* adaptation to tropical and subtropical areas by acquisition of "built-in mechanisms to protect themselves from poor feed supplies," which include late puberty, suppression of estrus during lactation, and a tendency to even display this when well fed (Warwick, 1967). Gestation length in Brahman cows was 292.8 d (Plasse et al., 1967c), and average calving interval was 409.9 d and, if skipped years were excluded, 374.7 d (Plasse et al., 1967a); this interval tended to shorten with increasing cow age. Although Plasse et al. (1967a) concluded that shortening the breeding season would increase selection pressure and therefore increase overall reproductive efficiency, enforcement of defined breeding seasons may result in eventual reproductive failure (as soon as ages 4 to 6) for Brahman cows (and probably crossbreds).

Peacock et al. (1971) reported evidence of genotype environment interaction influence on expression of heterosis in Brahman and Shorthorn crosses. Pregnancy rates of purebred and F_1 cows were 11 and 19% higher for cows on highly improved pastures as compared to the same breed groups on native range. Weaning rates for the two groups were 10 and 15.7% higher on the improved pastures. The heterosis expressed for percent weaning rate increased linearly with improved conditions: 11.6% for cows on native range, 15.8% for cows on a combination pasture program, and 18.2% on highly improved pastures.

Implications

Crossbreeding research in Florida has produced results that generally support the dominance model of heterosis expression. There were two notable exceptions. More than 70% of the weaning rate heterosis expressed by F_1 Brahman-Devon with backcross calves appeared to be lost in ¾ Brahman ¼ Devon (⅜ - ⅝ calves) and ⅜ Brahman ⅝ Devon cows with calves from *inter se* matings (Crockett, 1973a). There appeared to be almost total loss of heterosis for yearling weight and 18-mo weight in ⅜ Brahman ⅝ Devon heifers (Crockett, 1973a) and for cow weight in all non-F_1 (F_2, backcross, and three-breed cross) cows (Olson et al., 1993).

Early work in Florida also highlighted the complex interaction of reproductive performance with lactation status, age of cow, and nutritional plane. It is a very worthy challenge to appropriately model these interactions when studying and describing cow reproductive performance.

There is large continual emphasis in the United States on genetic improvement of calf growth performance; economies of scale in the feeder and packer segments of the beef industry are partly responsible for this emphasis. Efforts have been made to apply the selection programs that have been so successful in improvement of calf growth and dairy milk yield to cow reproductive traits; however, these programs are likely to be slower and less effective than crossbreeding. There is a renewed interest in crossbreeding, even among dairy researchers, as a means of improvement of fertility. The reviewed work here in each case included 10 or more years of reproductive data, which are especially large studies relative to most, but not all, of the studies of similar traits today. Even with these large data sets, it was difficult to estimate significant contrasts. Support for long-term research into cow reproductive performance is rare today; there are at least two major similar studies in Texas. This seems inadequate, because the problems are not resolved. Such studies could be conducted while providing the population as a source for DNA mapping or other popularly funded work.

Much of what is understood about cow performance has come from this early Florida work. The cooperation and interaction among the cattle research entities in Florida during these reviewed studies enhanced the impact of this group and should serve as a model and example for researchers today.

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Reproduction of *Bos Indicus* Breeds and Crosses

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ABSTRACT: Reproductive endocrinology of *Bos indicus* cattle differs from that of *Bos taurus* cattle. The duration of estrus is shorter and less intense and occurs late in relation to an estrogen stimulus in *Bos indicus* females. The *Bos indicus* female has a smaller preovulatory LH surge which occurs earlier relative to the onset of estrus, and ovulation occurs earlier after the onset of estrus. The corpus luteum of *Bos indicus* females is smaller and contains less progesterone, resulting in lower concentrations of circulating progesterone. Crosses between *Bos indicus* and *Bos taurus* are intermediate with respect to these endocrine parameters. *Bos indicus* males secrete LH in the same pulsatile pattern as *Bos taurus*, but at lower concentrations. Testis response to LH is similar between *Bos indicus* and *Bos taurus* bulls, with lower circulating concentrations of testosterone in the *Bos indicus*. The greatest reproductive difference between *Bos indicus* and *Bos taurus* cattle is the greater age at puberty in both female and male *Bos indicus* cattle. Most crosses reach puberty nearer the *Bos taurus* parent breed than the *Bos indicus* parent breed. Seasonality of reproductive efficiency differs between *Bos indicus* and *Bos taurus*. *Bos indicus* cattle have reduced reproduction during the winter, and *Bos taurus* cattle can have reduced reproduction during extreme summer temperatures. During the winter, *Bos indicus* females have reduced preovulatory LH surges and become anovulatory. During the extremes of summer temperatures, *Bos taurus* females have reduced oocyte quality and reduced conception rates and *Bos taurus* males have reduced semen quality. Some of the advantage for *Bos indicus* x *Bos taurus* crosses in reproduction may derive from their ability to maintain reproductive efficiency during extremes in temperature and photoperiod throughout the year.

Key Words: *Bos indicus*, *Bos taurus*, Reproduction

Introduction

The most numerous *Bos indicus* breed in the United States is the Brahman. The Brahman breed was developed in the Gulf Coast states by upgrading native U.S. cattle with various breeds of *Bos indicus* cattle from India (Phillips, 1963; Yturria, 1973). Breeders did not control the proportions of different *Bos indicus* breeds used in developing the Brahman. Even with this genetically diverse beginning, the adaptation of this new *Bos indicus* breed to the Gulf Coast environment has led to its use in crossbreeding and development of other Brahman-influenced breeds. The adaptive traits of the Brahman and its crosses that account for their use in beef production systems include: tolerance of internal and external parasites; tolerance of high solar energy, high ambient temperature, and humidity; and the ability to utilize high fiber forages (Koger, 1963). The positive influence of *Bos indicus* breeding on beef production is well documented (Rhoad, 1955; Cartwright and Fitzhugh, 1972; Koger, 1973). Reproduction has generally been reported to be lower in *Bos indicus* compared with *Bos taurus* breeds (Kincaid, 1957; Warnick, 1963; Reynolds, 1967; Temple, 1967; Plasse, 1973). Research results explaining some of the reasons for these results will be presented in this manuscript.

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Age at Puberty: Bulls

Bos indicus and *Bos indicus*-influenced breeds of bulls reach puberty at older ages than *Bos taurus* bulls (Table 1). Puberty in bulls has been defined as the time when a bull is capable of producing an ejaculate containing at least 50 million sperm with at least 10% progressive motility (Wolf et al., 1965; Killian and Amann, 1972; Barber and Almquist, 1975). *Bos taurus* bulls (Lunstra et al., 1978) have the first sperm in the ejaculate at younger ages than *Bos indicus* bulls (Neuendorff et al., 1985; Nolan et al., 1990; Chase et al., 1994) and reach puberty (50 million sperm in the ejaculate with at least 10% progressive motility) earlier than *Bos indicus* bulls (Fields et al., 1982; Neuendorff et al., 1985; Tatman et al., 2001). *Bos indicus* breeds and *Bos indicus* crossbred bulls must reach an older age before they are capable of impregnating a cow than *Bos taurus* bulls. Scrotal circumference is an important measurement taken into consideration in the Breeding Soundness Evaluation

Table 1. Age at puberty in bulls

Breed	Age (days)	Source
Brown Swiss	264	Lunstra et al. (1978)
Red Poll	295	Lunstra et al. (1978)
Angus	296	Lunstra et al. (1978)
Angus	348	Fields et al. (1982)
Angus	396	Chase et al. (1997a)
Angus	430	Chase et al. (1997a)
Angus	373	Tatman et al. (2001)
Hereford	326	Lunstra et al. (1978)
Hereford	407	Chase et al. (1997a)
Wagyu	320	Tatman et al. (2001)
Romosinuano	433	Chase et al. (1997a)
Romosinuano	369	Tatman et al. (2001)
Senepol	416	Chase et al. (1997a)
Bonsmara	291	Tatman et al. (2001)
Tuli	328	Tatman et al. (2001)
Brahman	477	Fields et al. (1982)
Brahman	454	Neuendorff et al. (1985)
Brahman	485	Chase et al. (1997a)
Brahman	510	Chase et al. (1997a)
Brahman	427	Tatman et al. (2001)
Nelore x Brahman	468	Chase et al. (1997[a])

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Table 2. Scrotal circumference at puberty

Breed	Scrotal circumference (cm)	Source
Brown Swiss	27.2	Lunstra et al. (1978)
Red Poll	27.5	Lunstra et al. (1978)
Angus	28.6	Lunstra et al. (1978)
Angus	28.8	Fields et al. (1982)
Angus	29.2	Chase et al. (1997)
Angus	30.4	Chase et al. (1997)
Angus	28.1	Tatman et al. (2001)
Hereford	27.9	Lunstra et al. (1978)
Hereford	28.7	Chase et al. (1997)
Wagyu	24.5	Tatman et al. (2001)
Romosinuano	28.8	Chase et al. (1997)
Romosinuano	26.0	Tatman et al. (2001)
Senepol	29.9	Chase et al. (1997)
Bonsmara	28.2	Tatman et al. (2001)
Tuli	26.1	Tatman et al. (2001)
Brahman	33.4	Fields et al. (1982)
Brahman	26.6	Neuendorff et al. (1985)
Brahman	31.0	Chase et al. (1997)
Brahman	28.2	Chase et al. (1997)
Brahman	28.0	Tatman et al. (2001)
Nelore x Brahman	27.4	Chase et al. (1997[a])

(Society for Theriogenology, 1976). Scrotal circumference is a growth trait that may be affected by genetic, environmental, and or individual animal differences. Reports in the literature exist that *Bos indicus* bulls have smaller scrotal circumferences at a given age and that allowances should be made for them in the Breeding Soundness Evaluation (Morris et al., 1978; Chenoweth and Ball, 1980; Morris et al., 1987, 1989). In contrast, scrotal circumferences appear to be similar at puberty (Table 2) in two

reports (Neuendorff et al., 1985; Tatman et al., 2001) and smaller in one report (Fields et al., 1982) when comparing *Bos indicus* with *Bos taurus* bulls. The common factor among all of the reports is that *Bos indicus* bulls are considerably older at puberty than are *Bos taurus* bulls (Table 1)

Scrotal circumference is greater in *Bos taurus* bulls than in *Bos indicus* bulls following puberty (Godfrey et al., 1990a). Post-pubertal Hereford bulls from two genetic origins (Origin A, 15.6 months of age, scrotal circumference of 32.2 cm; Origin B, 14.1 months of age, scrotal circumference of 33.0 cm) had larger scrotal circumferences than Brahman bulls (20 months of age, scrotal circumference of 30.8 cm).

The slower growth curve of the Brahman bulls required them to be about 35 months of age by the time they reached scrotal circumferences similar to the Hereford bulls. These findings support the reports of Morris et al. (1978), Chenoweth and Ball (1980) and Morris et al. (1987). Young *Bos indicus* bulls are penalized when using the Breeding Soundness Evaluation scoring system developed for *Bos taurus* bulls. The modified scoring chart suggested by Morris et al. (1987) should be used for *Bos indicus* bulls when performing the Breeding Soundness Evaluation.

Age at Puberty: Heifers

Emphasis on heifers calving at 2 years of age has made early maturity an important economic trait. *Bos indicus* heifers reach puberty at older ages than *Bos taurus* heifers (Table 3). *Bos indicus* and *Bos indicus* composite breeds mature later than *Bos taurus* breeds (Warnick et al., 1956; Luktuke and Subramanian, 1961; Temple et al., 1961; Reynolds et al., 1963; Reynolds, 1967; Plasse et al., 1968a). *Bos indicus,* but not *Bos indicus* x European, heifers reach puberty at too old of an age to calve at 2 years of age.

Table 3. Age at puberty in heifers

Breed	Age (days)	Source
British breeds	436	Reynolds (1967)
Angus	459	Chase et al. (1997b)
Hereford	413	Chase et al. (1997b)
Hereford x Bos taurus	358	Lammoglia et al. (2000)
Limousin x Bos taurus	379	Lammoglia et al. (2000)
Piedmontese x Bos taurus	338	Lammoglia et al. (2000)
Romosinuano	427	Chase et al. (1977b)
Senepol	481	Chase et al. (1997b)
Hereford x Senepol	384	Chase et al. (1997b)
Senepol x Hereford	427	Chase et al. (1997b)
Senepol x Angus	475	Chase et al. (1997b)
Tuli x Angus	466	Chase et al. (1997b)
Brangus	528	Reynolds (1967)
Brahman x Bos taurus	438	Reynolds (1967)
Brahman x Angus	478	Chase et al. (1997b)
Brahman	690	Reynolds (1967)
Brahman	592	Chase et al. (1997b)

Table 4. Gestation length

Breed	Gestation length (days)	Source
Bos taurus	282	Lush (1945)
Brahman	293	Plasse et al. (1968b)
Brangus	286	Reynolds (1967)
Nelore	291	Veiga et al. (1946)
Nelore and Guzerat	293	Haines (1961)
Nelore, Gir and Guzerat	292	Briquet and DeAbrea (1949)
Afrikander	295	Joubert and Bonsma (1959)
Afrikander	295	VanGraan and Joubert (1961)
African Zebu	283	Hutchison and Macfarlane (1958)
Ethiopian Zebu	283	Mukasa-Mugerwa and Tegegne (1989)

Gestation Length

Cows of different breeds have different gestation lengths. There is a disadvantage for breeds with

longer gestation periods when they are expected to maintain a 365-day calving interval. The *Bos indicus* breeds derived from India have gestation lengths about 10 days longer than *Bos taurus* breeds (Table 4). To maintain a yearly calving interval, the Bos indicus cow must rebreed within 73 days after calving, whereas the *Bos taurus* cow must rebreed within 83 days after calving. Composite breeds that include *Bos indicus* breeding are intermediate between *Bos taurus* and *Bos indicus* with regard to gestation length. The only *Bos indicus* cattle with gestation lengths similar to *Bos taurus* (Table 4) are the small African Zebu breeds that lack the productivity of the Indian breeds.

Postcalving Fertility

The principal reason that *Bos indicus* or *Bos indicus* crossbred cows are not pregnant at the end of the breeding season is that they do not come into estrus during the breeding season (Reynolds, 1967). Reynolds (1967) found that average intervals from calving to estrus were shortest in Angus, intermediate in Brangus and longest in Brahman cows (Table 5).

More recent reports (Stahringer et al., 1999; Webb et al., 2001; Strauch et al., 2003) indicate that the interval from calving to estrus is similar in the Brahman compared with *Bos taurus* breeds. With intervals of less than 60 days, there does not appear to be a longer interval from calving to estrus in the *Bos indicus* cow compared with *Bos taurus* cows. The greatest proportion of *Bos indicus* cows can return to estrus after calving quickly enough to rebreed to calve on annually. Reports in the literature spanning over 30 years show that Brahman cows can have between 61- and 65-day intervals from calving to conception (Plasse et al., 1968c; Stahringer et al., 1999). First service conception rates in postpartum Brahman cows were from 50 to 73% in one report (Webb et al., 2001) and from 40 to 68% in another report (Strauch et al., 2003). From these results there seems to be little evidence of reduced postcalving fertility, at least in current Brahman genetics.

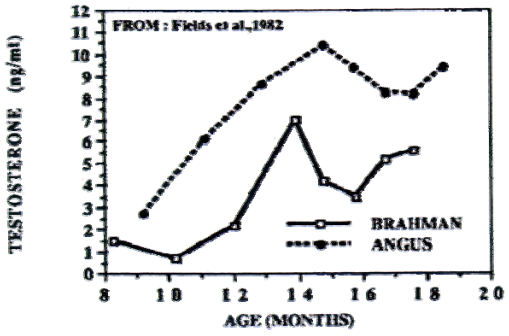


Figure 1. Effect of breed and age on plasma testosterone.

Endocrine Controlled Reproductive Traits: Bulls

The reproductive processes are controlled by hormones. Testosterone, secreted from the Leydig cells of the testes, is responsible for male sexual characteristics. Testosterone secretion is controlled by luteinizing hormone (LH), which is secreted from the pituitary gland. Libido is an important trait and has been found to be lower in Brahman (libido score = 2.5) than in Angus (libido score = 4.4) bulls (Hardin et al., 1981). Young Brahman bulls have been reported to have lower circulating concentrations of testosterone (Figure 1) than young Angus bulls (Fields et al., 1982). Sexually mature Brahman and Hereford bulls secrete LH in a pulsatile fashion and at a similar frequency (Godfrey et al., 1990b). The Brahman bulls have lower basal concentrations of LH with lower pulse amplitude than the Hereford bulls (Figure 2). Mature Brahman bulls respond to the pulses of LH with pulsatile release of testosterone at the same frequency but greater amplitude than the Hereford bulls (Figure 3). When the mature bulls were given a large dose of gonadotropin-releasing hormone (200 µg) to cause release of LH from the pituitary gland, they responded by secreting LH followed by testosterone (Godfrey et al., 1990b). The Hereford bulls released more LH compared with the Brahman bulls (Figure 4) but testosterone release was similar (Figure 5).

Table 5. Interval from calving to estrus

Breed	Interval (days)	Source
Hereford	59	Warnick (1955)
Angus	63	Reynolds (1967)
Brangus	74	Reynolds (1967)
Brahman	79	Reynolds (1967)
Brahman	45	DeFries et al. (1998)
Brahman	48	Stahringer et al. (1999)
Brahman	54	Webb (2001)
Brahman	59	Strauch et al. (2003)

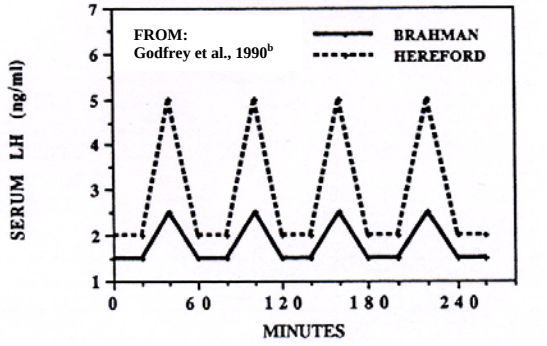


Figure 2. Pulsatile LH in mature bulls.

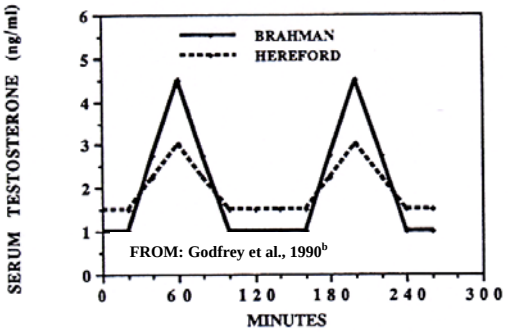


Figure 3. Pulsatile testosterone in mature bulls.

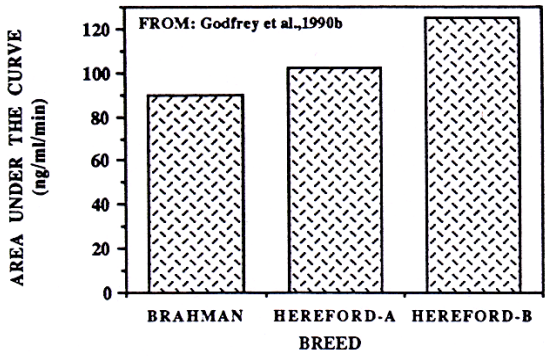


Figure 4. Effect of breed on GnRH induced LH release.

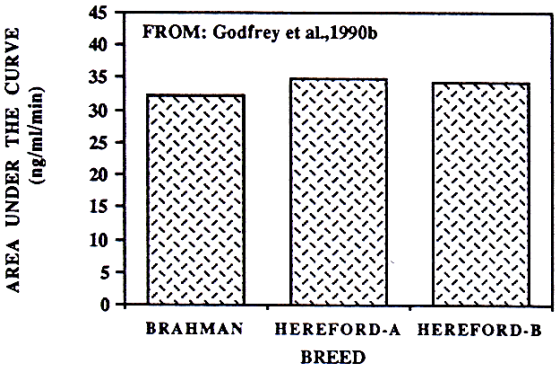


Figure 5. Effect of breed on testosterone release following GnRH induced LH release.

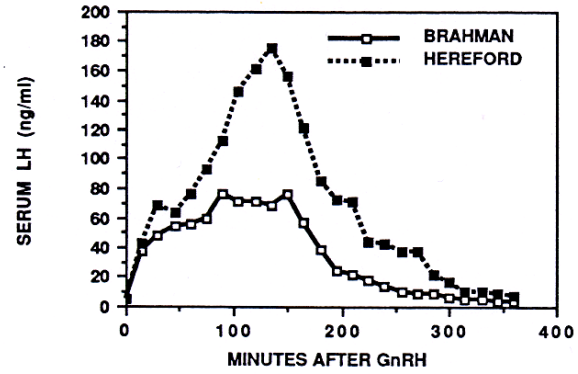


Figure 6. Response of ovariectomized cows to GnRH.

The low concentrations of circulating testosterone reported for young Brahman bulls (Figure 1) are probably related to stage of maturation and testes size and not to a lack of response to either gonadotropin releasing hormone or to LH. Reproductive hormone patterns are similar in mature *Bos indicus* and *Bos taurus* bulls, with *Bos indicus* bulls having lower concentrations of LH but similar release of testosterone as *Bos taurus* bulls.

Endocrine Controlled Reproductive Traits: Cows and Heifers

Estrogen induces estrus behavior in cattle (Short et al., 1973) and is the primary stimulus for the preovulatory LH surge (Henricks et al., 1971; Christensen et al., 1974). The duration of standing estrus is shorter in *Bos indicus* cattle compared with *Bos taurus* cattle (Anderson, 1936; De Alba et al., 1961; Plasse et al., 1970; Rhodes and Randel, 1978).

Ovariectomized Brahman cows have been reported to be less responsive to exogenous estrogen than ovariectomized Brahman x Hereford or Hereford cows (Rhodes and Randel, 1978). Ovariectomized Brahman cows did not accept heterosexual mounting at any estrogen dose, and a lower proportion of Brahman x Hereford cows accepted heterosexual mount at the 1 mg dose than did the ovariectomized Hereford cows (Table 6). When homosexual behavior was used as the measurement for behavioral estrus, a lower response was reported for the ovariectomized Brahman compared with the ovariectomized Brahman x Hereford or Hereford cows (Table 7). Duration of estrogen-induced estrus was shorter in the ovariectomized Brahman and Brahman x Hereford cows than in the ovariectomized Hereford cows (Table 8). The differential response to estrogen may be clearer when the time from estrogen stimulus to behavioral estrus is compared between breed types. The time from estrogen to estrus was longest in the ovariectomized Brahman, intermediate in Brahman x Hereford and shortest in Hereford cows (Table 8).

Table 6. Proportion of ovariectomized cows accepting heterosexual mount after injection of estrogen

	Cows showing estrus (%) Estradiol-17ß dose			
Breed	1 mg	2 mg	4 mg	8 mg
Brahman	0**	0**	0**	0**
Brahman x Hereford	33†	100	100	100
Hereford	83	100	100	100

From: Rhodes and Randel (1978)
†P < 0.10.
**P < 0.005.

Table 7. Proportion of ovariectomized cows accepting homosexual mount after injection of estrogen

Breed	Cows showing estrus (%) Estradiol-17ß dose			
	1 mg	2 mg	4 mg	8 mg
Brahman	66*	83*	66*	83*
Brahman x Hereford	83	100	100	100
Hereford	83	100	100	100

From: Rhodes and Randel (1978).
*P < 0.05.

Table 8. Response of ovariectomized cows to estrogen injection

Breed	Duration of estrus (hours)	Time to estrus (hours)
Brahman	8.2	20.6
Brahman x Hereford	8.4	12.9
Hereford	12.3	9.9

From: Rhodes and Randel (1978).

The greatest concentrations of circulating estrogen before estrus (Randel, 1980) in estrous cycling heifers occur nearest estrus in Hereford, intermediate in Brahman x Hereford, and furthest from estrus in Brahman (Table 9). The elapsed time between endogenous estrogen and onset of estrus in estrous cycling heifers is remarkably similar to the elapsed times from estrogen stimulus to behavioral estrus in ovariectomized cows (Tables 8 and 9). These results show that *Bos indicus* and *Bos taurus* cows have different responses to estrogen. Bos indicus cows have a shorter, less intense estrus that occurs later after the estrogen stimulus than in *Bos taurus* cows. Bos indicus x *Bos taurus* crosses are intermediate to the parent breeds for these physiological parameters.

Luteinizing hormone (LH) is responsible for ovulation in cattle, and the preovulatory LH surge occurs 20 to 22 hours before ovulation (Schams and Karg, 1969) or 3 to 6 hours after the onset of estrus (Henricks et al., 1970) in *Bos taurus* cattle. Gonadotropin-releasing hormone (GnRH) is the hormone responsible for pituitary release of LH in cattle (Convey, 1973).

Griffin and Randel (1978) challenged ovariectomized Brahman and Hereford cows with 500 µg injections of GnRH, and all cows responded by increasing circulating concentrations of LH within 15 minutes (Figure 6). Mean concentrations of LH were lower ($P < 0.005$) in ovariectomized Brahman (34 ± 4 ng/ml) than in ovariectomized Hereford (67 ± 20 ng/ml) cows. Peak LH concentrations were lower ($P < 0.005$) in ovariectomized Brahman (95 ± 7 ng/ml) than in ovariectomized Hereford (185 ± 68 ng/ml) cows. These results, that *Bos indicus* females show a smaller pituitary response than *Bos taurus* females, are similar to those reported (Godfrey et al., 1990b) for *Bos indicus* and *Bos taurus* bulls (Figure 4). From these results it seems appropriate to assume that the *Bos indicus* pituitary gland secretes less LH when given a measured dose of GnRH than does the *Bos taurus* pituitary gland, regardless of sex.

Comparative data evaluating the preovulatory LH surge in Brahman, Brahman x Hereford, and Hereford heifers have been reported for estrous synchronized heifers (Randel, 1976) and normal estrous cycling heifers (Randel and Moseley, 1977). In estrous synchronized heifers (Figure 7) and normal estrous cycling heifers (Figure 8), the Brahman heifers had the smallest preovulatory LH surge, with the Brahman x Hereford heifers and Hereford heifers having the larger LH surges. In both experiments, the time from estrus to the preovulatory LH peak was shorter in the Brahman heifers than in the Hereford heifers (Table 10).

Estrogen has been reported to be the primary stimulus for hypothalamic release of GnRH which, in turn, stimulates pituitary release of LH in cattle (Henricks et al., 1971; Hobson and Hansel, 1972; Short et al., 1973; Christensen et al., 1974). Rhodes et al. (1978) found that elapsed time from estrogen injection to peak LH concentration was longest in ovariectomized Brahman,

Table 9. Time of peak circulating estrogen before estrous in estrous cycling heifers

Breed	Time (hours)
Brahman	24[a]
Brahman x Hereford	16[b]
Hereford	8[c]

From: Randel (1980).
[a,b,c]Different superscript differ $P < 0.05$.

Table 10. Timing of the preovulatory LH surge

Breed	Time from estrus to peak LH (mean hours ± SE)	
	Randel (1976)	Randel and Moseley (1977)
Brahman	0.4 ± 3.4	2.0 ± 1.3
Brahman x Hereford	6.8 ± 2.1	3.0 ± 1.3
Hereford	5.3 ± 1.3	6.5 ± 1.8

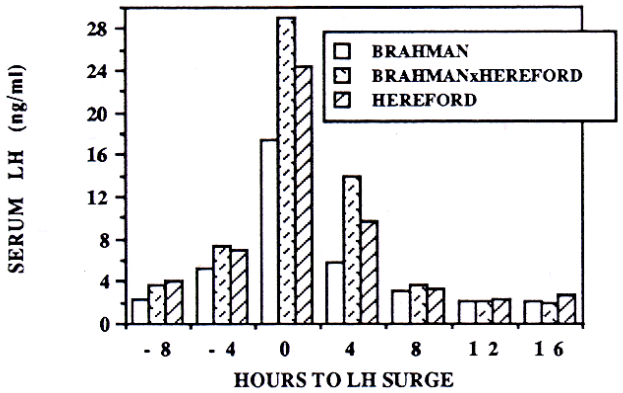


Figure 7. The preovulatory LH surge in estrous synchronized heifers.

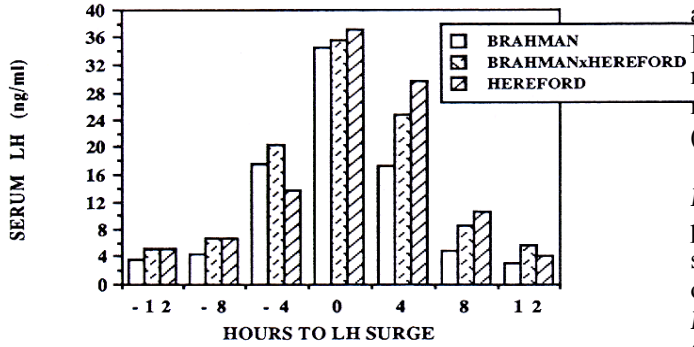


Figure 8. The preovulatory LH surge in estrous synchronized heifers.

intermediate in Brahman x Hereford and shortest in Hereford cows (Table 11). Ovariectomized Brahman cows had the smallest area under the LH release curve, Brahman x Hereford were intermediate, and Hereford cows released the greatest amount of LH (Table 11).

Bos indicus cows have a smaller preovulatory LH surge, a smaller estrogen or GnRH releasable pool of pituitary LH, and are slower to respond to an estrogen stimulus with GnRH secretion from the hypothalamus compared with *Bos taurus* cattle.

The timing of physiological events leading to ovulation has been reported for Brahman, Brahman x Hereford, and Hereford heifers (Randel, 1976). Brahman heifers ovulated earlier after the onset of estrus than did the Brahman x Hereford or Hereford heifers (Table 12). The interval from the LH surge to ovulation did not differ among the breeds. Ovulation times following the onset of estrus have been reported for grade Brahman heifers in Florida (25.6 hours; Plasse et al., 1970), for Brahman heifers in Venezuela (20.6 hours; Troconiz, 1976) and for *Bos taurus* heifers in Montana (33.2 hours; Randel et al., 1973). *Bos indicus* females ovulate 8-10 hours earlier after the onset of estrus than *Bos taurus* females. The primary difference between *Bos indicus* and *Bos taurus* females is that the *Bos indicus* female takes longer from the peak in estrogen to onset of behavioral estrus and then a shorter time from estrus onset to ovulation than the *Bos taurus* female.

Detection of corpora lutea (CL) by rectal palpation is more difficult in *Bos indicus* females than in *Bos taurus* females (Plasse et al., 1968a). Brahman heifers have smaller CL than Brahman x Hereford or Hereford heifers (Irvin et al., 1978), and CL from Brahman cows are smaller than in Angus cows (Segerson et al., 1984; Table 13). Progesterone content of CL from Brahman heifers, Brahman x Hereford heifers, and Brahman cows has been reported to be lower than Hereford heifers (Irvin et al., 1978) or Angus cows (Segerson et al., 1984; Table 14). Conversely, Segersen et al. (1984) found that Brahman cows had greater ovarian and stromal weights on day 17 after estrus compared with Angus cows (Table 15). Brahman cows also had greater numbers of small (< 5 mm) follicles and more follicular fluid but smaller numbers of large (> 5 mm) compared to Angus cows (Table 16).

Because *Bos indicus* cows have smaller CL and both *Bos indicus* and *Bos indicus* x *Bos taurus* cows have less progesterone in the CL than *Bos taurus* cows, it is not surprising that both have lower circulating concentrations of progesterone from day 2 through 11 after estrus than *Bos taurus* (Randel, 1977; Figure 9). Segerson et al. (1984) also reported that Brahman cows had lower serum progesterone from day 7 through 17 after estrus than Angus cows (Figure 10).

Table 11. LH response to estrogen injection in ovariectomized cows

Breed	Time to peak LH (mean hours ± SE)	Area under the LH curve (mean ± SE)
Brahman	27.8 ± 2.0[a]	6.0 ± 2.8[a]
Brahman x Hereford	23.8 ± 0.9[b]	11.1 ± 2.1[b]
Hereford	22.1 ± 1.0[c]	25.1 ± 7.4[c]

From: Rhodes et al. (1978).
[a,b,c]Means in columns with different superscripts differ P < 0.05.

Table 12. Timing of physiological events leading to ovulation (mean hours ± SE)

Breed	Estrus to LH surge	LH surge to ovulation	Estrus to ovulation
Brahman	0.4 ± 3.4	18.5 ± 3.1	18.9 ± 2.2[a]
Brahman x Hereford	6.8 ± 2.1	22.2 ± 2.6	29.0 ± 1.3[b]
Hereford	5.3 ± 1.3	23.3 ± 2.1	28.6 ± 1.5[c]

From: Randel (1976).
[a,b,c]Means in columns with different superscripts differ P < 0.05.

Table 13. Corpus luteum weight (mean g ± SE)

	Day of the estrous cycle		
Group	8	13	17
Brahman heifers[a]	2.5 ± 0.1[c]	2.7 ± 0.1[c]	--
Brahman x Hereford heifers[a]	4.6 ± 0.4[d]	3.8 ± 0.3[d]	--
Hereford heifers[a]	4.0 ± 0.4[d]	3.6 ± 0.3[d]	--
Brahman cows[b]	--	--	2.4 ± 0.1[c]
Angus cows[b]	--	--	4.1 ± 0.3[d]

[a]From: Irvin et al. (1978).
[b]From: Segerson et al. (1984).
[c,d]Means in columns with different superscripts differ P < 0.05.

Table 14. Progesterone content of corpora lutea (mean ± SE)

Group	µg/CL	Source
Brahman heifers	216.9 ± 45.0	Irvin et al. (1978)
Brahman x Hereford heifers	217.7 ± 35.3	Irvin et al. (1978)
Hereford heifers	334.6 ± 87.8	Irvin et al. (1978)
Brahman cows	190.8 ± 28.9	Segerson et al. (1984)
Angus cows	266.3 ± 23.9	Segerson et al. (1984)

Influence of Season

The *Bos indicus* and *Bos indicus* crossbred cows are long day breeders. There are numerous reports in the literature that as day length decreases, reproductive function decreases in *Bos indicus* cattle (Anderson, 1944; Tomar, 1966; Jochle, 1972; Randel, 1984). *Bos indicus* tend to become anestrus during unfavorable seasons (Dale et al., 1959; Tomar, 1966; Plasse et al., 1968a). The frequency of estrus without ovulation also increased in *Bos indicus* females during unfavorable seasons (Luktuke and Subramanian, 1961; Plasse et al., 1970).

Research from our laboratory (Stahringer et al., 1990) supports the literature. Brahman heifers experiencing normal estrous cycles in October experienced a relatively high proportion (88%) of either anestrus or abnormal estrus cycles in November, December, January, and February before returning to normal estrous cyclicity in March (Figure 11). Serum progesterone concentrations were lower ($P < 0.001$) in heifers during November, December, January, and February than in either October or March.

Jochle (1972) reported that conception rates in Brahman cattle were higher during the summer. Data from our laboratory (Neuendorff et al., 1984) show that Brahman females have higher ($P < 0.005$) first service conception rates in the summer (61%) compared with the late fall (36%). This experiment reported results from artificial insemination so that there were no seasonal influences due to the males involved. Season does negatively influence sperm production and ejaculate quality in Bos indicus bulls (Godfrey et al., 1990b). In this report, Brahman bulls had decreased sperm production during the winter compared with the summer and with the Hereford bulls at any time of the year.

Season of birth has been shown to influence age at puberty in bulls (Ararindakshan et al., 2000). In our laboratory, season of birth dramatically influenced age at sexual maturity in Brahman bulls (Tatman et al., 2004). Fall-born bulls were older but body weights were similar compared with spring-born bulls at first sperm (Table 17). Age and weight at puberty did not differ due to season of birth, but age and weight at sexual maturity were greater in fall-born bulls than in spring-born bulls. Scrotal circumference, paired testis volume, and motility in the ejaculate at sexual maturity were all greater in fall-born than in spring-born bulls (Table 18).

Post-puberal development began during the winter in fall-born bulls, which was during the short photoperiod with decreasing environmental temperatures. Perhaps an altered endocrine profile during this unfavorable season delayed reproductive development in the fall-born bulls (Figure 12). Conversely, bulls born in the spring reached this stage of development during the summer months, with longer photoperiods and higher temperatures resulting in unrestricted development.

Production of gametes is also affected by season in the female. Bastidas and Randel (1987) reported that the number of transferable embryos produced per Brahman donor cow was highest in the fall and lowest in the winter (Figure 13). Bos *taurus* breeds have not been reported to be affected by season in production of transferable embryos (Massey and Oden, 1984), yet in this report the authors found that Brahman cows produced the

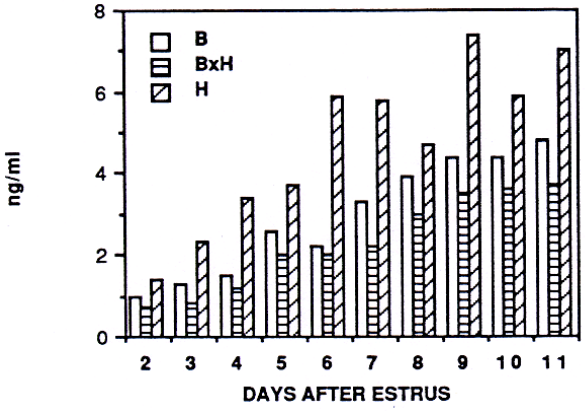


Figure 9. Serum progesterone.

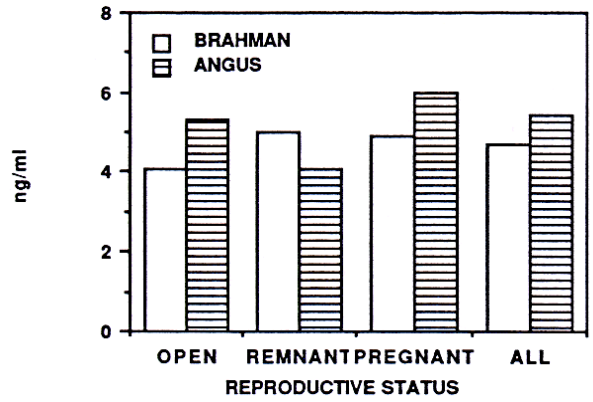


Figure 10. Serum progesterone in mature cows 7-17 days after breeding.

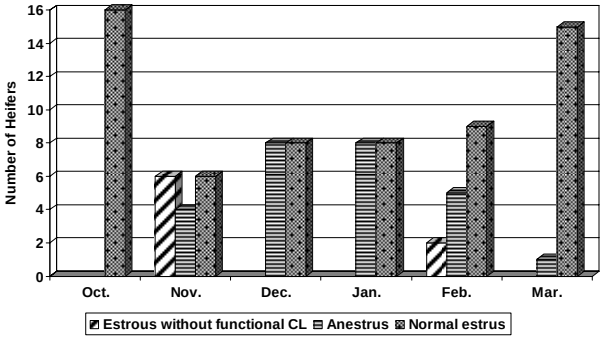


Figure 11. Distribution of the occurrence of normal estrus, estrus without formation of functional CL and anestrus by month in Brahman heifers.

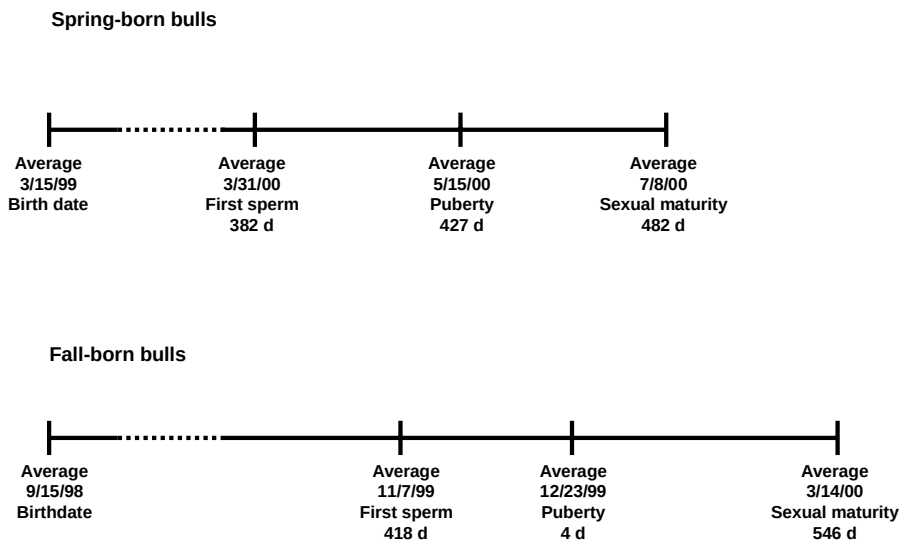


Figure 12. Timeline of sexual development for fall- and spring-born Brahman bulls.

greatest number of embryos in the spring season. Bastidas and Randel (1987) found that pregnancy rates per Brahman donor cow were lower in the winter months (Figure 14). The combination of reduced production of transferable embryos and lower pregnancy rates in the winter months resulted in fewer pregnant recipient cows per Brahman donor cow (Figure 15).

Not all of the fertility data are negative for the *Bos indicus* cattle. High ambient environmental temperatures decrease pregnancy rates in *Bos taurus* cattle (Biggers et al., 1987; Dunlap and Vincent, 1971; Ingraham et al., 1974; Putney et al., 1988; Putney et al., 1989a; Ryan et al., 1992). *Bos taurus* heifers subjected to heat stress during the later stages of oocyte maturation produced fewer embryos to superovulation and had a greater proportion of embryos with retarded development (Putney et al., 1989b).

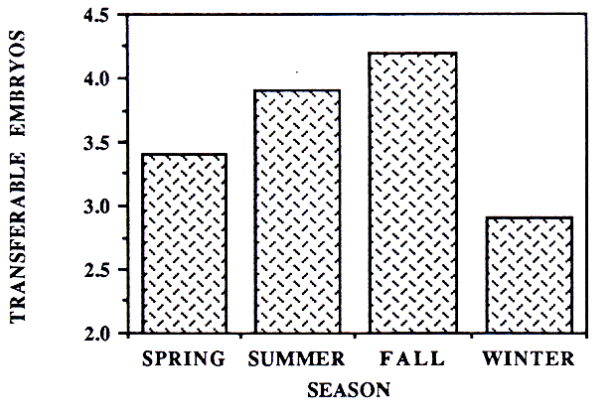


Figure 13. Transferable embryos per Brahman donor cow.

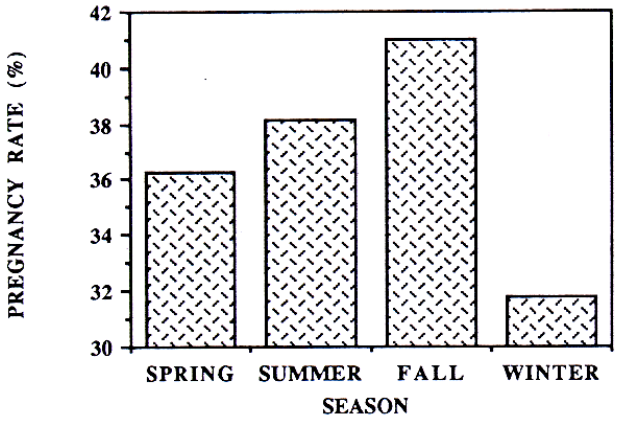


Figure 14. Pregnancy rate per Brahman donor cow.

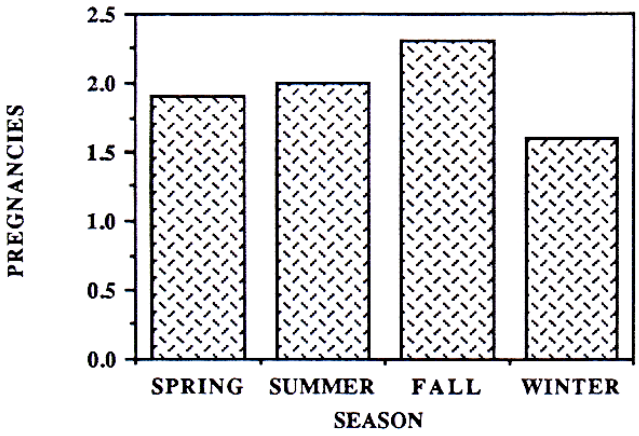


Figure 15. Pregnant recipient cows per Brahman donor cow.

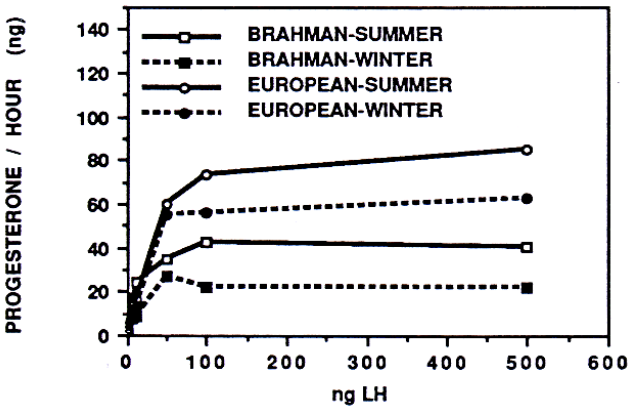


Figure 16. Progesterone secretion by cultured luteal cells.

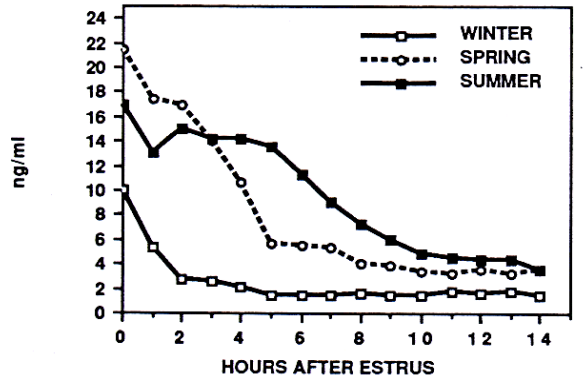


Figure 17. Serum LH in Brahman cows.

An experiment was carried out to determine the effects of environmental temperature and humidity on both Brahman and Holstein oocytes (Rocha et al., 1998). Brahman and Holstein donor cows were treated with follicle stimulating hormone and oocytes were harvested in August and in January. When these oocytes collected in August were fertilized in vitro and incubated through developmental stages allowing for transfer to recipient cows, none of the oocytes from Holstein cows (Table 19) resulted in transferable embryos, but reasonable proportions of Brahman oocytes developed into transferable embryos (Table 20). Brahman cows responded to super stimulation with production of similar numbers and quality of oocytes as in the summer months. It appears that if a Brahman cow is estrous cycling during the winter, she produces high quality oocytes capable of being fertilized and developing into a normal embryo.

In an experiment evaluating the effect of breed and season (Rhodes et al., 1982), Brahman heifers had smaller corpora lutea than *Bos taurus* heifers (Table 21). Both *Bos indicus* and *Bos taurus* corpora lutea that developed in the winter had higher concentrations and content of progesterone than those from the summer. When luteal cells from these corpora lutea were incubated with luteinizing hormone in a culture system, the luteal cells from the Brahman heifers produced less progesterone and were less responsive to luteinizing hormone than cells from *Bos taurus* heifers, and luteal cells collected in the winter were less responsive than those collected in the summer (Figure 16).

A possible explanation for some of the seasonal influences found in *Bos indicus* cattle may be that pituitary function is altered during the winter. Brahman cows have a lower preovulatory luteinizing hormone surge during the winter compared with the spring or summer periods (Harrison et al., 1982; Figure 17).

It is clear from these experiments that season moderates endocrine function to a greater extent in *Bos indicus* cattle than in *Bos taurus* cattle, resulting in suppressed reproductive function in *Bos indicus* cattle during the winter months.

Table 15. Ovarian and stromal weights on day 17 after estrus (mean ± SE)

	Ovarian weight (g)		Stromal weight (g)	
Breed	Active[a]	Inactive[b]	Active	Inactive
Angus	9.2 ± 0.4	4.6 ± 0.3[c]	3.9 ± 0.3[c]	3.6 ± 0.3[c]
Brahman	11.0 ± 1.1	7.9 ± 0.9[d]	6.8 ± 0.9[d]	6.2 ± 0.7[d]

From: Segerson et al. (1984)
[a]Active ovary contains CL.
[b]Inactive ovary does not contain CL.
[c,d]Means in columns with different superscripts differ P < 0.01.

Table 16. Ovarian follicular characteristics on day 17 after estrus (mean ± SE)

	Number of follicles			
Breed	Small (< 5 mm)		Large (> 5 mm)	
	Active[a]	Inactive[b]	Active	Inactive
Angus	22.3 ± 3.4	20.2 ± 0.3	2.3 ± 0.5	1.8 ± 0.5
Brahman	40.8 ± 5.6	37.1 ± 5.3	1.2 ± 0.3	0.9 ± 0.2

From: Segerson et al. (1984).
[a]Active ovary contains CL.
[b]Inactive ovary does not contain CL.

Table 17. Age and body weight of spring- and fall-born Brahman bulls (mean ± SE)

Stage of development	Measurement	Fall-born	Spring-born
First sperm	Age (days)	418.0 ± 13.9[c]	381.9 ± 11.6[d]
	Body weight (lb)	790.0 ± 37.8	765.4 ± 31.7
Puberty	Age (days)	464.0 ± 16.8	426.6 ± 14.1
	Body weight (lb)	873.4 ± 47.7	865.9 ± 39.8
Sexual maturity	Age (days)	545.9 ± 16.5[a]	481.0 ± 13.8[b]
	Body weight (lb)	1,071.8 ± 46.6[c]	978.3 ± 38.9[d]

From: Tatman et al. (2004).
[a,b]Means in rows with different superscripts differ P < 0.05.
[c,d]Means in rows with different superscripts differ P < 0.075.

Table 18. Testicular and semen characteristics at first sperm, puberty, and sexual maturity of fall- and spring-born Brahman bulls

Stage of development	Measurement	Fall-born	Spring-born
First sperm	Scrotal circumference (cm)	25.0 ± 0.9	25.0 ± 0.7
	Paired testis volume (cm^3)	248.0 ± 21.0	231.1 ± 17.6
	Motility (%)	10.0 ± 6.3	13.6 ± 4.8
	Progressive motility score (1-5)	1.25 ± 0.48	0.43 ± 0.37
Puberty	Scrotal circumference (cm)	27.9 ± 0.9	28.0 ± 0.8
	Paired testis volume (cm^3)	350.6 ± 30.2	319.8 ± 25.3
	Motility (%)	37.9 ± 7.1	30.0 ± 6.0
	Progressive motility score (1-5)	2.57 ± 0.39[c]	1.50 ± 0.33[d]
	Normal sperm morphology (%)	53.4 ± 6.2	44.0 ± 5.5
Sexual maturity	Scrotal circumference (cm)	34.2 ± 0.7[c]	31.5 ± 0.6[d]
	Paired testis volume (cm^3)	608.0 ± 32.5[a]	450.8 ± 27.2[b]
	Motility (%)	60.0 ± 6.7[a]	40.5 ± 5.6[b]
	Progressive motility score (1-5)	2.29 ± 0.31	2.10 ± 0.26
	Normal sperm morphology (%)	60.7 ± 5.8	57.7 ± 4.8

From: Tatman et al. (2004).
Rows with different superscripts differ. ([a,b]) P < 0.05; ([c,d]) P < 0.075.

Table 19. Percentage of normal oocytes collected from Holstein cows and embryo development from the 2 cell to the blastocyst stage

		Percentage of	Percentage of Oocytes Developing To[a]			
Season	Total Number of Oocytes	Normal Oocytes	≥ 2-cell (48 h)	≥ 8-cell (96 h)	Morula (144 h)	Blastocyst (192 h)
Cool	67	80.0±19.1[b]	59.8 ± 11.7	44.4 ± 12.7[d]	34.2 ± 12.7[d]	29.0 ± 14.8[d]
Hot	28	24.6±6.3[c]	52.3 ± 10.6	1.1 ± 4.8[e]	0[e]	0[e]

From: Rocha et al. (1998).
[a]Numbers in parentheses indicate the number of hours post insemination. Normal and abnormal oocytes were fertilized.
Means in the same column with different superscripts differ: [bc]P = 0.01; [de]P ≤ 0.003.

Table 20. Percentage of normal oocytes collected from Brahman cows and embryo development from the 2 cell to the blastocyst stage

		Percentage of	Percentage of Oocytes Developing To[a]			
Season	Total Number of Oocytes	Normal Oocytes	≥ 2-cell (48 h)	≥ 8-cell (96 h)	Morula (144 h)	Blastocyst (192 h)
Cool	83	83.3 ± 17.4	83.1 ± 10.7	71.3 ± 11.6	55.5 ± 12.2	52.3 ± 13.5
Hot	89	77.0 ± 6.3	79.3 ± 10.6	69.9 ± 4.8	58.1 ± 4.8	41.3 ± 7.2

From: Rocha et al. (1998).
[a]Numbers in parentheses indicate the number of hours post insemination. Normal and abnormal oocytes were fertilized.

Table 21. Effect of breed and season on CL weight, progesterone (P_4) concentration and progesterone content[a]

	Brahman		Hereford x Holstein	
Measurement	Summer	Winter	Summer	Winter
Weight (g)	2.74 0.10[b]	3.01 0.29[b]	4.58 0.44[c]	5.11 0.49[c]
P_4 concentration (µg/g)	30.8 2.8[d]	52.6 7.8[e]	39.0 7.1[f]	40.4 1.9[f]
P_4 content (µg/CL)	104.0 5.3[g]	153.2 35.9[h]	174.1 35.9[i]	201.9 9.5[j]

[a]From: Rhodes et al. (1982).
[b,c]Means within a row with different superscripts differ P < 0.001.
[d,e,f]Means within a row with different superscripts differ P < 0.10.
[g,h,i,j,k]Means within a row with different superscripts differ P < 0.01.

Summary

Reproductive performance differs in subtle ways in *Bos indicus* cattle compared with *Bos taurus* cattle. Developmental differences are apparent during the pubertal process in both males and females. Reproductive endocrinology is similar between *Bos indicus* and *Bos taurus* in that the mechanisms are the same, yet nuances of timing are different around estrus and ovulation in the female. Reproductive efficiency, as measured by first service conception rates, is similar in *Bos indicus* and *Bos taurus* cattle. In fact, summer reproductive efficiency may be superior in Bos indicus compared with *Bos taurus* males and females. During the winter months *Bos indicus* cattle have marked decreases in reproductive efficiency compared with *Bos taurus*. In most reproductive traits, *Bos indicus* x *Bos taurus* animals are superior to the mean of the parents or not different from the superior parent breed type.

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Birth to Harvest Attributes of Brahman and Brahman-influenced Steers

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ABSTRACT: Data from 11 pasture and feedlot experiments conducted during a 19-yr period and utilizing more than 1,000 animals are presented for Brahman and Brahman-influenced steers. Brahman, F_1 British x Brahman, and 25% Brahman steers were used in multi-year experiments to quantify birth-to-harvest growth at the Texas Agricultural Experiment Station (TAES) at Overton, TX. Brahman dams were mated to Brahman (BRM), Angus (ANG), and Tuli (TUL) sires as a component of a 2-yr multi-state, collaborative project to assess genotype x environment interactions with tropically adapted beef breeds. Birthweight of BRM males at 77 lb was greater ($P <$ 0.001) than that of F_1 ANG x BRM at 70 lb or TUL x BRM at 66 lb. Weaning weight and ADG from birth-to-weaning was greater for ANG x BRM than BRM and TUL x BRM. Post-weaning gains evaluated at both TAES-Overton and USDA/ARS-El Reno, OK, on winter pasture were different among all breed types, with ANG x BRM at 2.40 lb/d, TUL x BRM at 1.96 lb/d, and BRM at 1.72 lb/d. Two-year, pasture ADG were greater at El Reno at 2.44 lb/d compared to Overton at 1.95 lb/d. Feedlot ADG at Hereford, TX, was similar for both years and locations at 3 lb/d, with ANG x BRM gaining more at 3.4 lb/d than both BRM at 2.9 lb/d and TUL x BRM at 2.6 lb/d. Brahman steers were less tender than the other breed types. Other multi-year, post-weaning experiments on rye-ryegrass at TAES-Overton resulted in average gains of 2.6 lb/d for both ANG x BRM and 25% BRM, Continental-sired steers, and 2 lb/d for BRM steers when pastures were grazed at medium to low stocking rates. During several experiments on Coastal bermudagrass, fall-born F_1 Hereford x Brahman and 25% BRM, Continental-sired steers gained 1.8 and 0.9 lb/d, respectively; whereas, winter-born yearling BRM steers gained 1.6 lb/d. Averaged over several experiments, F_1 British x Brahman steers had similar feedlot ADG and carcass traits as 25% BRM, Continental-sired steers, and both breed types exceeded performance traits of BRM steers. Both BRM and F_1 British x Brahman steers have industry acceptable birth-to-harvest attributes and have established standards for production from tropically adapted beef in specific environmental regions.

Key Words: Brahman, Growth, Pasture, Steers, Tropically Adapted Beef

Introduction

Brahman and Brahman-influenced cattle have long been the breed-type-of-choice in states bordering the Gulf of Mexico. This environmental region is characterized by mild winters, hot and humid summers, and warm-season perennial grass-based pastures. Hence, the environment constraints include climate and pastures that are categorized with the lowest nutritive density rating among classes of forages. The Brahman and Brahman crossbred breed types have been sustainable under these stressful conditions because of their adaptive traits (Koger, 1963). Commercial crossbreeding using Brahmans has had a major impact on beef production (Franke, 1980; Turner, 1980), and the resultant hybrid vigor of F_1 Brahman x *Bos taurus* cattle has been documented (Cartwright et al., 1964) and incorporated into merchandizing activities. Commercial management goals and objectives may include an array of factors; however, production and positive economic returns are usually high priority. Holloway et al., 1995, suggested that attainment of these goals may be optimized when cattle fit both the environmental and market niches. Nutritional constraints and opportunities to enhance growth rate of Brahman and Brahman-influenced steers under southern U.S. environmental conditions were the primary objectives of several experiments conducted at TAES-Overton and cooperator locations. The emphasis of this report was to provide summary information for future commercial, management systems or experimentation, and includes birth-to-harvest attributes of Brahman and Brahman-influenced steers. The objective of this report was to summarize data from several experiments conducted at TAES-Overton using Brahman, F_1 Brahman x *Bos taurus*, and other selected breed types with about 25% Brahman influence.

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Genotype x Environment

Comparisons of birth and weaning weights using tropically adapted sire breeds of Brahman, Tuli, Boran, and Senepol, and non-Brahman, *Bos taurus* dam types were summarized by Herring et al. (2005). The TAES-Overton location was the only site that used Brahman dams. During a 2-yr period (1992 and 1993), 242 calves were born from February to May to Brahman dams when artificially inseminated to 14 Angus, 18 Brahman, and 9 Tuli sires (Browning et al., 1995). Steers from these matings (n=102), in addition to Simmental x [Hereford x Brahman] (SIMX) steers (n=47), were compared for birth and weaning weight attributes (Tables 1-2). Although the SIMX male calves tended to be heaviest at birth, there was no significant difference in birth weight between them and Brahman (BRM) males. However, both SIMX and BRM males were heavier at birth than F_1 [Angus x Brahman] (AxB) and [Tuli x Brahman] (TxB) males. Table 2 shows actual, non-adjusted weaning weights for the older SIMX steers to be heavier than all other breed types and AxB steers heavier than both BRM and TxB. Browning et al (1995) showed similar trends; however, 205-d adjusted weights showed no difference in weaning weight between AxB and BRM and no difference between BRM and TxB. Table 2 shows ADG from birth-to-weaning to be similar for SIMX and AxB at about 2.1 lb/d and greater than both BRM and TxB at about 1.8 lb/d. Weaning weights of steers from three sire breeds and Brahman cows appear to be intermediate, with most locations presented by Herring et al. (2005).

In each year of the 2-yr experiment, the four steer breed types were fall weaned (mid-October), backgrounded at TAES-Overton for about 45 d, paired by weight-age within breed type, and assigned to winter pasture grazing at two locations. Grazing locations were TAES-Overton and USDA/ARS – El Reno, OK (Rouquette et al., 1996c). Winter pastures at Overton were rye-ryegrass and, at El Reno, were wheat. Both were each grazed from early December to mid-May each year. The 2-yr overall location ADG showed similar pasture performance for SIMX and AxB at nearly 2.5 lb/d. These ADG were greater than TxB at about 2 lb/d, and all were higher than

Table 1. Birth and weaning weight of four breedtypes of males calved from February to early May in 1992 and 1993

Breedtype				Males		
Dam	Sire	Steer	n	Birth Weight,[1] (lb)	Weaning	
					Weight[1], (lb)	Age, d
F-1 (HxB)	Simmental	SIMX	47	82 a[2]	557 a[2]	230
Brahman	Angus	AxB	35	70 b	460 b	191
Brahman	Brahman	BxB	30	77 a	400 c	184
Brahman	Tuli	TxB	37	66 b	388 c	179

[1]Least square means.
[2]Numbers in a column followed by a different letter, differ at $P < 0.0001$.

Table 2. Average daily gain (ADG) of four breedtypes of steer calves from birth to weaning during 1992-93 and 1993-94

Steer Breedtype[1]	n	Weaning Age (days)	ADG[2] (lb/d)
SIMX	47	230	2.08 a[3]
AxB	35	191	2.09 a
BxB	30	184	1.82 b
TxB	37	179	1.75 b

[1]Simmental x (Hereford x Brahman), Angus x Brahman, Brahman x Brahman, and Tuli x Brahman.
[2]Least square means.
[3]Numbers in a column followed by a different letter, differ at $P < 0.05$.

Table 3. Two-yr average daily gain of four breedtypes of weaned steers grazing cool-season annual grass pastures at either Overton, TX, or El Reno, OK, from December to mid-May

Steer Breedtype[1]	Average Daily Gain[2] (lb/d) Wintering Location				
	Overton, TX		El Reno, OK		2-Yr AVG
	YR 1	YR 2	YR 1	YR 2	
SIMX	2.72 a[3]	1.76 a	2.70 a	2.89 a	2.52 a
AxB	2.63 a	1.68 a	2.56 a	2.75 a	2.40 a
BxB	2.02 b	0.89 c	1.83 c	2.16 b	1.72 c
TxB	2.19 b	1.39 b	2.11 b	2.14 b	1.96 b

[1]Simmental x (Hereford x Brahman), Angus x Brahman, Brahman x Brahman, and Tuli x Brahman.
[2]Least square means.
[3]Numbers in a column followed by a different letter, differ at $P < 0.01$.

BRM at about 1.7 lb/d (Table 3). Location and year effects reflected gain responses to climatic impact on forage growth. For example, in yr 2 at TAES-Overton, climate and stocking rate resulted in dramatic reductions in ADG of all breed types. However, with average climatic conditions and adequate forage available, ADG of both SIMX and AxB steers were similar and approached 2.75 lb/d; whereas, BRM and TxB steers had ADG of about 2.1 lb/d. Winter pasture ADG was greater in yr 1 and on wheat pastures in El Reno, primarily because of reduced forage availability and cold weather in yr 2 at TAES-Overton (Table 4). At termination of winter pasture grazing each year in mid-May, all steers were transported to a commercial feedlot in Hereford, TX, and fed during the summer in separate pens by breed type and location (8 pens each year) (Rouquette et al., 1996b). Across all breed types, feedlot ADG was similar for both locations and both years at about 3 lb/d. Feedlot ADG, however, was similar for AxB and SIMX, respectively at 3.37 and 3.15 lb/d, and both breed types had higher ADG than BRM at 2.87 and TxB at 2.6 lb/d (Table 5). Although SIMX steers were about 40 days older and 60 lb heavier than AxB steers, both had lifetime weight per day of age at about 2.4 lb/d. The AxB steers were about 275 lb heavier at harvest compared to both BRM and TxB steers. Weight per day of age

Table 4. Two-year average daily gain on winter pasture and feedlot for four breedtypes pastured at two locations

Item	Average Daily Gain[1]	
	Winter Pasture	Feedlot
Grazing Location	(lb/d)	
Overton, TX	1.95 b[2]	3.09 a
El Reno, OK	2.44 a	2.93 a
Year		
1	2.39 a	3.06 a
2	1.97 b	2.96 a

[1]Least square means.
[2]Numbers in a column and within an item grouping, and followed by a different letter, differ at $P < 0.0001$.

Table 5. Feedlot average daily gain (ADG) of four breedtype of steers following winter pasture grazing at Overton, TX, and El Reno, OK

Steer Breed Type[1]	n	Harvest[2]			
		Feedlot ADG	Weight	Age	Weight/day Age
		(lb/d)	(lb)	(d)	(lb/d)
SIMX	47	3.15 a[3]	1,416 a	596 a	2.38 a
AxB	35	3.37 a	1,354 b	556 b	2.44 a
BxB	30	2.87 b	1,077 c	534 c	2.02 b
TxB	37	2.60 b	1,097 c	551 b	1.99 b

[1]Simmental x (Hereford x Brahman), Angus x Brahman, Brahman x Brahman, and Tuli x Brahman.
[2]Least Square Means.
[3]Numbers in a column followed by a different letter, differ at $P < 0.0001$.

was similar for both BRM and TxB at 2 lb/d. Table 6 shows feedlot x breedtype performance traits for combined locations in yr 1, and separate winter pasture locations in yr 2. Dry matter feed:gain ratios were very acceptable for all cattle and especially the tropically adapted breedtypes at about 5:1. Intake as a percentage of BW was greatest for SIMX at nearly 2.5%, and about 2% for the other breedtypes. In yr 2, cattle grazed at Overton had reduced pasture gains and required 160 d on feed compared to steers grazed at El Reno, OK that required 132 d to reach harvest conditions.

Birth-to-harvest growth and body weights are shown for both grazing locations in yr 1 (Figure 1). This illustration clearly depicts the similarities in growth from birth through winter pasture for SIMX and AxB, and for BRM and TxB. However, during the feedlot phase, there were growth differences that favored AxB vs. SIMX and BRM vs. TxB (Figure 1, Table 6). Paschal et al (1995) showed the growth rate advantage for F_1 calves, using an array of *Bos indicus* breeds. Growth from birth-to-harvest in yr 2 and grazing at TAES-Overton shows similar AxB vs. SIMX responses; however, the BRM steers never exhibited compensatory growth trends (Figure 2). The BRM and TxB growth on wheat pastures at USDA/ARS El Reno was similar for yr 1 and 2 (Figure 3). However, growth rate in yr 2 for both AxB and SIMX steers at El Reno were identical (Figure 3).

Carcass attributes for the four breedtypes (Rouquette et al., 1996a) during the 2-yr experiment showed expected hot carcass weight differences for SIMX (889 lb), AxB (848 lb), BRM (672 lb), and TxB (685 lb) (Table 7). The targeted, visual backfat of 0.4-inch was achieved only by AxB steers at 0.48-inch. The SIMX and TxB had less fat at harvest at about 0.35-inches; however, all breedtypes had more backfat than BRM at 0.25-inches. Under controlled feeding conditions, more uniform backfat may have been attained. Table 6 also shows the influence of

Figure 1. Weights from birth to harvest for Simmental crossbred (SIMX), Angus x Brahman (AxB), Tuli x Brahman (TxB), and Brahman x Brahman (BxB) steers grazed post-weaning on winter pasture at two locations and fed at Hereford, TX. Year 1(93-94).

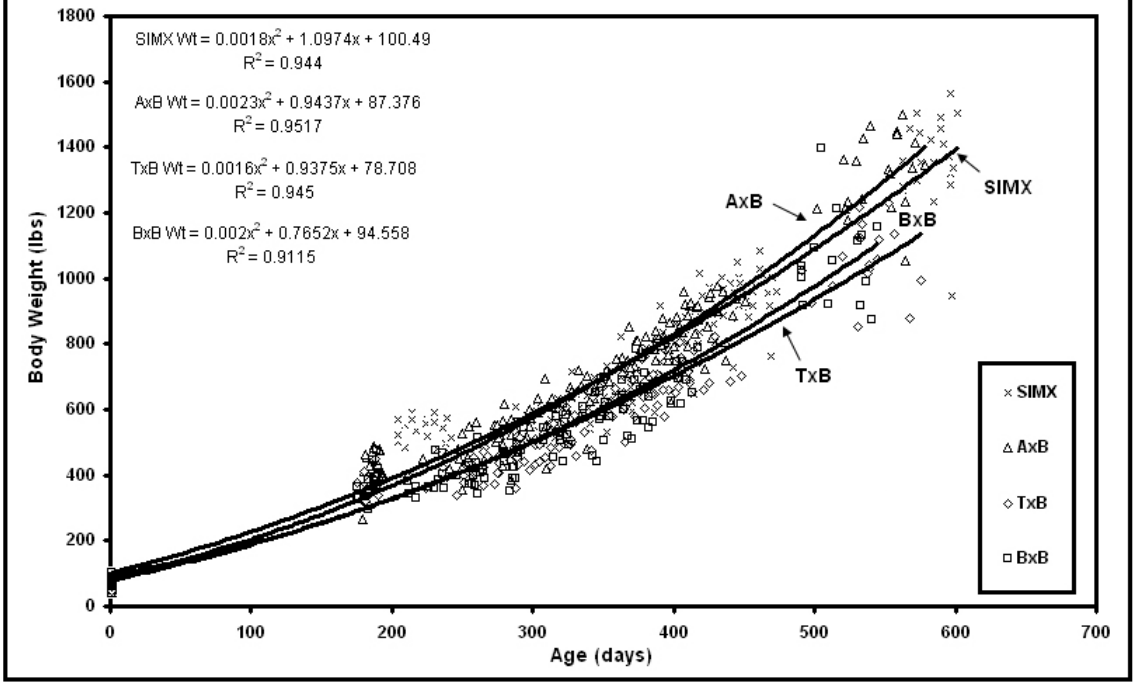


Figure 2. Weights from birth to harvest for Simmental crossbred (SIMX), Angus x Brahman (AxB), Tuli x Brahman (TxB), and Brahman x Brahman (BxB) steers born and grazed on rye-ryegrass pasture at Overton, TX, and fed at Hereford, TX, in Year 2 (94-95).

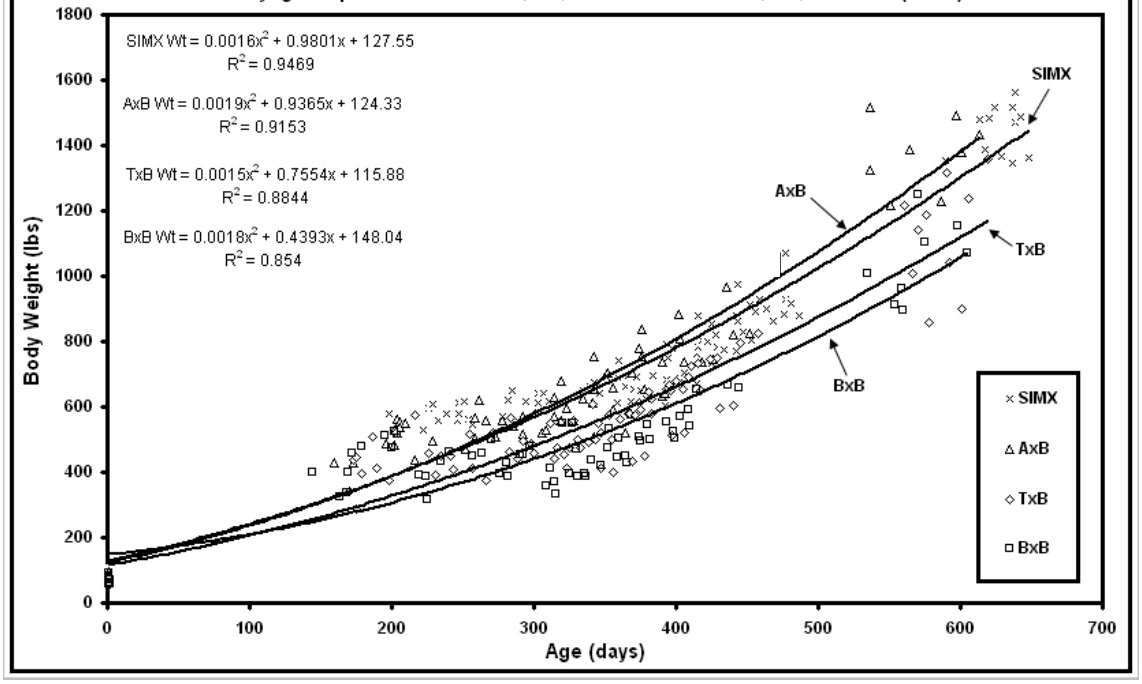


Table 6. Feedlot performance of four breed types of steers pastured at two locations

Year	Item	Breed types[1] from both locations			
		SIMX	**AxB**	**BxB**	**TxB**
1	Feedlot Arrival Wt. (lb)	938	863	663	716
1	Final Pay Wt. (lb)	1360	1317	1056	1055
1	Days on Feed	126	126	126	126
1	Total Gain (lb)	459	487	417	366
1	Ave Daily Gain (lb/d)	3.63	3.85	3.30	2.90
1	Feed:Gain (dry)	7.3:1	5.7:1	4.1:1	5.1:1
1	Ave Consumption (lb/d)	33.5	27.6	17.1	18.7
1	Ave Daily Intake (% BW)	2.91	2.53	1.99	2.11
		Breed types grazed at Overton			
		SIMX	**AxB**	**BxB**	**TxB**
2	Feedlot Arrival Wt. (lb)	886	794	559	681
2	Final Pay Wt. (lb)	1,443	1,372	1,045	1,127
2	Days on Feed	160	160	160	160
2	Total Gain (lb)	583	600	502	466
2	Ave Daily Gain (lb/d)	3.64	3.75	3.14	2.91
2	Feed:Gain (dry)	6.5:1	4.7:1	4.3:1	4.3:1
2	Ave Consumption (lb/d)	29.8	22.3	17.0	15.8
2	Ave Daily Intake (% BW)	2.56	2.06	2.12	1.75
		Breed types grazed at El Reno, OK			
		SIMX	**AxB**	**BxB**	**TxB**
2	Feedlot Arrival Wt. (lb)	1,079	984	794	795
2	Final Pay Wt. (lb)	1,496	1,411	1,156	1,150
2	Days on Feed	132	132	132	132
2	Total Gain	449	456	385	378
2	Ave Daily Gain (lb/d)	3.40	3.46	2.92	2.87
2	Feed:Gain (dry)	6.7:1	4.5:1	4.8:1	5.1:1
2	Ave Consumption (lb/d)	28.4	19.7	17.4	18.2
2	Ave Daily Intake (%BW)	2.20	1.65	1.78	1.87

[1]Simmental x (Hereford x Brahman), Angus x Brahman, Brahman x Brahman, and Tuli x Brahman.

commercial feedlot marketing conditions including lot-size and truckload scenarios; hence, days on feed were constant for both locations in yr 1, and varied, but were uniform for location, in yr 2. Ribeye area was greatest for both SIMX and AxB at nearly 14 in^2, intermediate for TxB at 12.3 in^2, and least for BRM at 11.4 in^2 (Table 7). Others have shown no difference in ribeye area between Brahman- and Tuli-sired steers (Herring et al., 1996; Ferrell and Jenkins, 1998). Percent KPH was similar for all breed types at about 2.2%, and USDA Yield Grades favored BRM and TxB at about 2.45 compared to AxB at 3.1 and SIMX at 2.8. Marbling scores were predictably higher for AxB, intermediate for SIMX and TxB, and least for BxB. The average marbling scores for all breed types was nearly at USDA Choice minus for AxB, but mid-range USDA Select for the other three breed types. Results from this 2-yr experiment were in agreement with Franke (1997) in that the Tuli crossbred steers provided no distinct growth or carcass trait advantages over Brahman.

Table 7. Carcass attributes of four breed types of steers during two year experiment

	Breedtypes[1]			
Carcass Traits	**SIMX**	**AxB**	**BxB**	**TxB**
Hot Carcass Weight (lb)	889a[2]	848b	672c	685c
Back Fat (in)	0.37b	0.48a	0.25c	0.33b
Ribeye Area (in^2)	14.0a	13.5a	11.4c	12.3b
KPH (%)	2.24a	2.27a	2.18a	2.23a
Yield Grade	2.78a	3.06a	2.47b	2.44b
Marbling[3]	366b	392a	342c	367b
Crest Score[4]	1.74	2.2	4.4	3.2

[1]Least square means for Simmental x (Hereford x Brahman), Angus x Brahman, Brahman x Brahman, and Tuli x Brahman.
[2]Numbers in a row, followed by different letters, differ at $P < 0.01$.
[3]Marbling scores of 300 to 399 are USDA Select.
[4]Crest score, 1 = none; 5 = severe

During the 2-yr experiment, 139 steers were evaluated for shear values and sensory traits of juiciness and tenderness (Rouquette et al., 1996d). Winter pasture grazing location did not affect shear or

Figure 3. Weights from birth to harvest for Simmental crossbred (SIMX), Angus x Brahman (AxB), Tuli x Brahman (TxB), and Brahman x Brahman (BxB) steers born at Overton, grazed wheat pasture at El Reno, OK, and fed at Hereford, TX, during Year 2 (94-95).

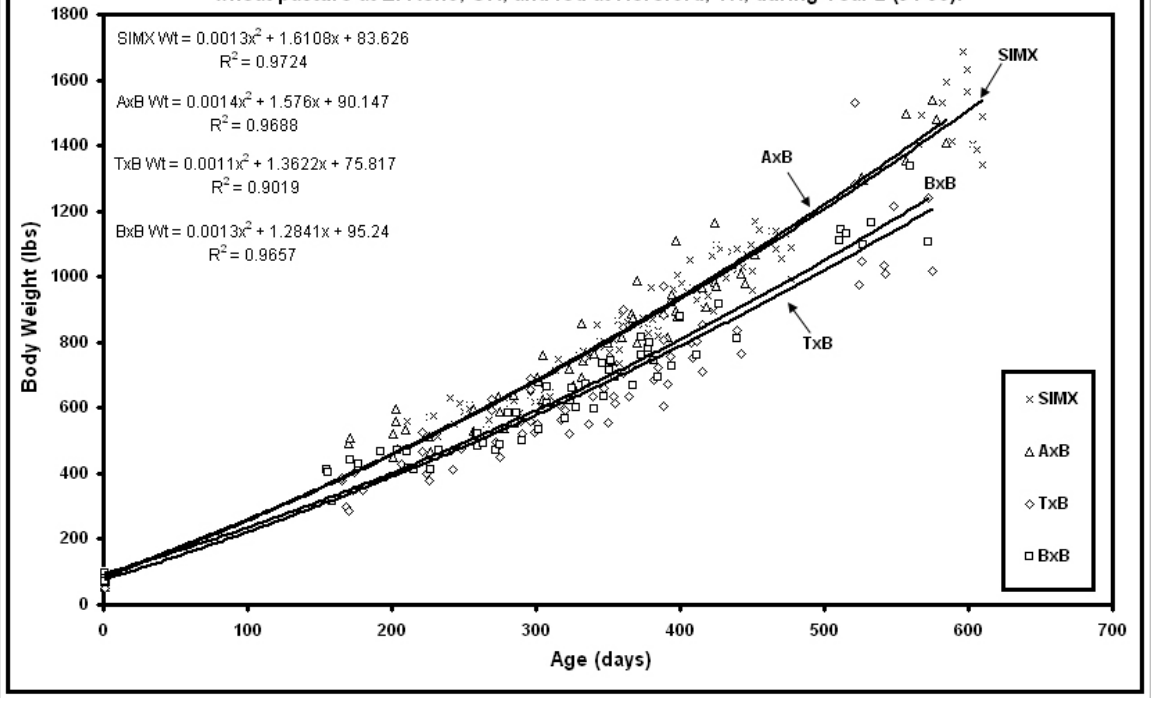
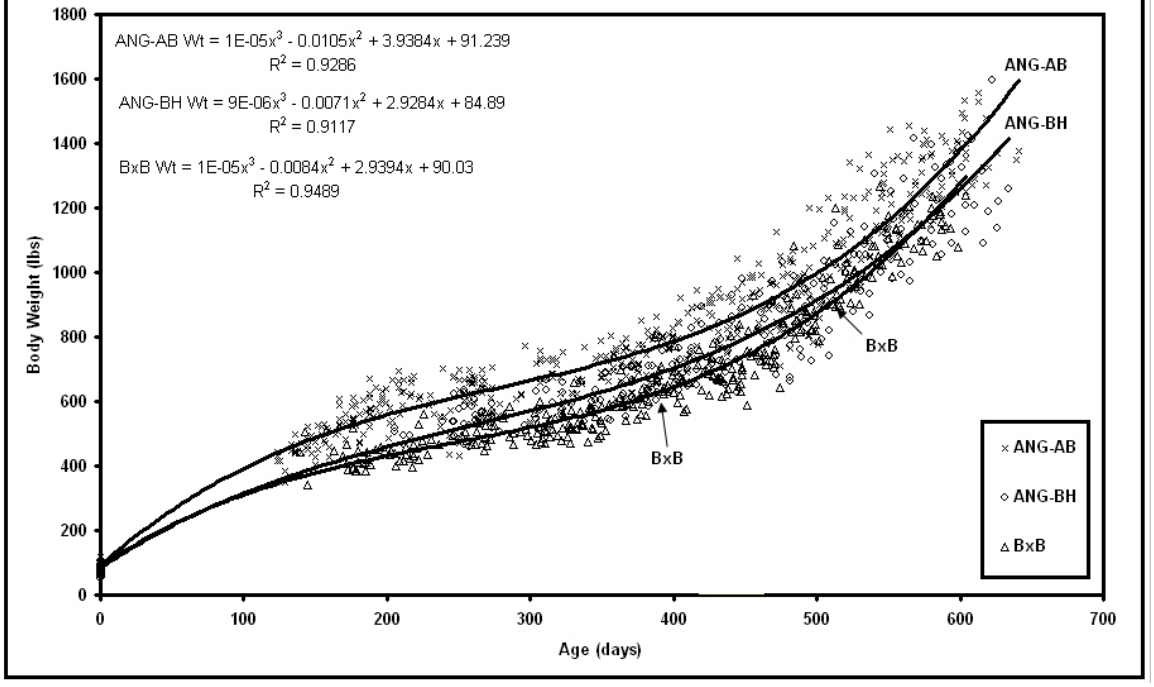


Figure 4. Birth-to-harvest weights for Angus x [Angus x Brahman] (ANG-AB), Angus x [Brahman x Hereford] (ANG-BH) and Brahman (BxB) steers grazed on rye-ryegrass post-weaning.



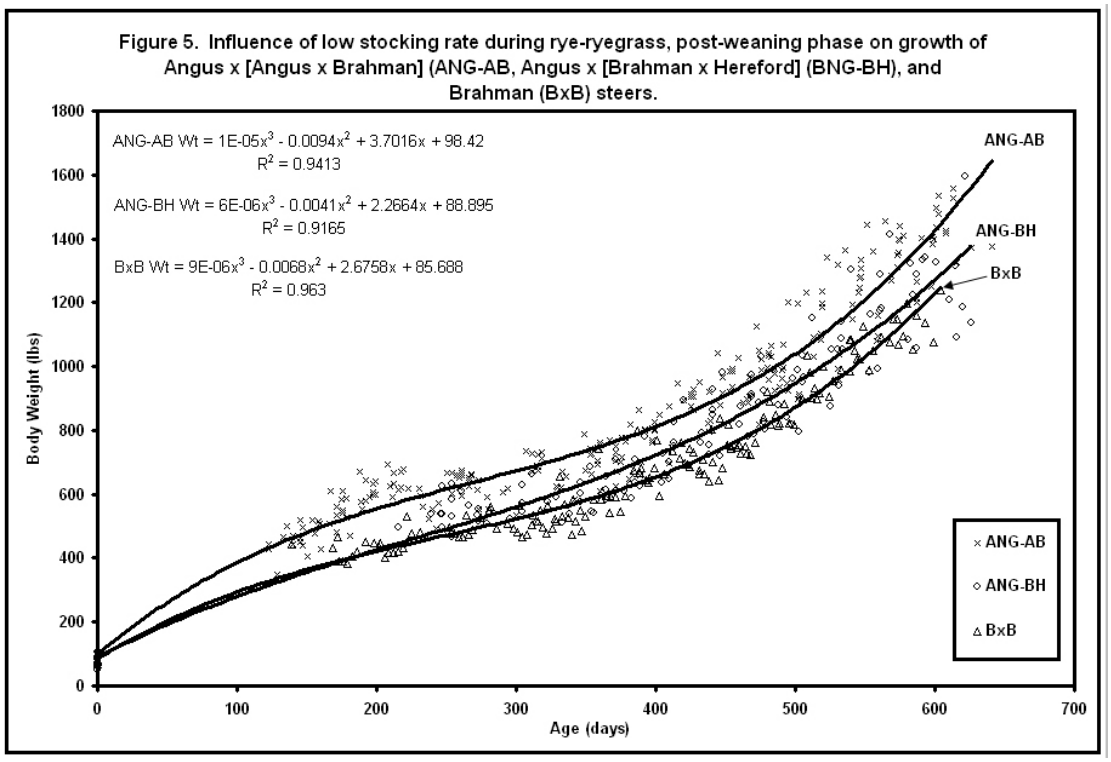


Figure 5. Influence of low stocking rate during rye-ryegrass, post-weaning phase on growth of Angus x [Angus x Brahman] (ANG-AB, Angus x [Brahman x Hereford] (BNG-BH), and Brahman (BxB) steers.

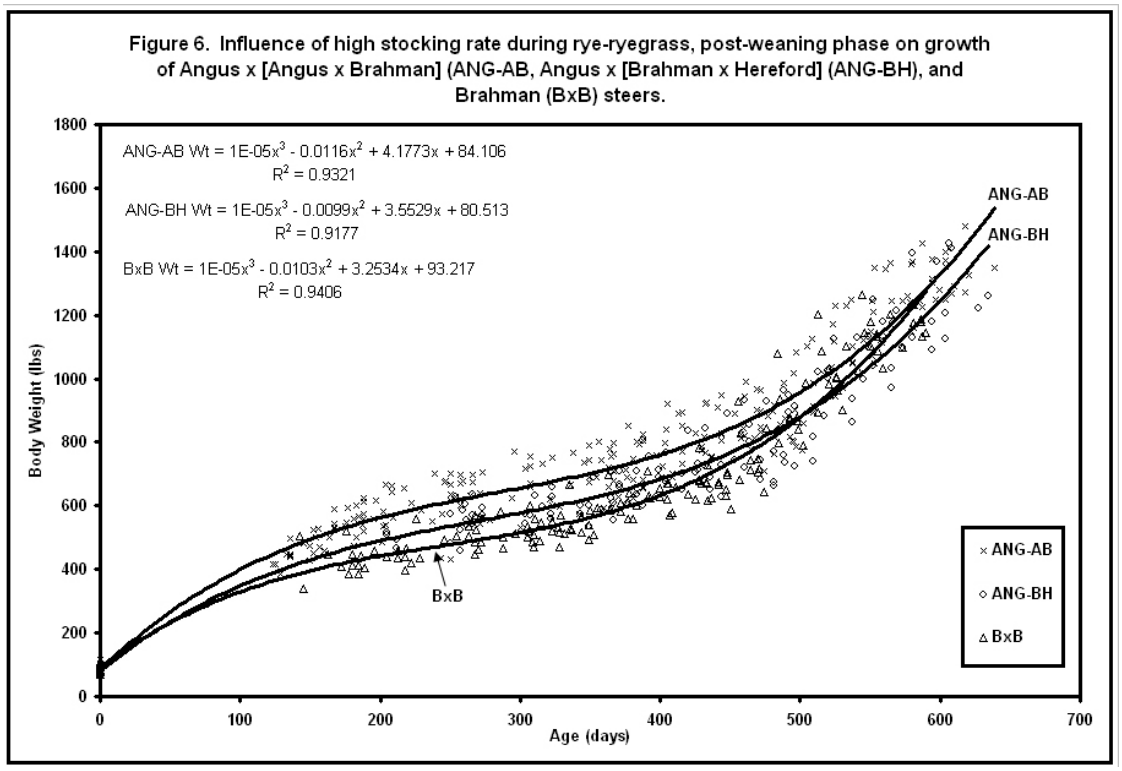


Figure 6. Influence of high stocking rate during rye-ryegrass, post-weaning phase on growth of Angus x [Angus x Brahman] (ANG-AB, Angus x [Brahman x Hereford] (ANG-BH), and Brahman (BxB) steers.

the sensory traits (Table 8). Both juiciness and tenderness were more desirable from steers in yr 2 compared to yr 1. Shear values showed an opposite trend with potentially less tender steaks in yr 2. More than likely, shear values from the BRM steers in yr 2 contributed to these differences. Breed type shear values were similar at about 8 lb for SIMX, AxB, and TxB; however, BRM shear values were higher than we anticipated at more than 10 lb. From a sensory evaluation, there were some minor differences in rankings of juiciness and tenderness; however, all breed types received a slightly above-average rating on a 1-8 scoring basis. The BRM steers were less tender than the other three breed types (Table 8).

Table 8. Selected sensory traits of four breedtypes of steers grazed at Overton, TX, and El Reno, OK, during each of two years

		Sensory Traits[1]		
Item	**n**	**Shear[2]**	**Juiciness[3]**	**Tenderness[4]**
		(lb)		
Year				
1	66	7.83 b	4.80 b	5.61 b
2	73	8.85 a	5.48 a	6.05 a
Grazing Location				
Overton	72	8.41 a	5.06 a	5.82 a
El Reno	67	8.3 a	5.26 a	5.86 a
Breed Types				
SIMX	46	7.87 b	5.36 a	6.01 a
AxB	35	8.14 b	4.91 c	5.79 a
BxB	21	10.26 a	4.96 bc	5.32 b
TxB	37	8.12 b	5.27 ab	5.97 a

[1]Least Square Means.
[2]Shear force measured via Warner-Bratzler.
[3]Juciness, 8 = extremely juicy, 1 = extremely dry.
[4]Tenderness, 8 = extremely tender, 1 = extremely tough.

Birth-to-Harvest Growth

A post-weaning stocking rate x stocking method experiment included Angus-sired steers from Angus x Brahman (AAB) and Hereford x Brahman (ABH) dams, and BRM steers (Rouquette et al., 2002). Winter- and spring-born steers were weaned in early October and backgrounded for about 60 d on bermudagrass pasture and/or hay plus 2 lb/hd/d of a 24% protein supplement fed five times per week. Steers grazed rye-ryegrass pastures from about mid December to mid May. Birth-to-harvest growth of the three breed types showed that the AAB steers had faster ADG throughout the pre-weaning and post-weaning pasture phase (Figure 4). The AxB dams were heifer mates to steers sired in 1992 and 1993. These original Angus sires were selected for growth rate; hence, it was not surprising that these dams produced calves that exhibited the fastest growth overall. Of particular interest was growth of the three breed types when grazing winter pasture at low stocking rates (Figure 5) in which forage availability was approximately 2000 lb forage DM/ac vs. high stocking rates (Figure 6) in which forage available for consumption approximated 750 lb DM/ac. At low stocking rates, there was distinct separation of breed types, with AAB having highest ADG and BRM the lowest ADG. At the termination of winter pasture grazing, all cattle were transported to the Texas Tech University Alltech Research feedlot in Lubbock and assigned to pens of 4-7 head according to breed type (Cleere et al., 2002a). At initiation of feeding, both AAB and ABH were heavier than BRM steers (Table 9). Feedlot ADG during the summer months was different for all three breed types, with AAB at 4.21 lb/d, ABH at 3.81 lb/d, and BRM at 3.46 lb/d. The BRM steers that grazed rye-ryegrass at high stocking rates appeared to make compensating feedlot gains. Feed:gain ratios were similar for all at about 6.5:1. Hot carcass weights were different for all three breed types since final feedlot weights were also different (Cleere et al., 2002b) (Table 10). All breed types met or exceeded the 0.5-inch backfat since harvest was based on ultrasound data. Ribeye area was smaller for BRM compared to both Angus-sired steer groups. Marbling was highest for ABH steers at USDA Choice, whereas both AAB and BRM steers graded USDA Choice minus. The slightly "over-finished" AAB steers with 0.7-inch backfat had a USDA Yield Grade of 4.0. Even with carcass discounts for yield grade, the AAB exhibited the highest gross returns due to growth rate and hot carcass weight. These steers had gross returns of about $175 more per head than the BRM steers (Table 10).

Table 9. Influence of breed types across winter pasture stocking rates on subsequent feedlot performance of steers

BREED TYPE[1]	INITIAL WT (lb)	FINAL WT (lb)	ADG (lb/d)	DAYS ON FEED (d)	FEED:GAIN
AAB	857 a[2]	1,375 a[2]	4.21 a[2]	132	6.74
ABH	749 a	1,218 b	3.81 b	132	6.55
BRM	671 b	1,151 c	3.46 c	113	6.45

[1]AAB = Angus x (Angus x Brahman); AHB = Angus x (Brahman x Hereford); BRM = Brahman x Brahman.
[2]Means followed by different letters within a column are different ($P < 0.05$).

Table 10. Carcass traits of three breed types of steers

BREED TYPE	HCW (lb)	REA (in^2)	MARB[3]	FAT (in)	YG	GRID PRICE $/cwt	VALUE $/hd
AAB	834 a[2]	12.3 a	489 b	0.71 a	4.0 a	104.67 ab	872.82 a
ABH	750 b	12.2 a	549 a	0.68 a	3.6 b	107.20 a	804.93 b
BRM	689 c	10.6 b	466 b	0.56 b	3.6 b	101.54 b	700.53 c

[1]AAB = Angus x (Angus x Brahman); AHB = Angus x (Brahman x Hereford); BRM = Brahman x Brahman.
[2]Means followed by different letters within a column are different ($P < 0.05$).
[3]Marbling (MARB) scores of 400 to 499 are USDA Choice minus; scores of 500 to 599 are USDA Choice.

Interest in effects of gain on pasture on subsequent feedlot performance as well as season of feedlot residence were determined in an experiment which evaluated fall-born compared to spring-born BRM steers (Rouquette et al., 1990). Fall-born steers grazed bermudagrass post-weaning and gained 1.17 lb/d, and were transported to TAES-Amarillo at approximately 365 days of age (Table 11). Spring-born BRM steers grazed rye-ryegrass post-weaning and gained 2.18 lb/d, and were transported to TAES-Amarillo at approximately 395 d of age. All steers were fed in Pinpointers for individual intake measurements. The effect of low temperatures during the winter feeding period reduced feedlot ADG to 1.85 lb/d, whereas, spring-born, summer- and fall-fed steers gained 2.82 lb/d. Feed:gain ratios also favored the summer-fed steers at 5.8:1 compared to winter-fed steers at 8.3:1. Steers from both seasons were combined and allotted to one of three Relative Gain Codes. Resultant codes of 1-3 had respective mean pasture ADG of 1.25 (1), 1.65 (2), and 2.09 lb/d (3) (Table 12). In general, as pasture gain increased, feedlot gains increased. However, this was likely confounded due to the winter pasture ADG and subsequent summer-fall feeding period. The

Table 11. Stocker performance of fall-born and spring-born Brahman steers fed at two different seasons in Amarillo, TX

Season of birth	Fall	Spring
Season of stockering	Summer	Winter
Forage for stocker	Bermudagrass	Rye-ryegrass
On-pasture weight, lb	520	436
Off-pasture weight, lb	620	656
Days on test	85	102
ADG on pasture, lb/d	1.17 a[1]	2.18 b
Season in feedlot	Winter-Spring	Summer-Fall
Age entering feedlot (d)	365	395
On-feedlot weight, lb	648	612
Off-feedlot weight, lb	948	1,068
Total gain, lb	300	456
Days on feed	162	159
ADG, lb/dy	1.85 a	2.82 b
Total feed consumption, lb/h	2,481	2,455
Avg. daily feed consumption, lb/d	16.1	15.0
Avg. feed consumption, % BW	2.02	1.79
Feed:gain ratio	8.3:1 a	5.8:1 b

[1]Means within a row followed by a different letter, differ ($P < 0.001$).

Table 12. Compensatory gain assessment of Brahman steers using a relative gain coding method

	Relative Gain Code		
Item	**1**	**2**	**3**
Mean ADG on pasture as stockers, lb/d	1.25[a]	1.65[b]	2.09[c]
Feedlot ADG, lb/d	2.16[e]	2.27[ef]	2.55[f]
Avg. daily feed consumption, lb/d	14.8[e]	15.4[ef]	16.3[f]
Feed:Gain ratio	7.2:1	7.2:1	6.6:1

[a,b,c]Means within a row followed by a different letter, differ ($P < 0.001$)
[e,f]Means within a row differ ($P < 0.05$)

Pinpointer data showed that steers with the highest feedlot ADG also consumed the most feed, but tended to have better feed:gain ratios. Steers were fed for about 160 days and were harvested at about 18 months of age. Both groups of steers had less backfat than the targeted 0.4-inch. This may be attributed to management's failure to accurately appraise visual backfat for this phenotype of steer, which is different from *Bos taurus* steers (Table 13). Carcass traits were relatively uniform for both calving seasons of BRM steers, with USDA Yield Grades at about 2.3 and USDA Quality Grades of Select.

A 2-yr experiment evaluated post-weaning performance of three breed types of steers grazing rye-ryegrass at three stocking rates and two stocking methods (Rouquette et al., 2000). The same cows that were bred to Angus bulls (Figures 4-6) were bred to Simmental bulls. The three winter- and spring-born steer breed types were AxB, Simmental x [Angus x Brahman] (SIM-AB) and Simmental x [Brahman x Hereford] (SIM-BH). In year 1 (Figure 7), the SIM-AB steers had higher ADG and faster rate of growth than both SIM-BH and AxB. In year 2 (Figure 8), similar differences in growth were noted between SIM-AB and SIM-BH; however, in yr 2, the AxB steers exhibited the fastest rate of growth on winter pasture and feedlot. Growth rates were best fitted to a third order equation primarily due to the 60-75 d post-weaning backgrounding period in which steers had reduced ADG of about 1 lb/d or less. The effect of stocking rate on subsequent feedlot gains as well as overall lifetime growth attributes is illustrated in Figures 9 and 10. Incorporating all breed types, feedlot compensatory gain was not a factor in year 1, (1997-98); however, the reduced forage availability during yr 2, 1998-99, of the winter pasture phase resulted in substantially reduced ADG for all stocking rates and especially steers on high stocking rate pastures. Consequently, steers on high stocked pastures were fed longer to reach a common backfat end point, and feedlot gains showed some compensation of growth.

Grazing Method and Supplementation

In an effort to enhance steer performance on rye-ryegrass pastures, both SIM-HB and BRM steers were offered self-limiting rations of either fishmeal to provide an un-degraded protein source or corn to serve as an energy source (Grigsby et al., 1988b). Fishmeal consumed at less than one-half pound per head per day due to lack of palatability did not affect ADG of SIM-HB or BRM (Table 14). The corn-based supplement consumed at about 0.2% BW increased gain on pasture of SIM-HB steers to about 2.8 lb/d and of BRM steers to about 2.3 lb/d. Both breed types had lower than anticipated supplement:extra gain conversion which was likely attributable to both the self-limiting delivery method and the small percent of BW consumption.

Table 13. Carcass characteristics of fall-born and spring-born Brahman steers

Season of birth	Fall	Spring
Season in feedlot	Winter-Spring	Summer-Fall
Age at harvest (d)	527	554
Hot carcass weight, lb	601 a[3]	671 b
Ribeye area, in[2]	10.50 a	12.00 b
Back Fat, in	0.22	0.28
Dressing %	63.40	62.80
USDA Yield grade[1]	2.40	2.27
Marbling score	365	359
USDA Quality grade[2]	365	328
Maturity	A	A

[1]Yield grade score of 1 = very lean and 5 = very fat
[2]USDA QG 300 to 399 = USDA Select
[3]Means within a row followed by a different letter, differ at $P < 0.01$.

During summer grazing, and especially on bermudagrass pastures, BRM and F_1 Brahman x *Bos taurus* steers often have higher ADG than low or no percentage Brahman steers. Two 2-yr grazing experiments on bermudagrass evaluated method of grazing with SIM-HB and BRM steers (Rouquette et al., 1992 and 1994a). Several experiments have previously evaluated continuous vs. rotational stocking; however, few have investigated the use of multiple herds used in rotational stocking. In the case of either a two-herd (Table 15) or three-herd (Table 16) rotational stocking approach, the objective was to allow the first herd the opportunity to remain on any one pasture long enough to consume primarily leaves. The subsequent grazers or herds would thereby be forced to defoliate the forage to a shorter stubble height, and, in the process, consume more low nutritive value stems than would be preferred. A comparison of SIM-HB and BRM steers stocked continuous, rotational-1 herd, or rotational-2 herd showed that yearling BRM steers had higher ADG than fall-born, June-weaned SIM-HB steers (Table 15). Maximum ADG resulted from steers assigned to the first grazers in the two-herd rotational stocked strategy. BRM steers gained nearly 2 lb/d under grazing management that promoted leaf selection. A continuation of this experiment was followed by a 2-yr, three-herd rotational stocked system (Table 16). The ADG declined with grazing herds in the same manner as performance on stocking rate experiments. Essentially, the forced consumption of the lower strata of the bermudagrass stubble composed mainly of stems had the same impact on ADG as did reducing both forage mass and nutritive value. In this experiment, suckling SIMX calf response was buffered by milk intake and hence ADG

Figure 7. Growth rate comparisons for Angus x Brahman (AxB), Simmental x [Angus x Brahman] (Sim-AB), and Simmental x [Brahman x Hereford] (Sim-BH) steers grazing rye-ryegrass post-weaning (97-98).

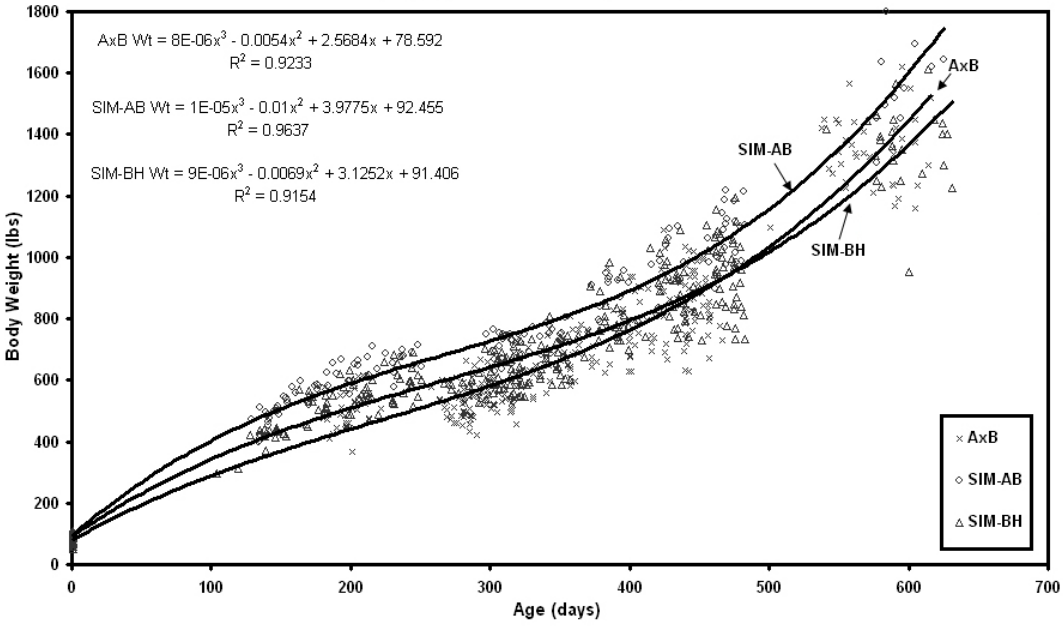
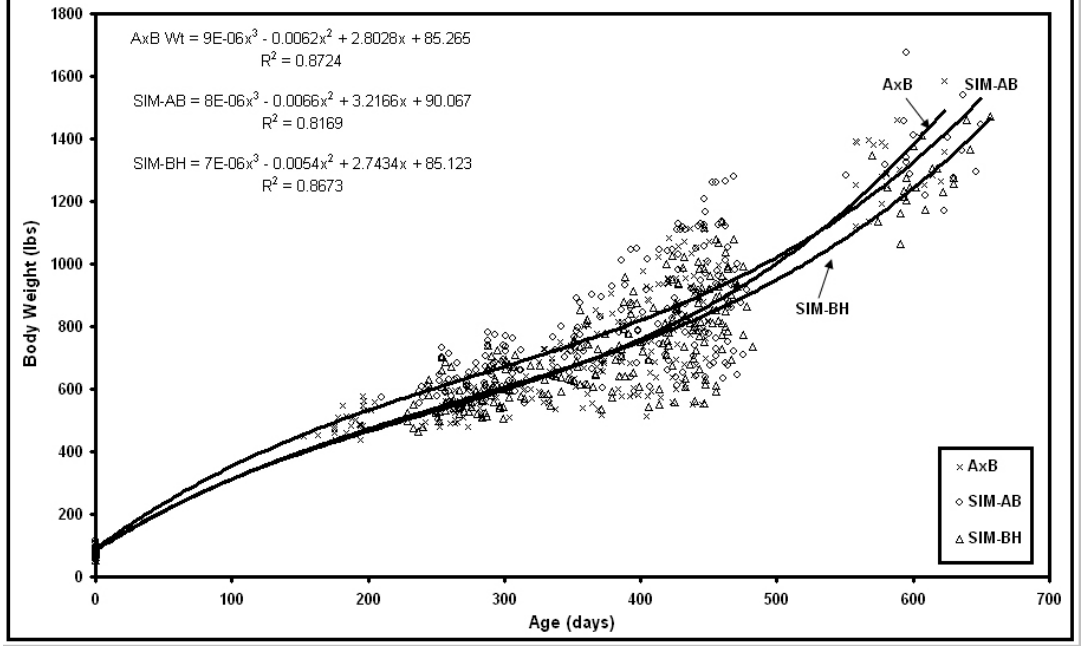
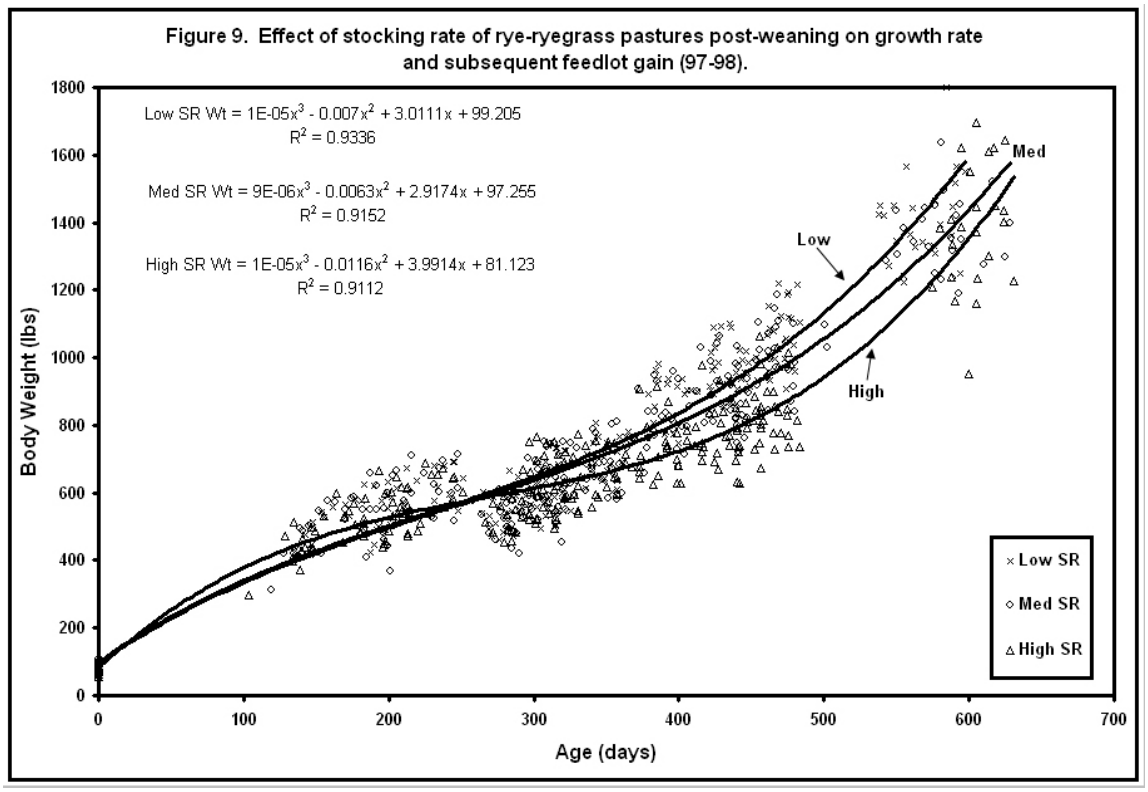


Figure 8. Growth rate comparisons for Angus x Brahman (AxB), Simmental x [Angus x Brahman] (Sim-AB), and Simmental x [Brahman x Hereford] (Sim-BH) steers grazing rye-ryegrass post-weaning (98-99).




Figure 9. Effect of stocking rate of rye-ryegrass pastures post-weaning on growth rate and subsequent feedlot gain (97-98).
Low SR Wt = 1E-05x3 - 0.007x2 + 3.0111x + 99.205
R2 = 0.9336
Med SR Wt = 9E-06x3 - 0.0063x2 + 2.9174x + 97.255
R2 = 0.9152
High SR Wt = 1E-05x3 - 0.0116x2 + 3.9914x + 81.123
R2 = 0.9112
Low
Med
High
Low SR
Med SR
High SR
Body Weight (lbs)
Age (days)
0
200
400
600
800
1000
1200
1400
1600
1800
0
100
200
300
400
500
600
700

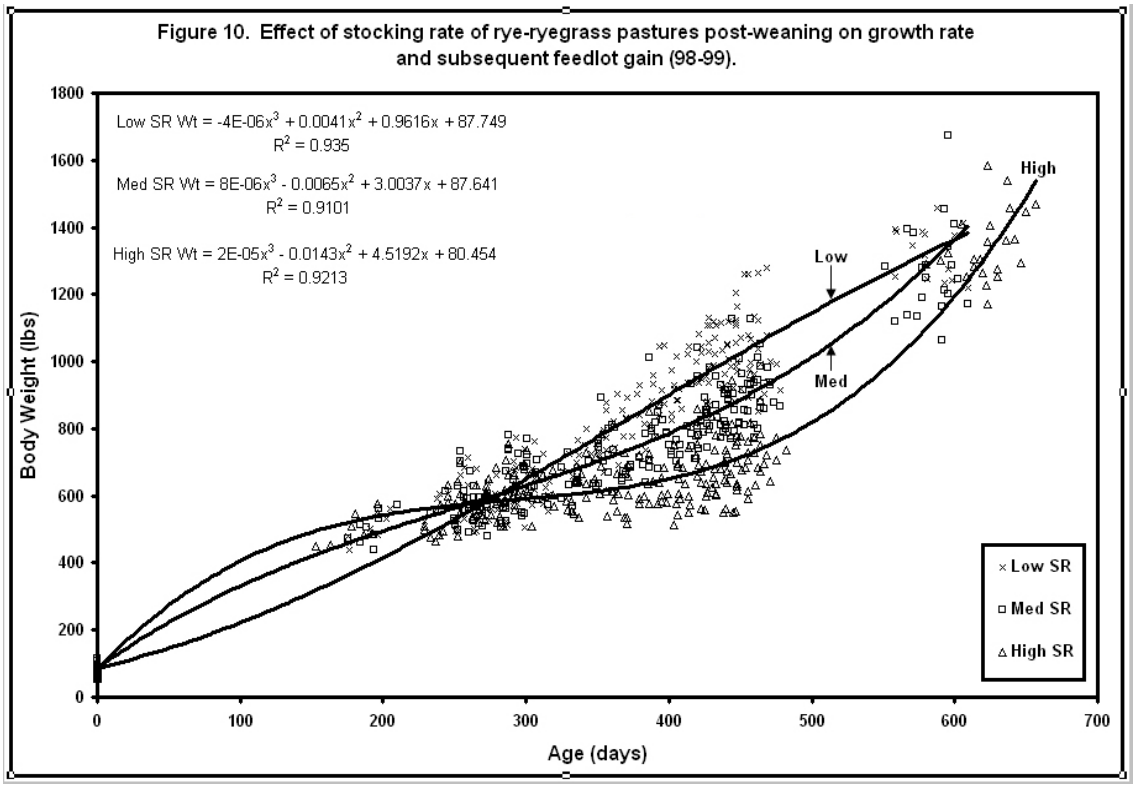

Figure 10. Effect of stocking rate of rye-ryegrass pastures post-weaning on growth rate and subsequent feedlot gain (98-99).
Low SR Wt = -4E-06x3 + 0.0041x2 + 0.9616x + 87.749
R2 = 0.935
Med SR Wt = 8E-06x3 - 0.0065x2 + 3.0037x + 87.641
R2 = 0.9101
High SR Wt = 2E-05x3 - 0.0143x2 + 4.5192x + 80.454
R2 = 0.9213
High
Low
Med
Low SR
Med SR
High SR
Body Weight (lbs)
Age (days)
0
200
400
600
800
1000
1200
1400
1600
1800
0
100
200
300
400
500
600
700

Table 14. Performance of Simmental x [Hereford x Brahman] (SIMX) and Brahman steers grazing rye-ryegrass and receiving supplemental feed

Item	Treatment†		
	PAS[1]	FISH[2]	CRN[3]
SIMX (n=30)			
Average Daily Gain, lb/d	2.40[b4]	2.53[b]	2.77[a]
Average Daily Consumption (ADC), lb/d	0	0.32	1.13
Incremental Gain (IG), lb/d	0	0.13	0.37
ADG:IG (lb:lb)	0	2.46	3.05
Visual Condition Score‡			
Initial	5.21	4.79	5.00
Final	6.50	6.71	6.67
Brahman (n=36)			
Average Daily Gain, lb/d	1.91[b]	1.88[b]	2.29[a]
Average Daily Consumption (ADC), lb/d	0	0.45	0.74
Incremental Gain (IG), lb/d	0	-0.03	0
ADC:IG (lb:lb)	0	---	1.95
Visual Condition Score			
Initial	4.50	4.50	4.50
Final	6.12	6.08	6.42

[1]PAS = rye + ryegrass pasture with free-choice minerals.
[2]PAS plus pelleted Menhaden fishmeal with Rumensin fed self-limiting.
[3]PAS plus pelleted corn with Rumensin fed self-limiting.
[4]Means within the same row and followed by different letters, differ ($P < 0.05$).

Table 15. Two-year average daily gain from Simmental x [Hereford x Brahman] (SIMX) and Brahman (BRM) steers grazing bermudagrass and stocked continuous, rotational-one herd, or rotational-two herds

Grazing Method	Average Daily Gain (lb/d)		
	SIMX	BRM	AVG
Continuous Stocked	0.65 b[1]	1.22 a	0.94
Rotational stocked, 1-herd	0.56 b	1.51 a	1.04
Rotational stocked, 2-herds			
First Grazers	1.35 b	1.91 a	1.63
Second Grazers	0.48 b	1.04 a	0.76

[1]Numbers in a row followed by a different letter, differ at $P < 0.05$.

Table 16. Two-year gain summaries of cattle grazed in a three-herd rotational stocked bermudagrass pasture using Simmental x [Hereford x Brahman] (SIMX) and Brahman (BRM) steers

	Average Daily Gain, lb/d			
	Pairs		Weaned steers	
Grazing Sequence	Cow	SIMX Calf	SIMX	BRM
First grazers	0.70	2.23 a[1]	0.91 c	1.48 b
Second grazers	-0.06	1.76 a	0.43 c	0.81 b
Last grazers	-0.26	1.49 a	0.04 c	0.51 b

[1]Numbers in a row followed by a different letter, differ at $P < 0.05$.

was greater than weaned SIMX or BRM steers. Again, ADG from BRM steers was higher than SIMX steers for each grazer herd. Multi-herd, rotational stocking offers an opportunity to increase forage utilization; however, the class of cattle for each herd should be carefully considered to allow for cattle requiring maximum gain to be in the first grazer herd, and cattle requiring least gain such as dry, pregnant, mature cows to be in the last herd.

Spring-born BRM calves weaned in the fall and grazed on winter pastures until May offer alternative management options that include a stocker phase on bermudagrass pastures from June to October. Steers that fit this management scenario entered the feedlot at 18-20 months of age and were fed at the same time as younger fall-born BRM and SIMX steers that entered the feedlot at about 12-13 months of age (Rouquette et al., 1994b). The SIMX steers had the highest feedlot pay weight ADG of about 3.75 lb/d (Table 17). Although the older BRM steers had slightly higher ADG than the yearling BRM steers (2.6 vs. 2.4 lb/d), feed:gain was higher and intake as a percentage of BW was reduced for the older BRM steers. Likewise, carcass traits for both BRM age groups were similar, with most steers grading USDA Select. Both hot carcass weight and USDA Quality Grade were higher for the SIMX steers. A noteworthy consideration of this experiment was the potential economic impact of 111 d on feed for the older BRM, 188 d on feed for the yearling BRM, and 163 d on feed for the SIMX steers. Considerations should also be given to maturity status of the carcass before delaying feedlot entry of cattle.

Protein supplement rations consisting of either feathermeal or fishmeal were used to enhance ADG of yearling BRM and crossbred steers (Rouquette et al., 1993). The BRM steers gained more than the crossbred steers (about 30% Brahman-influence) at each level of treatment. The feathermeal supplement resulted in ADG of 2.28 for BRM steers (Table 18). Both the crossbred and BRM steers had similar gain enhancements and supplement:extra gain was very acceptable at 2:1 to 3.5:1. An earlier study using a self-limiting fishmeal ration for both BRM and SIMX steers grazing bermudagrass pastures showed that breed type ADG were similar on pasture only; however, SIMX steers gained more when receiving the fishmeal supplement (Grigsby et al., 1988a). Fishmeal consumed at about 1.25 lb/d or about 0.2% BW essentially doubled ADG for both breedtypes (Table 19). In addition, the supplement:extra gain ratio was about 1.8:1 for both groups. As noted earlier, enhanced supplement:extra gain ratios were likely attributable to self-limiting delivery system, intake of supplement at a small (0.2 to 0.3% BW) percent of BW, and inclusion of minerals, and an ionophore (Rumensin in this case) in the ration.

Stocker performance on bermudagrass pastures in the South has been closely linked to forage nutritive value, forage available for consumption, and climatic conditions, primarily heat and humidity. The release of Tifton 85 bermudagrass was based on increased digestibility of fiber, and with lower concentrations of lignin and ether-linked feralic acid (Mandebvu et al., 1999). These changes in nutritive parameters have enhanced animal performance from cattle grazing Tifton 85 bermudagrass compared to Coastal and other bermudagrasses. Two experiments were conducted at TAES-Overton using Coastal and Tifton 85 bermudagrass pastures, supplemental protein, and grazed with F_1 [Hereford x Brahman] (HxB) steers and 25% Brahman-influenced steers (Rouquette et al 2003c). In both experiments, steer ADG on Tifton 85 bermudagrass exceeded steer gains from Coastal bermudagrass plus protein supplement (Table 20). The ADG of fall-born HxB steers was identical in both years for Coastal bermudagrass plus supplement at 2.04 lb/d, and for Tifton 85 bermudagrass without supplement at 2.3 lb/d. For these same two treatments, 25% Brahman steers gained about 0.5 to 0.8 lb/d less than HxB steers. The combination of Tifton 85 bermudagrass and 50% Brahman-influenced steers for summer grazing in South has been a positive example of matching forage and animal breed types x environment.

Other Tropically Adapted Genotypes

Romosinuano sires obtained from USDA/ARS Brooksville, FL, were mated to F-1 AxB dams for fall calves. These Romosinuano-sired steers (ROMOX) were used in both pre- and post-weaning experiments to evaluate performance from birth to yearling status (Rouquette et al., 2003a). Both fall-born ROMOX and HxB steers grazed bermudagrass without and with a commercial liquid molasses supplement. Although supplement did not affect ADG of either, the HxB steers had from 0.6 to 0.9 lb/d higher ADG than the ROMOX steers. At termination of bermudagrass grazing in mid-October, the ROMOX, HxB, and long-yearling BRM steers were transported to a commercial feedlot in South Texas to assess gain and carcass attributes (Rouquette et al., 2003b). The ROMOX and HxB steers entered the feedlot at 12-14 months of age; the BRM steers were 17-18 months old. After 160 to 177 d on feed, feedlot ADG was different for all breed types at 2.68 lb/d for BRM, 3.21 lb/d for ROMOX, and 3.86 lb/d for HxB (Table 22). Additionally, feed:gain ratios ranged from 6:1 for HxB to 8.4:1 for the older BRM steers. Growth in body weight for these three breed types is shown in Figure 11 and weights are presented by Julian date as opposed to age of calf. This graph illustrates the rapid growth by HxB steers post-weaning, especially during the feedlot phase. Also, the ROMOX steers exhibited accelerated gains in the feedlot compared to BRM steers. At time of harvest, all carcasses were electrically stimulated as per the routine assembly at the South Texas packing facility. The targeted backfat of 0.4-inch was achieved for all breed types, which may reflect management familiarity with visually assessing finish for BRM and 50% Brahman-influenced cattle (Table

Table 17. Feedlot performance and carcass traits of two age groups of Brahman and one calving season Simmental x [Hereford x Brahman] (SIMX) steers following bermudagrass grazing

	Feedlot performance		
Item	**Brahman**	**Brahman**	**SIMX**
Number	27	17	19
Calving Season	Spring '91	Fall '91	Fall '91
Date into lot	10-21-93	10-21-92	10-21-92
Date out of lot	2-10-93	4-29-93	4-5-93
Days on feed	111	188	163
Lot, arrival wt, lb/hd	874	583	668
Transit shrink, %	7.8	7.1	6.7
Lot, final wt, lb/d	1,204	1,076	1,331
Feedlot ADG, lb/d	2.97	2.62	4.07
Pay weight, lb/hd	1,156	1,033	1,278
Pay weight ADG, lb	2.55	2.39	3.74
Feed:Gain (dry)	7.99	7.75	6.03
Avg. daily consumption, lb	24.78	20.88	27.17
Estm. consumption, % BW	2.38	2.52	2.72
		Carcass Traits[1]	
Approx. age at harvest, mos.	23	19	18
Hot carcass wt, lb	723	665	828
Estm. dressing %	62.5	64.4	64.8
Backfat, in	0.31	0.35	0.35
Ribeye area, in^2	12.1	11.2	14.1
KPH, %	1.42	1.42	1.36
USDA Yield Grade	2.5	2.5	2.3
USDA Quality Grade			
% Choice	3.7	12.5	38.9
% Select	96.3	87.5	61.1

[1]All carcasses electrically stimulated at harvest site as per commercial routine.

Table 18. Performance of crossbred (x-bred) and Brahman steers grazing Coastal bermudagrass (PAS) and receiving supplemental protein ration as fishmeal or feathermeal

	Average Daily Gain (lb/d)	
Treatment	**x-bred**	**Brahman**
Pasture Only	1.02 ± .06	1.61 ± .03
PAS + Fishmeal[1]	1.44 ± .07	1.97 ± .10
PAS + Feathermeal[2]	1.61 ± .06	2.28 ± .11
Additional Gain		
PAS + Fishmeal	0.42	0.36
PAS + Feathermeal	0.59	0.67
Feed:Extra Gain		
PAS + Fishmeal	3:1	3.5:1
PAS + Feathermeal	2.1:1	1.9:1

[1]Menhaden fishmeal mixed with corn at 1:1 ratio for 34.5% protein ration hand-fed daily at 1.25 lb/hd/d.
[2]Feathermeal mixed with corn at 64:36 corn:feathermeal ratio for 34.5% protein ration hand-fed at 1.25 lb/hd/d.

23). In general, carcasses were similar for dressing percentage, KPH, marbling score, USDA Yield Grade, and USDA Quality Grade. The range of carcass quality grade varied widely for the ROMOX steers, with 2.5% high Choice, 12.5% average Choice, 47.5% low Choice, 35% Select, and 2.5% Standard. The HxB steers graded 82% low Choice and 18% Select; the BRM steers graded 60% low Choice and 40% Select. Estimates of tenderness using the Warner-Bratzler technique showed that ROMOX steers exhibited less shear force at 7.3 lb than BRM steers at 8.3 lb (Table 24). The HxB steers were intermediate at 8 lb and not different from either of the others. Cooking loss at 33% for the BRM steers was higher than the other two at 27% loss.

A winter grazing and subsequent feedlot-carcass experiment was conducted with limited numbers of HxB (50% BRM), AAB (25% BRM), Braunveigh crossbred (0% BRM), and Bonsmara x Angus (BONX) steers (Cleere et al., 2002c, 2002d). Feedlot

ADG at the Texas Tech University Alltech Research facility was slightly less for BONX steers at 3.5 lb/d compared to the other breed types at 4 lb/d (Table 25). Feeding period ranged from 115 - to 136 d for the 750 lb feeders. Targeted backfat of 0.4-inch was met by all breed types using ultrasonography, and they ranged from about 0.5 to 0.6-inch (Table 26). The USDA Yield Grades were similar among breed types at 2.7 to 3.4, and marbling was similar at about 400. Most carcasses were at the differentiation mark between low Choice and Select. The grid price reflects these slight variations, and the total value once again was directly related to hot carcass weight insofar as radical quality grade differences were not present.

Implications

Performance illustrates that F_1 Brahman x British steers are well adapted to environmental conditions and warm-season perennial grass-based pastures typical of the Gulf Coast and the Southeast. Post-weaning growth on winter annual forages and feedlot performance are competitive with and often exceed gains of Continental-sired, 25% Brahman steers used in the region. Brahman steers have slower growth rates compared to F_1 (Brahman x *Bos taurus*) steers. Long-yearling Brahman steers, however, had very acceptable performance when grazing bermudagrass with or without protein supplementation during hot, humid conditions. Feedlot gains and feed:gain conversions of Brahman steers have been biologically and economically acceptable when the feedlot residence time does not include harsh, low temperatures. Thus, feedlot performance of Brahman steers has been best on the High Plains when they were fed in the summer. Carcass traits of both F_1 and Brahman steers were acceptable and generally resulted in USDA Choice minus and Select grades, with smaller ribeye area for Brahman. Although the heifer marketing has sustained purebred Brahman and commercial F_1 producers, steer performance is of sufficient magnitude to warrant an increase in vertically integrated operations. Marketing and merchandizing of the finished product remain the top management priority. Carcass discounts for actual or perceived rationales may discourage feeding Brahman and Brahman-influenced cattle in non-Brahman environments. The limited database available on the more recently imported tropically adapted cattle has not been encouraging from the perspective of growth rate of steers from birth-to-harvest or carcass attributes. Since many tropically adapted breeds have been sustainable in their native environment due to foraging, body and frame size, lactation, and fertility, the most rapid adoption of these breed types may be for maternal use. Moving these new breed types, as well as existing Brahman and Brahman-influenced cattle, into future production systems requires attention to growth and enhanced carcass attributes that fit market requirements.

Table 19. Performance of Brahman and Simmental x [Hereford x Brahman] (SIMX) steers grazing bermudagrass pastures only (PAS) or with fishmeal (FISH) supplement

	Brahman		SIMX	
Item	**PAS[1]**	**FISH[2]**	**PAS**	**FISH**
Average Daily Gain (lb/d)	0.63[b]	1.32[a]	0.80[b]	1.66[c]
Average Daily Consumption (ADC) (lb/d)	---	1.15	---	1.35
Extra Gain (lb/d)	---	0.69	---	0.86
Suppl:Extra Gain	---	1.88	---	1.74

[1]PAS - Bermudagrass pasture plus free-choice minerals.
[2]FISH - PAS plus 34.5% crude protein supplement containing fishmeal and Rumensin.
[a,b,c] Means in the same row followed by a different letter are different, $P < 0.01$.

Table 20. Average daily gain comparisons for two experiments (EXP) during the grazing-backgrounding summer on Coastal and Tifton 85 bermudagrass

	Average Daily Gain				
Pasture	**EXP 1[1] HHAB[3]**	**EXP 1[1] HxB[3]**	**EXP 2[2] SIM X[3]**	**EXP 2[2] HxB[3]**	**EXP 2 All Cattle**
	---------- (lb / d) ----------				
Coastal PAS			0.91 d	1.64 c	1.01 d
Coastal + SUPL[5]	1.54 a[4]	2.03 b	1.18 c	2.04 b	1.30 c
Tifton 85 + PAS	1.61 a	2.30 a	1.58 b	2.33 b	1.69 b
Tifton 85 + SUPL			1.86 a	2.89 a	2.02 a

[1]EXP 1 grazing from 6-16 to 8-31.
[2]EXP 2 grazing from 6-25 to 9-25.
[3]Breed types included Hereford x (Angus x Brahman) [HHAB], Simmental x (AxB) [SIMX] and F_1 (Hereford x Brahman) [HxB].
[4]Means in a column followed by a different letter differ ($P < 0.05$).
[5]SUPL = 2 lb/hd/d of a 1:1 (Corn:soybean meal), 28% protein ration containing minerals and Rumensin, and hand fed daily.

Table 21. Influence of steer breed type on average daily gains from bermudagrass pasture (PAS) and liquid molasses supplement (MOL), and molasses with Cattle-Ase (MCAS)

Treatment	Breed Type[1]	Initial Weight (lb)	Final Weight (lb)	ADG[2] (lb/d)
PAS	ROMOX	639	729	1.07 b
PAS	F_1 HxB	516	681	1.96 a
MOL	ROMOX	612	699	1.03 b
MOL	F_1 HxB	506	661	1.85 a
MCAS	ROMOX	626	703	0.91 b
MCAS	F_1 HxB	510	640	1.5 a

[1]Breed type are 1/2 Romosinuano x 1/4 Angus x 1/4 Brahman (ROMOX) and 1/2 Hereford x 1/2 Brahman (F_1 HxB).
[2]Means in a column followed by a different letter are different ($P < 0.05$).

Table 22. Feedlot performance of Romosinuano crossbred (ROMOX), F_1 Hereford x Brahman (HxB), and Brahman steers

	Steers			
Item	ROMOX	F_1 HxB	Brahman	*P* value
Number	40	11	10	
Feedlot in date	10-24-01	10-24-01	10-24-01	
Age in feedlot, mos.	12-14	12-13	17-18	
Weight in feedlot, lb	711 a	649 b	758 a	0.003
No. days on feed	164 b	177 a	160 b	0.001
Weight out feedlot, lb	1,239 b	1,333 a	1,187 b	0.01
Pay weight-out, lb	1,189 b	1,278 a	1,140 b	0.0001
Feedlot ADG, lb/d	3.21 b	3.86 a	2.68 c	0.0001
Pay weight ADG, lb/d	2.91 b	3.56 a	2.39 c	0.0001
Avg. consumption, lb/hd/da	22.9	23.6	20.2	
Feed:Gain, DM, lb	6.45	6.02	8.39	

Numbers followed by a different letter in a row are different at *P* levels shown.

Table 23. Carcass characteristics of Romosinuano crossbred (ROMOX), F_1 Hereford x Brahman (HxB), and Brahman steers

	Steers[1]			
Carcass Trait[2]	ROMOX	F_1 HxB	Brahman	*P* value
Number	40	11	10	
Pay Wt, Live, lb	1,189 b	1,278 a	1,140 b	0.006
Hot carcass, wt, lb	760 b	821 a	719 b	0.006
Dressing, %	63.9 a	64.1 a	63.0 a	0.34
Back Fat, in	0.41 a	0.50 a	0.38 a	0.12
Ribeye Area, in^2	13.6 a	13.9 a	11.9 b	0.0001
REA/wt carcass	1.80 a	1.71 ab	1.67 b	0.04
KPH, %	2.39	2.41	2.55	
Marbling Score[3]	431 a	432 a	404 a	0.46
Yield Grade	2.53 a	2.90 a	2.88 a	0.08
Ave Quality Grade, score	699 a	709 a	700 a	0.68
% High choice (767-799)	2.5	---	---	
% Avg choice (734-766)	12.5	---	---	
% Low choice (700-733)	47.5	82	60	
% Select (600-699)	35	18	40	
High Std. (500-599)	2.5	---	---	

[1]Numbers followed by a different letter in a row are different at *P* levels shown.
[2]All steers electrically stimulated at packing facility.
[3]Marbling scores of 400-499 = USDA Choice minus.

Table 24. Warner-Bratzler shear force and cooking loss of Romosinuano crossbred (ROMOX), F_1 Hereford x Brahman (HxB) and Brahman steers

	Carcass Evaluations[2]	
Steers	**Shear Force, lb**	**Cooking Loss, %**
ROMOX	7.33 a[1]	26.8 a
F_1 HxB	8.02 ab	27.4 a
Brahman	8.34 b	32.6 b

[1]Numbers followed by a different letter in a column are different at $P < 0.02$.
[2]All steers electrically stimulated at packing facility.

Table 25. Effect of steer breed types across winter pasture stocking rates on subsequent feedlot performance

BREED TYPE[1]	INITIAL WT (lb)	FINAL WT[2] (lb)	ADG (lb/d)	FEED:GAIN (lb/d)	DAYS ON FEED (d)
BONX	737	1,159 b	3.45 b	--	115-136
BRVX	754	1,232 ab	3.94 a	--	115-136
AAB	780	1,257 ab	4.03 a	6.48	115-136
F_1HxB	787	1,321 a	4.14 a	6.13	136

[1]Breedtypes used included Bonsmara x Angus (BONX), Braunvieh x Simmental x Angus x Hereford (BRVX), Angus x [Angus x Brahman] (AAB), and F_1 [Hereford x Brahman] (HxB).
[2]Means followed by different letters within a column are significantly different ($P < 0.05$).

Table 26. Effect of steer breed type across winter pasture stocking rates on carcass traits

BREED TYPE[1]	MARB[3]	REA (in^2)	FAT (in)	HCW (lb)	YG	GRID PRICE[4] $/cwt	VALUE $/hd
BONX	400	12.4 b[2]	0.56 ab	693 b	3.10	105.14	728.37
BRVX	372	13.5 a	0.47 b	739 ab	2.71	103.44	766.97
AAB	412	12.2 b	0.60 a	748 ab	3.43	107.75	775.80
F_1HxB	404	12.1 b	0.51 ab	781 a	3.37	102.94	803.94

[1]Breedtypes used included Bonsmara x Angus (BONX), Braunvieh x Simmental x Angus x Hereford (BRVX), Angus x [Angus x Brahman] (AAB), and F_1 [Hereford x Brahman] (HxB).
[2]Means followed by different letters within a column are different ($P < 0.06$).
[3]Marbling (MARB) scores 300 to 399=USDA Select; 400-499 = USDA Choice minus.
[4]Grid pricing based on Excel Formula in fall 2001.

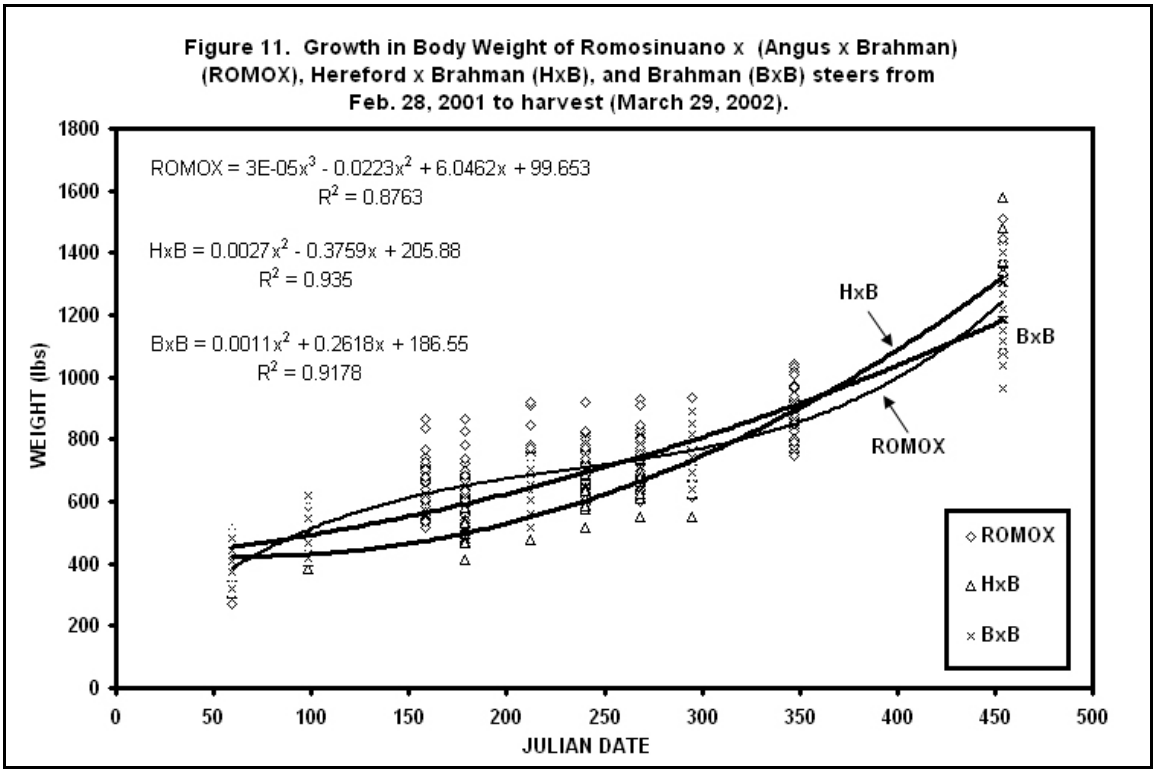


Figure 11. Growth in Body Weight of Romosinuano x (Angus x Brahman) (ROMOX), Hereford x Brahman (HxB), and Brahman (BxB) steers from Feb. 28, 2001 to harvest (March 29, 2002).

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Zero, ¼, and ½ Brahman Cows in Spring vs Fall Calving Programs

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ABSTRACT: *Bos indicus* genetics are of interest in the beef industry of the southern United States. Oklahoma sits along the border between the hotter, more humid climate of the South and more temperate areas of the Midwest. It is also a region where many beef producers use both spring and fall calving seasons. The purpose of this research was to examine proportions of Brahman breeding in spring vs fall calving seasons. A cow herd was developed, over a three-year period, by mating purebred Hereford and Angus cows to Angus, Hereford, Brahman, ½ Brahman-½ Angus and ½ Brahman-½ Hereford bulls. These matings produced heifers which were Angus-Hereford, Hereford-Angus, ¼ Brahman-¼ Angus-½ Hereford, ¼ Brahman-¼ Hereford-½ Angus, ½ Brahman-½ Angus or ½ Brahman- ½ Hereford. The design was a 3 x 2 factorial arrangement of 0, ¼, and ½ Brahman in fall vs spring calving seasons. All heifers were managed to enable them to calve at 2 yr of age and were kept in the herd, unless physical infirmity or failure to become pregnant for two consecutive years, until all the cows were more than 10 years old. More than 300 heifers started the experiment. Cows were mated, artificially, to bulls from one or two sire breeds each year. The % expressing heat (0, ¼, ½ Brahman; spring vs fall) and % pregnant were 69.2 vs 78.8%, 63.9 vs 31.5% 50.2 vs 17.8% and 86.4 vs 62.9 %, 97.2 vs 37.7 %, 86.8 vs 13.5%, respectively for 2-yr-old cows. These deficiencies for the ½ Brahman cows were reversed for cows that were 3-5 yr of age. Weaning weights generally favored the higher percentage Brahman breeding. These results suggest that maternal performance increased as percent Brahman increased, but that there was a serious compromise in reproductive performance, especially for the ½ Brahman at 2 yrs of age. Generally the ¼ Brahman breeding proportion was the most efficient.

Key Words: Beef Cattle, *Bos Indicus*, Genotype x Environment Interaction

Introduction

Crossbreeding is well recognized as the appropriate approach to breeding programs for the beef industry. The choice of breeds to use is an important consideration and, for much of the southern United States, the Brahman breed is a logical choice as a component of the crossbred cow. There are also differing management systems which may affect the recommendation of breed type. An example of differing management systems is the common practice of having both spring and fall calving programs in regions of the country where winter is not as severe. There is the potential for genotype (breed) x environment (season of birth) interactions. The objectives of this study were to examine the use of 0, ¼ and ½ Brahman breeding for cow-calf operations, compare spring vs fall calving programs and examine the interaction between proportion Brahman breeding and season of birth. These results have been reported previously (Bolton et al., 1987a,b; McCarter et al., 1990, 1991a,b,c; Ziehe, 1993).

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Materials and Methods

Angus and Hereford cows, from a previous selection experiment, were randomly assigned to spring and fall calving groups and mated to Hereford, Angus, Brahman x Hereford, Brahman x Angus, and Brahman bulls to develop six crossbred groups which were 0 (Hereford x Angus, Angus x Hereford), ¼ (Hereford x Brahman-Angus, Angus x Brahman-Hereford) and ½ (Brahman x Hereford, Brahman x Angus) Brahman breeding. These matings were conducted over a three-year period to produce approximately 900 calves.

The experiment was conducted at the Southwest Livestock and Forage Research Laboratory near El Reno, OK. Cows were maintained on native tall grass pastures. Since the grasses in these pastures were dormant in winter, the cows received supplemental feeding (alfalfa and cottonseed meal).

The calves from these matings were weighed at birth and weaned at approximately 205 days of age in the spring calving group and 240 days in the fall calving group. Spring calving took place between February and April, and fall calving occurred September through November. Birth weights and weaning weights were analyzed using least squares.

The model included the proportion Brahman, calf sex, dam age, year, season, and interactions.

Heifers were retained to be bred to calve at 2 yr of age. They were maintained on tall grass pastures and supplemented with oat-alfalfa silage, corn, milo, and cottonseed meal. Post-weaning gain was measured to a year of age. Age at puberty was assessed using teaser bulls with chin ball markers from 325 to 410 d of age, at which time the heifers were placed in breeding pastures. A variety of breeds of sire were used throughout this study; Limousin was a primary contributor as sire of calves. Pregnancy status was determined for all heifers approximately 80 d after the end of a 75-d breeding season. These data were analyzed using a least squares model that included the proportion of Brahman breeding, dam age, year, season of birth, and interactions.

Heifers were allowed to calve at 2 yr of age. Birth weight, weaning weight, and weaning rate were analyzed with least squares. The model included crossbred cow group, sire of dam within cow group, season and year of calving, sire of calf, and sex of calf and interactions.

Following their first calving experience, cows were continued in the herd in the same season in which they were born. General management methods were maintained throughout the course of the experiment. Weaning rate, birth weight, weaning weight, and weight weaned per year for cows age 3 to 5 yr were analyzed using a least squares model that included crossbred cow group, sex of calf, season of calving, year of calving, age of dam, sire of calf, and interactions. Further analyses of weaning rate and weaning weight for cows ranging in age from 5 to 8 yr were conducted with a similar model.

Results and Discussion

Calves with varying proportion Brahman showed a difference in birth weight ($P<0.05$), but there was no evidence of an interaction between proportion Brahman and season of birth (Table 1). There was an interaction between proportion Brahman and season of birth for weaning weight ($P<0.05$) and postweaning average daily gain for heifers ($P<0.05$). Weaning weights were different ($P<0.05$) among varying proportions of Brahman breeding for spring-born calves but not for fall-born calves. There were significant differences among proportions Brahman for postweaning daily gain of heifers for both spring and fall calving programs. All cases where proportion Brahman was significant showed the pattern of increased performance as proportion Brahman increased.

Table 1. Performance traits for 0, ¼, and ½ Brahman calves in spring and fall calving seasons

Proportion Brahman	n	Birth weight (lb)[c]	Weaning weight (lb)[a]		Average daily gain (lb/d)[b]	
			Spring[c]	Fall	Spring[c]	Fall[c]
0	164	74.6	429	405	0.73	1.08
1/4	377	77.7	449	403	0.84	1.17
1/2	364	82.9	469	407	0.90	1.31

[a]The interaction between proportion Brahman and season was significant ($P<0.05$).
[b]Heifers only.
[c]There was a significant (<0.05) difference among the various proportions of Brahman.

Heifers were assessed for age at puberty, % expressing heat, and % pregnant. There was a significant interaction between proportion Brahman and season for % expressing heat and % pregnant. The ½-Brahman heifers had much lower ($P<0.05$) performance for % expressing heat, in both seasons, and % pregnant for the fall season (Table 2). The ¼-Brahman had the best performance ($P<0.05$) among the breed groups for age at puberty (averaged across season) and % pregnant in the spring.

Table 2. Reproduction traits for 0, ¼, and ½ Brahman heifers in spring and fall calving seasons

Proportion Brahman	% Expressing heat[a]		Puberty age*	% pregnant[a]	
	Spring*	Fall*		Spring*	Fall*
0	69.2	78.8	380	86.4	62.9
1/4	63.9	31.5	373	97.2	37.7
1/2	50.2	17.8	378	86.8	13.5

[a]The interaction between proportion Brahman and season was significant ($P<0.05$).
[b]There was a significant (<0.05) difference among the various proportions of Brahman.

The weaning rate among the breed groups did not differ significantly for spring calving, but there were striking differences ($P<0.05$) for fall calving (Table 3). Indeed, none of the Brahman x Hereford cows calved at 2 yr of age in the fall. This resulted in an interaction ($P<0.05$) between cow group and season for weaning rate. There was not such an interaction for either birth weight or weaning weight and calf weight at weaning increased ($P<0.05$) as proportion Brahman increased.

Table 3. Reproduction and performance traits for 0, ¼, and ½ Brahman cows (2 year old) in spring and fall calving seasons

Crossbred cow type	Number		Weaning rate (%)[a]		Birth wt (lb)	Weaning wt (lb)[b]
	Spring	Fall	Spring	Fall[b]		
H x A	26	23	82	77	70.4	413
A x H	12	14	88	30	73.0	425
A x BH	48	40	89	41	72.4	468
H x BA	38	28	85	40	73.0	470
B x A	42	38	86	33	69.1	480
B x H	37	28	75	0	72.2	483

[a]The interaction between proportion Brahman and season was significant (<0.05).
[b]There was a significant (<0.05) difference among the various proportions of Brahman.

The cows were evaluated while 3 to 5 yr of age for weaning rate, birth weight, and weaning weight (Table 4). There were differences ($P<0.05$) among breed groups for all traits. There was not an observable pattern among those differences for weaning rate in the spring, but the ½-Brahman cows had the highest weaning rate in the fall, resulting in an interaction between breed group and season. This may be partially explained by the fact that so few of them had calves at 2 yr of age. Weaning weights also increased ($P<0.05$) as proportion Brahman increased. Weight weaned per year was also evaluated for all cows from 2 to 5 yr of age. There was an interaction between breed group and season ($P<0.05$) and a significant ($P<0.05$) difference among breed groups in the fall. The highest group for weight weaned per year was the Brahman x Angus cow group.

A further investigation of weaning rate and weaning rate was conducted for cows from 5 to 8 yr of age (Table 5). The weaning rate decreased ($P<0.05$) as proportion Brahman increased, and weaning weight increased ($P<0.05$) as proportion Brahman increased. The difference was more pronounced for fall calving cows, resulting in an interaction between proportion Brahman and season.

Table 4. Reproduction and performance traits for 0, ¼, and ½ Brahman cows (3-5 yr old) in spring and fall calving seasons

Crossbred cow type	Weaning rate (%)[a]		Birth wt (lb)[b]	Weaning wt (lb)[b]	Wt weaned/yr (lb)[a]	
	Spring[b]	Fall[b]			Spring	Fall[b,c]
H x A	91	77	81.3	488	406	359
A x H	87	66	83.9	471	394	338
A x BH	88	71	79.9	506	438	324
H x BA	80	75	79.9	511	403	323
B x A	86	94	78.2	528	439	393
B x H	91	85	75.7	528	464	321

[a]The interaction between proportion Brahman and season was significant ($P<0.05$).
[b]There was a significant (<0.05) difference among the various proportions of Brahman.
[c]Wt weaned/year included calves born to 2- through 6-yr-old cows.

Table 5. Reproduction traits for 0, ¼, and ½ Brahman mature cows (5-8 yr old) in spring and fall calving seasons

Brahman	Weaning rate (%)[b]	Weaning wt (lb)[a]	
		Spring[b]	Fall[b]
0	86.1	521	466
1/4	81.7	554	530
1/2	72.7	574	557

[a]The interaction between proportion Brahman and season was significant ($P<0.05$).
[b]There is a significant (<0.05) difference among the various proportions of Brahman.

Implications

Results of this multi-year study indicated some advantages for Brahman breeding, at least up to ¼ in the cow herd, in Oklahoma conditions. The advantage was much more pronounced, overall, with spring calving. Indeed, the very poor reproductive performance for ½-Brahman cows that were managed to calve at 2 yr of age in the fall probably precludes the use of ½-Brahman breeding for fall calving herds. That characteristic, as well as some of the calf weight variables, suggest some influence of genotype (proportion Brahman) x environment (season) interaction.

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Cow-calf Performance of Brahman-British and Brahman-Continental Beef Females[1,2]

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ABSTRACT: Two separate studies were conducted to evaluate Brahman-British (Angus, Hereford, Shorthorn) and Brahman-Continental (Gelbvieh, Simmental) breeds and breed crosses for cow-calf performance. For Study 1 (S1), Brangus, Beefmaster, Gelbray, and Simbrah composite breeds were compared. Nine Brangus, 12 Beefmaster, 10 Gelbray, and 7 Simbrah sires were used in straightbred and crossbred [F_1 Brahman x Hereford (BH) cows] matings to generate 326 calves. For Study 2 (S2), a total of 1,011 reproductive and 752 calving records were collected. Nine Angus, 6 Brangus, 7 Gelbvieh, and 7 Gelbray bulls were mated to BH cows to produce Angus-, Brangus-, Gelbvieh-, and Gelbray-sired females, respectively. Contemporary BH heifers from 8 sires were purchased at weaning. Separate analyses were conducted for each study using a generalized linear mixed model procedure. In S1, Beefmaster and BH cows were of similar body weight, Brangus and Gelbray cows were intermediate ($P < 0.01$), and Simbrah cows were heaviest ($P < 0.01$). Calves sired by Brangus and Beefmaster bulls had lower birth ($P < 0.05$), weaning ($P < 0.01$), and 205-d ($P < 0.01$) weights than Gelbray- and Simbrah-sired calves. Simbrah-sired calves had greater weaning ($P < 0.01$) and 205-d ($P < 0.05$) weights than Gelbray-sired calves. For dam breed type comparisons, weaning and 205-d weights were greater ($P < 0.05$) for Beefmaster- and Brangus-sired calves with BH dams than with Beefmaster and Brangus dams. Weaning and 205-d weights were similar for Gelbray- and Simbrah-sired calves out of Gelbray and BH dams or Simbrah and BH dams. In S2, Brangus-sired females had pregnancy rates that were 28 to 33% lower ($P < 0.05$) for first and second exposures and 13% lower ($P < 0.05$) as multiparous cows than Angus-, Gelbvieh-, Gelbray-sired, and BH females. Body weights for Angus-sired cows were heavier ($P < 0.05$) than Brangus-sired cows, and body weights for Gelbvieh- and Gelbray-sired cows were similar. Calf 205-d weights for multiparous cows were heavier ($P < 0.01$) for BH cows than for Angus-, Brangus-, Gelbvieh-, and Gelbray-sired cows. In summary, weaning weights were heavier for Gelbray- and Simbrah-sired calves, and calves from BH cows were heavier at weaning than calves from Brangus and Beefmaster cows in S1. For S2, lower reproductive performance was exhibited by Brangus-sired females, and improved calf 205-d weight was achieved by BH females.

Key Words: Brahman, Breed Crosses, Cow-Calf, Weaning Weight

Introduction

Brahman (*Bos indicus*) genetics are characterized by tolerance to hot, humid climates and parasite challenges common to the southern region of the United States (Turner, 1980). In addition, the greater genetic divergence of Brahman inheritance relative to *Bos taurus* breeds offers heterotic (hybrid vigor) advantages when used in crossbreeding systems (Franke, 1980). This has resulted in the majority of commercial beef cattle herds in the southern United States being composed of crossbred cows with some degree of Brahman inheritance with British, Continental, and possibly dairy breeding. In addition, the majority of beef commercial herds are composed of a small number of cows with 78% of the U.S. beef herds having fewer than 50 cows (NASS, 2004). Small herd size precludes the use of many crossbreeding systems for most beef producers, due to the requirement for multiple breeding pastures or use of artificial insemination (Koger, 1980; Gregory and Cundiff, 1980). As a result of this limitation, production of crossbred replacement heifers of the

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desired breed composition presents a major problem for producers.

Formation of composite breeds for use in *inter se* matings, as an alternative to rotational crossbreeding, has the potential to offer desirable combinations of breeds (breed complementarity) and also maintain a moderate level of heterosis (Gregory and Cundiff, 1980). Brahman-derivative composite breeds have been developed for utilization by the commercial beef industry. Only limited studies have made direct comparisons among Brahman-derivative breeds.

Another possible alternative to rotational crossbreeding is using straightbred or Brahman-derivative composite sires mated to first cross dams (i.e., F_1 Brahman x British, F_1 Brahman x Continental) to produce three-breed cross replacement females. Three-breed rotational crossbred cow have been found to be superior in production over straightbred and two-breed rotation cows for reproductive and preweaning performances (Williams et al., 1990; Franke et al., 2001).

The objectives of these studies were to: 1) compare preweaning and weaning performances of "British" (Brangus and Beefmaster) and "Continental" (Gelbray and Simbrah) Brahman-derivative sired calves resulting from straightbred (*inter se*) and crossbred (F_1 Brahman-Hereford cows) matings; and 2) to compare reproductive and maternal performance of three-breed cross females resulting from mating Angus, Brangus, Gelbvieh, and Gelbray sires with F_1 Brahman x Hereford females.

Materials and Methods

Study 1. Brangus, Beefmaster, Gelbray, Simbrah, and F_1 Brahman-Hereford (BH) heifers and young cows were purchased over a 2-yr period. The 20 Brangus (5/8 Angus x 3/8 Brahman) cows were at least third-generation cows, except for 1 first-generation cow, were from 5 herds, and were sired by 5 bulls. The 20 Beefmaster (1/2 Brahman x 1/4 Hereford x 1/4 Shorthorn) cows were all advanced-generation purebreds, were from 9 herds and were sired by 13 bulls. It was necessary to purchase all of the Gelbray females from a single herd due to a lack of other sources of this breed. The 18 Gelbray cows were all first-generation purebreds (5/8 Gelbvieh x 3/8 Brahman) and were sired by 5 bulls. The 20 Simbrah (5/8 Simmental x 3/8 Brahman) cows (15 first-generation and 5 second-generation) were from 3 herds and were sired by 9 bulls. Thirty-five BH females were purchased from a single herd. Brangus (9), Beefmaster (12), Gelbray (10), and Simbrah (7) sires (i.e., those producing calves) were used in matings to dams of a like breed and in crossbred matings to BH dams to generate eight progeny breed groups as shown in Table 1. Breeding seasons began in mid-April and ended in mid-July (approximately 90 d) of each year. Matings for the first 60 d of the breeding season were by artificial insemination. Cleanup bulls were used for the remainder of the breeding season.

Cows were managed similarly throughout the year. During the summer and fall, cows grazed bermudagrass (*Cynodon dactylon* [L.] Pers.) and bahiagrass (*Paspalum notatum* Fluegge) pastures. In the late fall and winter, cows were fed warm-season, perennial grass hay and molasses-based protein supplements on an *ad libitum* basis. In late winter, and dependent upon forage availability, cows were allowed to limit-graze annual ryegrass (*Lolium multiflorum*) pastures. Following spring calving, cows with calves were removed from the calving herd and placed on a ryegrass pasture, remaining there until bermudagrass-bahiagrass pastures were available for grazing.

A total of 326 calves were born over a 5-yr period. Calf identification, sex, and birth weights were recorded within 24 h after birth. Male calves were castrated in April of each yr. Following standard management procedures, the calves were weaned in late September or early October of each yr. Cow traits evaluated were body weight and hip height at weaning. Maternal traits evaluated were calf birth, weaning, and adjusted 205-d (BIF, 1996) weights. More detailed information concerning experimental procedures for this study is presented in Wyatt et al. (2002).

Study 2. A total of 1,011 pregnancy and 752 calving records were collected. The mating scheme for producing the females in this study included mating BH cows to Angus, Brangus, Gelbvieh, and Gelbray sires to produce three-breed cross females. In addition, contemporary BH heifers of approximately the same age were purchased when the three-breed cross heifers were weaned. Percent Brahman inheritance was 25% in Angus- and Gelbvieh-sired females, 44% in Brangus- and Gelbray-sired females, and 50% in BH females. A total of 37 sires (9 Angus, 6 Brangus, 7 Gelbvieh, 7 Gelbray, and 8 Brahman or Hereford sires) were used to produce 244 females. An attempt was made to sample sires that were representative of the type of bulls used by commercial cow-calf producers in the southern United States.

The heifers were weaned over a 4-yr period and included 59 Angus-, 36 Brangus-, 57 Gelbvieh-, 42 Gelbray-sired, and 50 BH heifers. After weaning, heifers were managed similarly and developed on a forage-based diet. Spring-born heifers (n=152) were weaned in late September or early October and developed on prepared seedbed ryegrass pastures prior

to spring breeding. Fall-born heifers (n=92) were weaned in April and developed on bermudagrass pastures in the summer and wintered on bermudagrass hay supplemented with dried corn gluten meal followed with grazing on ryegrass pastures prior to spring breeding. Table 1 presents the mating scheme and dam breed composition of the females evaluated. Heifers were exposed to Red Poll bulls during a 60-d spring breeding season (May 1 to June 30) to calve first at 2 or 2 ½ yr of age. After their first calf, cows were exposed to Simmental bulls during a 60-d spring breeding season. For the last 3 breeding seasons, cows that were 4 yr and older were artificially inseminated with Simmental semen and then cleanup Simmental bulls were used 18 d after artificial insemination for 60 d. Cows ranged in age at calving from 2 to 8 yr of age.

Cows were managed similarly throughout the year. During the summer and fall, cows grazed bermudagrass pastures. In the late fall and winter, cows were fed bermudagrass hay with dried corn gluten meal. In late winter, cows were placed on ryegrass pastures shortly after calving. Cows remained on these pastures until bermudagrass pastures were available for grazing in the spring, summer, and early fall. Cows were weighed and body condition scored (BCS) using the 1 (emaciated) to 9 (obese) scoring system described by Vizcarra and Wettemann (1996) in January, April, July and October of each year (quarterly annual weights and scores).

A total of 752 calves were born over a 7-yr period. Calf identification, sex, and birth weight were recorded within 24 h after birth. Male calves were castrated at this time. Calves were weaned in late September or early October of each year. Heifers and cows were palpated at weaning to determine pregnancy status. Non-pregnant females were culled from the study. Cow traits evaluated were pregnancy rates by parity (first calving and subsequent calvings), body weight, and BCS. Maternal traits evaluated were calf birth, weaning, and adjusted 205-d (BIF, 1996) weights. More detailed information concerning experimental procedures for this study is presented in DeRouen et al. (2000).

Statistical Analyses. Data were analyzed using a generalized, linear, mixed-model. Sets of contrasts were constructed to further examine sire breed (Study 1), dam breed (Study 1 and 2), and dam breed within sire breed (Study 1) differences. Means generated from analyses were estimated least squares means.

Table 1. Mating schemes of sire and dam breeds by study.

Study 1[a]			Study 2[b]		
Sire breed		Dam breed	Sire breed[c]		Dam breed
BN	x	BN	RP / SM	x	AN-sired ($AN_2B_1H_1$)
	x	BH			
BM	x	BM	RP / SM	x	BN-sired ($B_7AN_5H_4$)
	x	BH			
GE	x	GE	RP / SM	x	GV-sired ($GV_2B_1H_1$)
	x	BH			
SI	x	SI	RP / SM	x	GE-sired ($B_7GV_5H_4$)
	x	BH			
			RP / SM	x	BH (B_1H_1)

[a]BN = Brangus, BM = Beefmaster, GE = Gelbray, SI = Simbray, BH = F_1Brahman-Hereford.

[b]RP = Red Poll, SM = Simmental, AN = Angus, B = Brahman, GV = Gelbvieh, H = Hereford; subscripts denote portion of breed composition (i.e., $AN_2B_1H_1$ represents ½ Angus – ¼ Brahman – ¼ Hereford).

[c]Red Poll bulls exposed to heifers for their first calf and Simmental bulls exposed to primi – and multiparious cows.

Table 2. Cow body weight (BW), hip height, and body condition score (BCS) by study.

Study 1				Study 2			
Dam breed[a]	n	BW at weaning, lb	n	Height at weaning, in	Dam breed[a]	n	BW, lb[b]	BCS[b]
BN	43	1105	33	53.1	AN-sired	172	1292	5.66
BM	51	988	36	52.0	BN-sired	38	1166	5.40
GE	35	1109	17	52.0	GN-sired	139	1210	5.53
SI	54	1208	39	55.5	GE-sired	87	1179	5.31
BH	96	996	66	51.6	BH	134	1225	5.62
Pooled SE		26		0.39			37	0.12
Probability level		< 0.01		< 0.01			0.09	0.14
		Dam breed contrasts						
BN vs BM		117± 23**		1.1± 0.4**	AN vs BN		126± 61*	0.26 ± 0.20
GE vs SI		-99 ± 25**		-3.5 ± 0.5**	GV vs GE		31 ± 48	0.23 ± 0.15
BH vs (BN + BM)/2		-51± 17**		-1.0 ± 0.3**	BH vs (AN + BN)/2		-3± 44	0.08 ± 0.13
BH vs (GE + SI)/2		-163 ± 17**		-2.3 ± 0.4**	BH vs (GV + GE)/2		31 ± 39	0.20 ± 0.12

[a]Refer to Table 1 for description of dam breeds.
[b]The average of annual quarterly (January, April, July, October) body weights and body condition scores of mature cows (3 to 8 years of age).
** $P < 0.01$.

Results and Discussion

Cow traits

Study 1. Both cow weight and height differed ($P < 0.01$) among dam breeds (Table 2). Brangus cows weighed more and were taller at weaning than Beefmaster cows ($P < 0.01$). Average weight and height at weaning of Brangus and Beefmaster cows (1,046 lb and 52.6 in) were greater ($P < 0.01$) than that of BH cows. Simbrah cows weighed more and were taller at weaning than Gelbray cows ($P < 0.01$). Average weight and height at weaning of Gelbray and Simbrah cows (1,159 lb and 53.7 in) were also greater ($P < 0.01$) than that of BH cows. Gregory et al. (1992a) reported similar average body weights for Gelbvieh and Simmental cows, but did observe a greater hip height for Simmental than for Gelbvieh cows. Relative to body weight at weaning of BH cows, Beefmaster cows were of similar size, Brangus and Gelbray cows were 11% heavier, and Simbrah cows were 21% heavier.

Study 2. The average of annual quarterly body weights tended to differ ($P < 0.10$) among dam breeds (Table 2). Angus-sired cows had heavier ($P < 0.05$) body weights compared with Brangus-sired cows. The average body weight of Angus- and Brangus-sired cows did not differ from BH cows. Gelbvieh- and Gelbray-sired cows were similar in body weight and the average body weight of Gelbvieh- and Gelbray-sired cows did not differ from BH cows. Although not tested statistically, body weights for Brangus- and Gelbray-sired and BH cows in Study 2 were heavier than body weights for Brangus, Gelbray and BH cows in Study 1. Average of annual quarterly BCS did not differ ($P = 0.14$) among dam breeds. Mean BCS ranged from 5.31 to 5.66 indicating little variation existed among dam breeds for BCS.

Pregnancy rates for heifers (first exposure), first-calving cows (second exposure), and mature cows (3 to 8 yr of age) are shown in Table 3. Dam breed affected ($P < 0.01$) pregnancy rate for first- and second-exposure heifers. For first exposure pregnancy rates, Angus-, Gelbvieh-, Gelbray-sired, and BH heifers had rates ranging from 86 to 92%, whereas Brangus-sired heifers were considerably lower at 64%. This pattern of lower fertility for Brangus-sired heifers was exhibited also at second exposure (first-calf cows). Brangus-sired females had pregnancy rates of 54%, whereas the other dam breeds ranged from 84 to 91%. Dam breed tended to affect ($P < 0.10$) pregnancy rate for mature cows with Brangus-sired cows again having lower pregnancy

rates. The only contrasts that were significant were those involving the Brangus-sired females due to the low pregnancy percentage exhibited by this dam breed. With the exception of the Brangus-sired females, reproductive performance was acceptable and similar among Angus-, Gelbvieh-, Gelbray-sired, and BH females across all parities. It should be noted that there was a lower number of Brangus-sired females produced and available for study (98 reproductive records) relative to the other four dam breeds (163 to 279 reproductive records), so some caution should be considered regarding inferences made of low fertility being associated with Brangus-influenced females. Conversely, Turner et al. (1968) found similar calving rates for Brangus cows compared with Brahman, Angus, and Hereford cows. Setshwaelo et al. (1990) reported non-significant Brangus breed effects relative to Angus-Hereford females for conception rate. Furthermore, Winder et al. (1992) reported that Brangus females had higher weaning percentages than Hereford females measured both as young (2 and 3 yr olds) and as mature (4 to 7 yr olds) females. Cundiff et al. (2004) found that first exposure pregnancy rates for Brangus-sired heifers were similar (92%) compared with other heifer sire breeds (Angus, Hereford, Beefmaster, Bonsmara, and Romosinuano).

Calf Preweaning Traits

Study 1. Calf birth, weaning, and adjusted 205-d weights for Study 1 are presented in Table 4 by the eight sire breed x dam breed mating groups. Calf birth weight tended to be affected ($P < 0.10$) by sire breed and was affected ($P < 0.01$) by dam breed within sire breed. Birth weights were similar for Brangus- and Beefmaster-sired calves. Crockett et al. (1979) reported a 4.6-lb heavier birth weight for Beefmaster-sired than for Brangus-sired calves. In a review article, Thrift (1997) reported that Brangus- and Beefmaster-sired calves weighed a respective 11 and 7 lb less at birth than Brahman-sired calves. Birth weights were also similar for Gelbray- and Simbrah-sired calves. Direct comparisons between Gelbray- and Simbrah-sired calves are not available in the literature; however, birth weights have been reported to be similar for Gelbvieh- and Simmental-sired calves (Gregory et al., 1991). Brangus- and Beefmaster-sired calves had lower ($P < 0.05$) birth weights than Gelbray- and Simbrah-sired calves (Table 4). Pala et al. (2000) reported similar birth weights for Brangus- and Gelbvieh-sired calves.

Straightbred Brangus calves were 6 lb heavier ($P < 0.05$) at birth than were Brangus-sired calves out of BH dams (Table 4). Birth weights were similar for Beefmaster-sired calves out of Beefmaster and BH

Table 3. Pregnancy rates of first exposure (1 and 1½ year olds), second exposure (2 and 2½ year olds), and mature (3 to 8 years) females – Study 2.

	First exposure females		Second exposure females		Mature females	
Dam breed[a]	n	Pregnancy rate, %	n	Pregnancy rate, %	n	Pregnancy rate, %
AN-sired	59	86	48	90	172	96
BN-sired	36	64	24	54	38	81
GV-sired	54	91	50	91	139	96
GE-sired	42	93	34	84	87	89
BH	50	92	44	84	134	95
Pooled SE		5.9		6.0		3.4
Probability level		< 0.01		< 0.01		0.09
			Dam breed contrasts			
AN vs BN		23 ± 8.1**		36 ± 9.2**		15 ± 6.0*
GV vs GE		-2 ± 7.8		7 ± 8.1		6 ± 4.2
BH vs (AN+BN)/2		17 ± 6.8*		12 ± 7.0		7 ± 4.1
BH vs (GV + GE)/2		0 ± 6.7		-3 ± 6.7		3 ± 3.5

[a]Refer to Table 1 for description of dam breeds.
*$P < 0.05$; ** $P < 0.05$.

Table 4. Calf birth, weaning, and adjusted 205-d weights – Study 1.

Sire breed[a]	Dam breed[a]	n	Birth weight, lb[cd]	Weaning weight, lb[bd]	Adjusted 205-d weight, lb[bd]
BN	BN	51	81	408	463
	BH	23	75	492	562
BM	BM	60	79	439	489
	BH	30	78	474	540
GE	GE	42	87	463	531
	BH	25	77	467	531
SI	SI	62	92	509	564
	BH	33	80	492	553
Pooled SE			3.3	19	36.2
			Sire breed contrasts		
BN vs BM			-0.2 ± 2.6	-4 ± 10.4	-2 ± 11.7
GE vs SI			-3.7 ± 2.9	-35 ± 10.5**	-29 ± 11.7*
(BN + BM)/2 vs (GE + SI)/2			-5.1 ± 2.2*	-29 ± 7.5**	-33 ± 8.4**
			Dam breed contrasts (within sire breed)		
BN vs BH			6.0 ± 2.9*	-84 ± 15.4**	-99 ± 17.2**
BM vs BH			0.9 ± 2.6	-35 ± 13.9*	-51 ± 15.4**
GE vs BH			10.6 ± 2.9**	4 ± 15.4	0 ± 17.4
SI vs BH			12.6 ± 2.4**	17 ± 13.2	9 ± 14.8

[a] Refer to Table 1 for description of sire and dam breeds.
[b] Sire breed effect ($P < 0.01$).
[c] Sire breed effect ($P < 0.10$).
[d] Dam breed within sire breed effect ($P < 0.01$).
*$P < 0.05$; **$P < 0.01$.

dams. Straightbred Gelbray and Simbrah calves were 10.6 to 12.6 lb heavier ($P < 0.01$) than Gelbray- and Simbrah-sired calves out of BH dams. Calf birth weight differences among dam breeds in this study are possibly associated with dam breed differences in percentage of Brahman breeding (38% in Brangus, Gelbray, and Simbrah vs 50% in Beefmaster and BH). A suppressing effect on calf birth weight of dams with Brahman breeding (Ellis et al., 1965) has been reported and is further supported by a negative maternal additive effect for birth weight of calves born to Brahman dams (Wyatt and Franke, 1986). Calving difficulty (dystocia) was extremely low for all dam breed types (0, 4.0, 2.3, 4.5, and 3.3% for BH, Brangus, Beefmaster, Gelbray, and Simbrah cows, respectively) in this study.

Calf weaning weight and adjusted 205-d weight were affected ($P < 0.01$) by both sire breed and dam breed within sire breed (Table 4). Brangus- and Beefmaster-sired calves had similar weaning and 205-d weights. Winder et al. (2000) reported heavier weaning weights for calves from Beefmaster than from Brangus dams, but calf 205-d adjusted weights were similar between calves from Beefmaster and Brangus dams. Simbrah-sired calves had heavier weaning ($P < 0.05$) and adjusted 205-d ($P < 0.01$) weights than Gelbray-sired calves. Conversely, Gregory et al. (1992b) reported similar 200-d weights for Gelbvieh- and Simmental-sired calves. Gelbray- and Simbrah-sired calves had heavier ($P < 0.01$) weaning and adjusted 205-d weights than Beefmaster- and Brangus-sired calves. Thrift (1997) reported lower weaning weights for Brangus- and Beefmaster-sired calves relative to Brahman-sired calves and also reported a slightly higher weaning weight for Simbrah-sired calves when compared with Brahman-sired calves. Pala et al. (2000) reported similar weaning weights for Gelbvieh- and Brangus-sired calves as well as for calves out of Brangus-Hereford and Gelbvieh-Hereford cows.

Dam breed within the British-Brahman sire breeds affected ($P < 0.01$) calf weaning and 205-d adjusted weights (Table 4). Brangus-sired calves with BH dams were 84 and 99 lb heavier ($P < 0.01$) for weaning and 205-d weights, respectively, than calves with Brangus dams. Likewise, weaning ($P < 0.05$) and 205-d adjusted ($P < 0.01$) weights were higher for Beefmaster-sired calves with BH dams than with Beefmaster dams. Weaning and 205-d adjusted weights for Gelbray- and Simbrah-sired calves were similar between BH dams and Gelbray or Simbrah dams (Table 4). The lack of difference between the

Gelbray and Simbrah purebreds and crossbreds could possibly be attributed to the Continental-Brahman composite cows having larger maternal and direct additive genetic influences on weaning weight than did the two British-Brahman composite cows. Also, residual heterosis for maternal traits expressed in the first- and second- generation Gelbray and Simbrah cows compared with the advanced-generation (> 3 generation) Brangus and Beefmaster cows may have partially contributed to increased weaning weights by the Continental-Brahman composite cows.

Study 2. Calf birth weight was not affected ($P = 0.40$) by dam breed for cows with their first calf (Red Poll-sired calves) or for cows calving after their first parity (Simmental-sired calves) (Table 5). Birth weights of Red Poll-sired calves were similar and ranged from 71 to 74 lb among the dam breeds. Simmental-sired calves were similar also and ranged from 91 to 95 lb among dam breeds. In contrast to what was found in Study 1, calf birth weight was not influenced by level of Brahman inheritance in the dam. Those cows with 25% Brahman breeding (Angus- and Gelbvieh-sired cows) had similar calf birth weights to those cows with 44% (Brangus- and Gelbray-sired cows) and 50% (BH) Brahman inheritance. In agreement with Study 1, however, calving difficulty was extremely low (< 2.0% assisted births) across all dam breeds.

Calf weaning performance is presented also in Table 5 by first and subsequent parities among the dam breeds. For first calving, weaning weight ($P < 0.07$) and adjusted 205-d weight ($P < 0.05$) were affected by dam breed. Red Polled-sired calves reared by BH dams had heavier weaning ($P < 0.05$) and adjusted 205-d weights ($P < 0.01$) than the average of calves reared by Angus- and Brangus-sired females. Likewise, Red Polled-sired calves raised by BH dams had heavier weaning ($P < 0.05$) and adjusted 205-d weights ($P < 0.01$) than the average of calves raised by Gelbvieh- and Gelbray-sired females (Table 5). For Simmental-sired calves (dams calving from 3 to 8 yr of age), weaning weight ($P < 0.13$) and adjusted 205-d weight ($P < 0.10$) tended to be influenced by dam breed. Similar rankings for calf weaning and 205-d weights existed among the dam breeds for mature cows as were found for first-calving females. Weaning and adjusted 205-d weights for calves from BH cows were 30 lb heavier ($P < 0.05$) than the average of calves from Angus- and Brangus-sired cows. The advantages exhibited by BH cows for maternal ability in Study 2 concur with Study 1 in that BH cows were superior to Brangus and Beefmaster cows for calf weaning weights. Conversely, Cartwright et al. (1964) found that Braford (5/8 Hereford x 3/8 Brahman) cows had calf weaning weights that were 20 lb less than calves from Brahman cows. In a review article, Franke (1980) reported that maternal heterosis for weaning weight of BH cows was large and ranged from 30.7 to 34.4%. In Study 2, weaning and adjusted 205-d weights for calves from BH cows were 26 to 27 lb heavier ($P < 0.05$) than the average of calves from Gelbvieh- and Gelbray-sired cows. This superiority of BH cows for maternal ability relative to Continental-influenced cows is not supported in Study 1, which found no difference in weaning weights among calves reared by BH, Gelbray, and Simbrah dams.

Implications

Heavier calf weaning weights of Gelbray- and Simbrah-sired calves compared with Brangus- and Beefmaster-sired calves would be a production benefit to consider for sire breed selection among Brahman-derivative breeds. The substantially lower fertility exhibited by crossbred Brangus-sired females would be a major factor to consider for reproductive efficiency. The superior maternal ability along with acceptable reproductive performance exhibited by F_1 Brahman-Hereford cows are important attributes to consider when deciding what type of dam breed composition to use for commercial cow-calf production.

Table 5. Calf birth, weaning, adjusted 205-d weights – Study 2.

	First-calving cows[b]				Mature cows[c]			
Dam breed[a]	n	Birth wt, lb	Weaning wt, lb	Adjusted 205-d wt, lb	n	Birth wt, lb	Weaning wt, lb	Adjusted 205-d wt, lb
AN-sired	46	74	494	537	174	94	550	554
BN-sired	24	73	490	531	36	91	550	555
GV-sired	50	73	503	546	133	94	559	564
GE-sired	33	71	485	527	85	95	550	551
BH	42	72	518	558	129	92	580	584
Pooled SE		4.8	8.7	8.2		2.7	12	12
Probability level		0.40	0.07	0.05		0.87	0.13	0.10
				Dam breed contrasts				
AN vs BN		1.3 ± 2.2	4.5 ± 13.2	6.2 ± 12.6		2.3 ± 4.3	0 ± 19.7	1.3 ± 19.5
GV vs GE		2.7 ± 2.0	18.5 ± 11.8	18.9 ± 11.1		-0.4 ± 3.1	9 ± 14.5	13.0 ± 14.3
BH vs (AN + BN)/2		-2.0 ± 1.7	26.4 ± 10.2*	26.4 ± 9.7**		-0.2 ± 2.8	30 ± 13.3*	29.8 ± 13.2*
BH vs (GV + GE)/2		-0.6 ± 1.6	24.2 ± 9.7*	23.8 ± 9.2**		-2.2 ± 2.4	26 ± 11.6*	26.7 ± 11.4*

[a]Refer to Table 1 for description of dam breeds.
[b]First-calving at 2 or 2 ½ years of age; Red Poll-sired calves.
[c]Calving from 3 to 8 years of age; Simmental-sired calves.
*$P < 0.05$; **$P < 0.01$.

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Feedlot Performance and Carcass Characteristics of Brahman x British and Brahman x Continental Beef Steers[1]

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ABSTRACT: Two studies were conducted to evaluate British-Brahman [Angus (AN), Hereford, Shorthorn; British-BR] and Continental-Brahman [Gelbvieh (GV), Simmental; Continental-BR] breeds and breed crosses for steer feedlot performance and carcass characteristics. Angus (12), Beefmaster (9), Brangus (BN; 12), Gelbray (GE; 9), and Simbrah (6) sires were mated to cows of their own breed and to Brahman x Hereford F_1 (B_1H_1) cows to generate the 209 steers utilized in Study 1 (S1). The 231 steers used in Study 2 (S2) were sired by AN (9), BN (6), GV (7), and GE (7) bulls mated to B_1H_1 cows. Breed combinations common to both studies were BN- and GE-sired steers having B_1H_1 dams. All steers were spring born in S1 and spring and fall born in S2. Continental-BR steers required more days on feed ($P < 0.05$) to reach the targeted physiological end point (10 mm backfat) than British-BR steers in both studies. Hot carcass weight was greater ($P < 0.01$) for Continental-BR than British-BR in S1 but was similar in S2. Dressing percentage did not differ between Continental-BR and British-BR in either study. Longissimus (LM) area was greater ($P < 0.01$) for Continental-BR than British-BR in S1, but no consistent advantage was observed in S2. Marbling score did not differ between Continental-BR and British-BR in S1, but was generally greater ($P < 0.05$) for British-BR than Continental-BR in S2. In general, shear force of the LM (and sensory evaluation for tenderness) was similar between Continental-BR and British-BR in S1, but shear force tended to be less for British-BR than Continental-BR steers in S2. Despite the increase in days on feed and carcass weight for Continental-BR steers, consistent differences in beef cutability and quality were not observed between Continental-BR and British-BR steers in the two studies.

Key words: Brahman, Breed Crosses, Carcass Traits, Feedlot Performance, Tenderness

Introduction

Tolerance to the hot climate and parasite challenges endemic to the southern region of the United States, coupled with the direct and maternal heterotic advantages of crossbreeding (Franke, 1980), have been the basis of the widespread infusion of Brahman genetics within southern beef herds (Turner, 1980). Composite breeds, containing some percentage of Brahman breeding (Brahman-influence or –derivative; usually 3/8), were developed to be utilized as general purpose straightbreds by the commercial industry; some of these breeds are very popular, however, there is limited scientific literature available on the feedlot performance and carcass traits of the Brahman-derivative breeds (Marshall, 1994 and Franke, 1997.). There are numerous reports on Brangus (Damon et al., 1960; Cundiff et al., 1993) but limited reports on the carcass and (or) palatability traits of Beefmaster (Crockett et al., 1979), Braford (O'Conner et al., 1997), Santa Gertrudis (Cundiff et al., 1993), and Simbrah (O'Connor et al., 1997). Two studies were initiated in Louisiana that had the common objective of comparing British-Brahman and Continental-Brahman breed resources for feedlot performances and carcass trait evaluations. The objectives of these studies are to present the feedlot performance and carcass trait evaluation of Brahman-derivative breeds that include both British (Angus, Hereford, and Shorthorn) and Continental (Gelbvieh and Simmental) breeding. Additional discussion will include the comparison of straightbred Angus to Brahman-influenced breeds and the effect of varying proportions of Brahman breeding on feedlot performances and carcass trait evaluations.

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Materials and Methods

Source of information. Information for this paper was derived from two different studies, both of which were conducted in Louisiana. The first study (**S1**) was conducted in 1989 through 1992 and used the following breed resources: Angus, Beefmaster, Brangus, Gelbray, Simbrah, and Brahman-Hereford F_1. The second study (**S2**) included Angus, Brangus, Gelbvieh, Gelbray, and Brahman-Hereford F_1 breed resources and was conducted in 1993 through 1996. Both studies contained information regarding the use of British-Brahman and Continental-Brahman breed combinations (Brahman, **BR**, being the tropically adapted breed). Feedlot performance and carcass characteristics data for this paper were taken from DeRouen et al. (2000), Bidner et al. (2002), and Wyatt et al. (2002).

Study 1. Brangus (**BN**, 9), Beefmaster (**BM**, 12), Gelbray (**GE**, 10), and Simbrah (**SI**, 7) sires were used in matings to dams of a like breed (i.e., BN bulls on BN cows) and in crossbred matings to Brahman-Hereford F_1 (**B_1H_1**) dams to generate eight progeny breed groups (Table 1). Calves were born in the spring over a 5-yr period at the Idlewild Research Station, Clinton. Following fall-weaning (late September or early October), steer calves (209) were annually transported approximately 50 mi to the St. Gabriel Research Station, St. Gabriel, fed hay and supplement (maintenance level) on a preconditioning program until forage growth was sufficient for stocking on annual ryegrass pastures. Following the preconditioning period, all steers were implanted with zeranol (Ralgro, Schering-Plough Animal Health Corp., Union, NJ) and grazed annual ryegrass pastures as a single group from early winter through spring of the following year.

Straightbred Angus (**AN**; 12 sires) bull calves were born each spring over a 5-yr period and were weaned and castrated in the fall of their birth year at the Iberia Research Station, Jeanerette. Angus steers were randomly selected at weaning and transported (90 mi) to the St. Gabriel Research Station. They were then combined with steer calves from the remaining breed groups for a common preconditioning and stocker program.

A total of 209 steers were available over the 5-yr period for feedlot comparisons. Steers were vaccinated for protection against infectious bovine rhinotracheitis virus, bovine virus diarrhea, parainfluenza type 3, bovine respiratory syncytial virus, Clostridia, and *Haemophilus somnus*; administered a combination anthelmintic- (ivermectin) flukecide (clorsulon; Ivomec Plus, Merial Limited, Iselin, NJ); implanted with zeranol (Ralgro); and administered oxytetracycline (i.m. injection; Pfizer Animal Health, Exton, PA) in mid- to late May of each year. Steers were then transported (100 mi) from the St. Gabriel Research Station to the Iberia Research Station for feeding.

Study 2. Angus (9), BN (6), Gelbvieh (**GV**, 7), and GE (7) sires were mated to B_1H_1 dams to produce spring- and fall-born calves over a 4-y period (Table 1) at the Hill Farm Research Station, Homer. Spring-born steer (castrated at birth) calves (132) were born from early February through mid-April and were weaned in September. Fall-born steer (castrated at birth) calves (99) were born from late July through early October and were weaned in April.

Following weaning, steer calves were fed hay and supplement (maintenance level) on a preconditioning program until forage growth was sufficient for stocking on either rye/annual ryegrass (spring-born calves) or bermudagrass (fall-born calves) pastures at the Hill Farm Research Station. Both spring- and fall-born steers were implanted with zeranol (Ralgro, Schering-Plough Animal Health Corp., Union, NJ) at the initiation of their respective stocker phases. Spring- (68) and fall-born (46) calves in the first two years of the study were respectively shipped (240 mi) in May and September of each year to the feedlot facilities at the Iberia Research Station, Jeanerette (**S2LA**). Prior to shipment, steers were routinely vaccinated for protection against infectious bovine rhinotracheitis virus, bovine virus diarrhea, parainfluenza type 3, bovine respiratory syncytial virus, Clostridia, and *Haemophilus somnus*; administered a combination anthelmintic- (ivermectin) flukecide (clorsulon; Ivomec Plus, Merial Limited, Iselin, NJ); implanted with zeranol (Ralgro); and administered oxytetracycline (i.m. injection; Pfizer Animal Health, Exton, PA).

It was decided at the mid-point of this study (Study 2) that the feeding and finishing of steers should be done in one of the major feeding and processing areas of the country. Therefore, spring- (64) and fall-born (53) calves in the latter two years of the study were respectively shipped (700 mi) in May and September to a commercial feedlot in Guymon, OK (**S2OK**).

Feedlot and slaughter phase. S1 and S2LA. Steers were allotted to one of six to eight pens (six to eight steers per pen) approximately 1 wk after arrival at the feedlot facilities, at which time the feedlot trial was initiated. To the extent possible, breed types were evenly distributed across pens annually. Steers were fed a ground corn-cottonseed hulls diet (76.5% and 15.7% as fed, respectively; 89% DM, 12% CP, 1.9 mcal/kg NE_m, and 1.3 mcal/kg NE_m). A shrunk weight (feed and water withdrawn for 18 h) was

obtained at the initiation of the trial. Fat cover over the 13th rib was evaluated by ultrasound (Scanner 400 Veterinary Ultrasound System, Pie Data Medical, Maastricht, The Netherlands) and subjectively by a trained evaluator on the first day of the trial.

After 84 d on feed and at 28-d intervals thereafter, steers were weighed and evaluated (ultrasonically and subjective visually) for fat cover. Steers attaining 0.4 in of backfat were weighed (feed withdrawal for approximately 18 h) the following day and transported (80 mi) to the Animal Science Department of the LSU Agricultural Center, Baton Rouge. In S1, steers failing to attain 0.4 in of fat cover during the trial period were slaughtered at the termination of the trial (typically the following February). In Study 2 (LA), steers failing to attain 0.4 in of fat cover following 140 d on feed were serially harvested (fattest third of remaining steers) at three subsequent 28-d intervals (168, 196, and 224 d on feed). Steers were weighed and slaughtered at the LSU Agricultural Center Meats Laboratory, Baton Rouge.

The carcasses were ribbed, and standard carcass data were collected by trained university personnel after a 2-d chilling period. Factors used to determine USDA yield grade (hot carcass weight, adjusted fat thickness, longissimus area (**LMA**), and estimated kidney, pelvic, and heart fat percentage) and quality grade (skeletal maturity, lean color, and marbling score) were recorded (USDA, 1989). Upon completion of the grading procedure, the 9th through the 11th rib section was removed from the right side of each carcass and separated into lean, fat, and bone. The boneless longissimus thoracic muscle was vacuum packaged and aged at 35°F for 10 d postmortem. This portion was frozen and 1-in frozen steaks were removed from the anterior end for sensory panel and Instron (Canton, MA) analyses with a Warner-Bratzler shear head. Steaks were later thawed and cooked to an internal temperature of 158°F for Instron shear (Boleman et al., 1995). The procedure for determination of Instron shear values was the same as the procedure described by Koh et al. (1987). The Instron Model 4501 Universal Testing Instrument was equipped with a Warner-Bratzler shear device and a crosshead speed of 100 mm/min.

Feedlot and slaughter phase. S2OK. Steers were group-fed a corn-based feedlot ration. Growth implants (Synovex-S®; 200 mg progesterone and 20 mg estradiol benzoate) were administered at the beginning of the finishing period. The feeding end point was determined by subjective estimation for backfat thickness by trained personnel at the feedlot. Once it was determined that the average backfat thickness of 0.4 inches was attained for the feeding group, steers were transferred to a nearby packing facility and harvested.

Carcass data were obrtained by trained personnel from the Cattlemen's Carcass Data Service (West Texas A&M University, Canyon, TX). The same procedures were used for obtaining carcass data as indicated above for steers fed in Louisiana. A portion of the longissimus from the 12th rib was obtained for shear force determinations and aged 10 d postmortem before blast-freezing and shipping to the Meats Laboratory, LSU Animal Science Department, Baton Rouge. Procedures for the Warner-Bratzler shear force determinations were identical to that described for S2LA.

Statistical analyses. A total of 209 and 231 steer feedlot and carcass records were collected for Studies 1 and 2 (114 and 117 steers for LA and OK), respectively (Table 1). Postweaning gain, feedlot, harvest, and carcass data in both studies were analyzed as randomized block designs using a generalized, linear, mixed-model procedure (PROC MIXED with the REML estimation method; Littell et al., 1996). In S1, the linear model included calf crop year and calf sire within sire breed as random effects and sire breed and dam breed within sire breed as fixed effects. Age of steer upon entry into the feedlot was included as a covariate for feedlot and harvest traits. Sire breed effect was further partitioned into single degree-of-freedom contrasts (Table 1). In S2, data from LA and OK were analyzed separately, but with similar analyses. The linear model included calf sire within sire breed, calf crop year, calf crop year x sire breed, and calf crop year x season of feeding as random effects and sire breed season of feeding and sire breed x season of feeding as fixed effects. Sire breed effect was further partitioned into single degree-of-freedom contrasts (Table 1).

Specific overlaps of the two studies include BN- and GE- sired calves (out of B_1H_1 dams). Specific contrasts of interest are the **Bri-Cont** (British x Brahman vs Continental x Brahman; where **Bri** contains both BN- and BM-sired steers and **Cont** includes both GE- and SI-sired steers; S1) and **BN-GE** (BN-sired steers vs GE-sired steers; S2LA and S2OK) contrasts. The former term (minuend) in each contrast has a 44-46% BR and a 54-56% British breed component and the latter term (subtrahend) has a 41-44% BR, 12-25% British, and a 31-47% Continental breed components (Table 1). These overlaps provide a means whereby the two studies may be "combined" for discussion of the influence of British x Brahman and Continental x Brahman breed combination effects on feedlot performances and carcass traits.

Table 1. Mating schemes (sire and dam breed), numbers of steers, steer breed compositions, and sire-contrasts breed compositions.

Breed of		Number of steers			Steer breed composition[a]				Breed group composition						
		Study 1	Study 2			Percentage, %			Minuend				Subtrahend		
Sire	Dam	LA[b]	LA[b]	OK[b]	Code	BR	Bri	Con	B	Bri	Con	vs	B	Bri	Con
Angus (AN)	AN	48			AN	0	100	0							
	B_1H_1[c]		30	30	$AN_2B_1H_1$	25	75	0							
Brangus (BN)	BN	25			BN	38	62	0							
	B_1H_1	11	27	39	$BN_2B_1H_1$	44	56	0							
Beefmaster (BM)	BM	34			BM	50	50	0							
	B_1H_1	14			$BM_2B_1H_1$	50	50	0							
Gelbvieh (GV)	B_1H_1		26	23	$GV_2B_1H_1$	25	25	50							
Gelbray (GE)	GE	19			GE	38	0	62							
	B_1H_1	12	31	25	$GE_2B_1H_1$	44	25	31							
Simbrah (SI)	SI	31			SI	38	0	62							
	B_1H_1	15			$SI_2B_1H_1$	44	25	31							
Sire breed contrasts															
Study 1															
AN-Rest										100		vs	43	34	23
Bri-Cont									46	54		vs	41	12	47
BN-BM									41	59		vs	50	50	
GE-SI									41	59		vs	41	59	
Study 2															
AN-GV									25	75		vs	25	25	50
BN-GE									44	56		vs	44	25	31
25BR-44BR									25	50	25	vs	44	41	15

[a]Steer breed composition is depicted in conventional coding and percentages of breed group composition, i.e., Brahman (BR), British (Bri), and Continental (Con).
[b]LA = Feedlot facilities at the Iberia Research Station, Jeanerette, La.; OK = commercial feedlot facilities in Guymon, Okla.
[c]Brahman x Hereford F_1 cow.

Results and Discussion

The comparison of British x Brahman and Continental x Brahman is the main objective of this paper. However, S1 also provides a comparison of straightbred Angus to Brahman-influenced steers (**AN-REST**), and S2LA and S2OK also provide a comparison of percentage Brahman breeding (25 vs 44%; **25BR-44BR**) affecting feedlot performance and carcass traits. Therefore, the order of discussion will be to contrast straightbred Angus to Brahman-influenced steers (S1), 25% to 44% Brahman breeding (S2LA and S2OK), and last, British x Brahman to Continental x Brahman breeding (S1, S2LA, and S2OK). This convention will be followed throughout the paper.

Initial feedlot weight, feedlot ADG, days on feed, and final feedlot weight were affected ($P < .05$) by sire breed in S1 and S2LA, but not in S2OK (Table 2). Sire breed affected carcass weight ($P < 0.01$), dressing percentage ($P < 0.05$), longissimus area ($P < 0.01$), and tended to affect backfat thickness ($P < 0.10$) in S1 (Table 3). Hot carcass weight and backfat thickness were affected ($P < 0.01$ and $P < 0.10$, respectively) by sire breed in S2LA, but not in S2OK. Longissimus muscle area was affected ($P < 0.05$) by sire breed in S2LA and S2OK. Marbling score ($P < 0.10$), USDA quality grade ($P < 0.01$), and Warner-Bratzler shear force ($P < 0.05$) were affected by sire breed in S1 (Table 4). Marbling score was affected ($P < 0.01$) by sire breed in both S2LA and S2OK. USDA quality grade was affected by sire breed in S2LA ($P < 0.01$) and in S2OK ($P < 0.10$), whereas, USDA yield grade was affected ($P < 0.05$) by sire breed only in S2OK. Sire breed affected ($P < 0.10$) Warner-Bratzler shear force in S2LA, but not in S2OK.

Angus vs Brahman-influenced breeds. In S1, straightbred Angus steers weighed 5% less ($P < 0.10$) upon entry into the feedlot, spent 55 fewer days ($P <$

Table 2. Sire breed effects on initial feedlot weight, feedlot ADG, days on feed, and final feedlot weight (Study 1 and 2).

	Initial feedlot wt, lb			Feedlot ADG, lb			Days on feed, d			Final feedlot wt, lb		
	Study 1	Study 2		Study 1	Study 2		Study 1	Study 2		Study 1	Study 2	
Sire breed[d]	LA[ab]	LA[ab]	OK[a]	LA[b]	LA[b]	OK	LA[c]	LA[b]	OK	LA[c]	LA[c]	OK
Angus	679	842	776	2.58	2.58	3.57	140	167	-	1034	1272	1239
Brangus	708	798	743	2.71	2.58	3.70	181	162	-	1177	1215	1228
Beefmaster	703			2.71			185			1175		
Gelbvieh		877	756		2.47	3.42		183	-		1329	1199
Gelbray	690	791	752	2.62	1.90	3.55	204	195	-	1199	1162	1210
Simbrah	767			2.67			211			1323		
Pooled SE	31	18	15	0.15	0.13	0.15	14	8		31	24	29
Sire breed contrasts												
Study 1												
AN-Rest	-37[†]			-0.09			-54[**]			-183[**]		
Bri-Cont	24			0.07			-25[*]			-84[**]		
BN-BM	4			0.00			-5			4		
GE-SI	-77[**]			-0.04			-7			-123[**]		
Study 2												
AN-GV		-35	20		0.11	0.15		-16[*]	-		-57	40
BN-GE		7	9		0.68[**]	0.15		-33[**]	-		53	18
25BR-44BR		64[**]	20		0.29[*]	-0.13		-4	-		112[**]	0

[†] $P < 0.10$; [*] $P < 0.05$; [**] $P < 0.01$.

[a]LA = Feedlot facilities at the Iberia Research Station, Jeanerette, La.; OK = commercial feedlot facilities in Guymon, Okla.

[bc]Sire breed effect ($P < 0.05$ and $P < 0.01$, respectively).

[d]Breed: AN = Angus; BN = Brangus; BM = Beefmaster; GV = Gelbvieh; GE = Gelbray; SI = Simbrah. Contrasts: AN-Rest = AN – (BN + BM + GE + SI); Bri-Cont = (BN + BM) – (GE + SI); 25BR-44BR = (AN + GV) – (BN + GE) where 25BR = Brahman breed percentage of 25%; 44BR = Brahman breed percentage of 44%.

0.05) in the feedlot, and weighed 15% less ($P < 0.01$) at harvest than the BR-influenced steers (Table 2). Although most breeds have changed dramatically since the 1950s, Damon et al. (1960) reported 8% heavier slaughter weights for BR-influenced steers than for straightbred AN steers. Young et al. (1978), Cundiff et al. (1984), and Paschal et al. (1995) reported heavier final feedlot weights for BR-cross compared to AN and AN-cross steers. Huffman et al. (1990) also reported heavier final feedlot weights for ¾ BR – ¼ AN and ½ BR – ½ AN steers when compared to AN and ¼ BR – ¾ AN steers, but also reported more days in the feedlot for AN steers than for BR-influenced steers when harvested across an array of backfat endpoints.

Carcass weight, dressing percentage, and LMA were all less (16, 2, and 10%, respectively; $P < 0.01$) for straightbred AN compared to BR-influenced steers (Table 3). Although steers were targeted to be removed at 0.4 inch backfat in S1, AN carcasses had more fat cover ($P < 0.01$); 0.44 vs 0.38 inches) than did BR-influenced steers. Young et al. (1978) reported lighter carcasses (adjusted to 468-day slaughter age) for Hereford x AN- compared to BR-sired steers. Peacock et al. (1979) also indicated that carcasses from AN were lighter than carcasses from BR x AN crosses. When steers were finished to comparable fat thickness end points, AN steers produced lighter carcasses than ½ AN-½ BR steers (Huffman et al., 1990). Paschal et al. (1995) reported that AN-sired calves produced lighter carcasses than Gray BR-sired calves. Higher dressing percentages of BR and BR-cross cattle than for British breeds or crosses have been reported by Damon et al. (1960), Koch et al. (1982), and Sherbeck et al. (1995); however, other studies have reported that dressing percentages of BR and BR-cross cattle were similar to *B. taurus* cattle (Huffman et al., 1990; Boyles and Riley, 1991). Damon et al. (1960) found that AN- and BN-sired calves had similar adjusted LMAs. Young et al. (1978) reported similar fat thicknesses

Table 3. Sire breed effects on hot carcass weight, dressing percentage, longissimus area, and backfat thickness (Study 1 and 2).

	Carcass wt, lb			Dressing percentage			Longissimus area, in^2			Backfat thickness, in		
	Study 1	Study 2		Study 1	Study 2		Study 1	Study 2		Study 1	Study 2	
Sire breed[e]	LA[ad]	LA[ad]	OK[a]	LA[c]	LA	OK	LA[d]	LA[c]	OK[c]	LA[b]	LA	OK
Angus	639	794	789	62.5	62.5	63.7	10.9	11.5	12.7	0.44	0.40	0.47
Brangus	736	754	789	64.3	62.3	64.4	11.5	11.3	12.4	0.41	0.41	0.42
Beefmaster	714			63.5			11.1			0.37		
Gelbvieh		818	778		61.8	65.1		13.7	13.6		0.34	0.34
Gelbray	754	732	758	64.3	62.9	62.8	12.8	11.2	12.4	0.35	0.31	0.39
Simbrah	827			64.0			12.8			0.37		
Pooled SE	18	15	18	0.5	0.6	0.6	0.2	0.6	0.2	0.03	0.03	0.03
Sire breed contrasts												
Study 1												
AN-Rest	-119**			-1.5**			-1.1**			0.06**		
Bri-Cont	-66**			-0.3			-1.5**			0.03		
BN-BM	22			0.8			0.3			0.04		
GE-SI	-73**			0.3			0.0			-0.02		
Study 2												
AN-GV (25)		-24	11		0.7	-1.4		-2.2*	0.9		0.06	0.13**
BN-GE (44)		22	31		-0.6	1.6		0.1	0.0		0.10*	0.03
25BR-44BR		62**	9		-0.4	0.8		1.3*	0.7**		0.01	0.00

†$P < 0.10$; *$P < 0.05$; **$P < 0.01$.

[a]LA = Feedlot facilities at the Iberia Research Station, Jeanerette, La.; OK = commercial feedlot facilities in Guymon, Okla.

[bcd]Sire breed effect ($P < 0.10$, $P < 0.05$, and $P < 0.01$, respectively).

[e]Breed: AN = Angus; BN = Brangus; BM = Beefmaster; GV = Gelbvieh; GE = Gelbray; SI = Simbrah. Contrasts: AN-Rest = AN – (BN + BM + GE + SI); Bri-Cont = (BN + BM) – (GE + SI); 25BR-44BR = (AN + GV) – (BN + GE) where 25BR = Brahman breed percentage of 25%; 44BR = Brahman breed percentage of 44%.

and LMAs for BR- and Hereford x AN-sired steers. When LMA was expressed relative to carcass weight (in^2/100 lb), AN-sired steers had larger LM area/100 lb than BR-influenced steers (Bidner et al., 2002; 1.71 and 1.59 in^2 LM/ 100 lb carcass weight) in S1. Peacock et al. (1979) reported that AN had a positive effect and BR had a negative effect on LM area per 100 lb carcass weight.

Despite similar marbling scores for Angus compared to BR-influenced steers (510 vs 489) in S1, there was a tendency ($P < 0.10$) for straightbred AN to have higher USDA quality grade than BR-derivative carcasses (11.5 vs 11) (Table 4). This difference was mainly the result of lower quality grades of the BM- and GE-sired steer carcasses. Damon et al. (1960) reported that carcasses of AN-sired steers had higher quality grades than those of BN-sired steers. Young et al. (1978) reported similar USDA yield grades for Hereford x AN- and BR-sired steers, but noted greater marbling and USDA quality scores for the Hereford x AN- (11.2 and 10, respectively) than for BR-sired steers (8.5 and 8.2, respectively). Paschal et al. (1995) reported that carcasses from AN-sired calves graded higher than those of Gray BR-sired calves, when both were fed for the same length of time. Warner-Bratzler shear force was greater ($P < 0.01$) for BR-derivative than for straightbred AN steers (10.4 vs 8.8 lb.) in S1. Other studies have shown that beef from AN cattle was more tender than beef from BR and BR x AN cattle (Luckett et al., 1975; Peacock et al., 1982).

Percentage Brahman breeding. In S2LA, steers having 25% BR breeding were 8% heavier ($P < 0.01$) upon entry into the feedlot, gained 13% faster on feed ($P < 0.05$), and were 9% heavier ($P < 0.01$) at harvest than steers having 44% BR breeding (Table 2). In S2OK, 25%- and 44%-BR steers had similar initial feedlot weights, feedlot ADG, and harvest weights. Huffman et al. (1990) compared AN and AN x BR crossbred steers varying in proportion of BR breeding (i.e., 0, 25, 50, and 75%). In that report, steers having 50% BR breeding were heavier upon entry into the feedlot and were heavier at harvest than steers with 25% BR breeding, but days on feed and feedlot ADG were similar between the two breed types. Sherbeck et al. (1995) compared Hereford and Hereford x BR steers varying in proportion of BR breeding (i.e., 0, 25, and 50%). Similar to S2LA, 25%-BR steers in

that report had feedlot daily gains that were a significant 7% higher than 50%-BR steers. Pringle et al. (1997) compared AN, BR, and AN x BR steers varying in proportion of BR breeding (i.e., 0, 25, 37, 50, 75, and 100%). Steers in that report were fed to a targeted end-point (0.35 and 0.55 inches backfat) and slaughter weights did not differ among the various breed types.

While carcass weights were 8.5% higher ($P < 0.01$) for the 25% - than for the 44%-BR-influenced steers in S2LA, carcass weights were similar in S2OK (Table 3). However, carcass weights were numerically higher for the 25% - than for the 44%-BR-influenced steers in both locations. Conversely, Crouse et al. (1989), Huffman et al. (1990), and Sherbeck et al. (1995) all reported heavier carcass weights for 50%-BR than for 25%-BR steers, but Pringle et al. (1997) observed no difference in carcass weights associated with an increasing percentage of BR breeding. Dressing percentages were similar between the 25%- and 44%-BR carcasses in both the S2LA and S2OK studies. Dressing percentages were also similar for 25%- and 50%-BR carcasses in data presented by Huffman et al. (1990), but Pringle et al. (1997) observed an increase in dressing percentage associated with increasing percentage of BR breeding. Longissimus areas were greater for the AN- and GV-sired steers than for the BN- and GE-sired steers in both S2LA (12.6 vs 11.3 in^2, $P < 0.05$) and S2OK (13.2 vs 12.4 in^2, $P < 0.01$). Crouse et al. (1989) reported no consistent effect on LMA associated with percentage BR breeding. Huffman et al. (1990) also reported no difference between 25%- and 50%-BR carcasses for LMA. However, both Huffman et al.

Table 4. Sire breed effects on marbling score, USDA quality grade and yield grade, and Warner-Bratzler shear force (Study 1 and 2).

	Marbling score[a]			Quality grade[b]			Yield grade			Shear force, lb		
	Study 1	Study 2		Study 1	Study 2		Study 1	Study 2		Study 1	Study 2	
Sire breed[g]	LA[cd]	LA[cf]	OK[f]	LA[e]	LA[f]	OK[d]	LA	LA	OK[e]	LA[e]	LA[d]	OK
Angus	510	503	522	11.5	11.4	11.5	3.1	3.3	3.1	8.8	9.0	10.1
Brangus	531	435	497	11.4	10.2	11.2	3.3	3.4	3.0	10.4	9.5	10.8
Beefmaster	456			10.5			3.2			11.2		
Gelbvieh		443	456		10.5	10.7		2.8	2.4		10.8	11.7
Gelbray	466	443	460	10.6	10.5	10.8	2.7	2.9	2.8	10.4	10.6	11.0
Simbrah	501			11.3			3.2			9.7		
Pooled SE	27	13	11	0.4	0.2	0.2	0.2	0.2	0.1	0.9	0.4	0.4
Sire breed contrasts												
Study 1												
AN-Rest	21			0.5[†]			-0.1			-1.5[**]		
Bri-Cont	10			0.0			0.3[†]			0.9		
BN-BM	75[*]			0.9[*]			0.1			-0.9		
GE-SI	-35			-0.7[†]			-0.5[†]			0.7		
Study 2												
AN-GV (25)		60**	66**		0.9**	0.8**		0.6	0.7**		-1.8*	-1.5
BN-GE (44)		-8	37		-0.3	0.4		0.4	0.2		-1.3	-0.2
25BR-44BR		34[*]	10		0.6[*]	-0.1		-0.1	-0.2		0.0	0.0

[†]$P < 0.10$; [*]$P < 0.05$; [**]$P < 0.01$.

[a]Marbling score: Slight = 400 to 499 and small = 500 to 599.

[b]Quality grade: Low select = 10, high select = 11, and low choice = 12.

[c]LA = Feedlot facilities at the Iberia Research Station, Jeanerette, La.; OK = commercial feedlot facilities in Guymon, Okla.

[def]Sire breed effect ($P < 0.10$, $P < 0.05$, and $P < 0.01$, respectively).

[g]Breed: AN = Angus; BN = Brangus; BM = Beefmaster; GV = Gelbvieh; GE = Gelbray; SI = Simbrah. Contrasts: AN-Rest = AN – (BN + BM + GE + SI); Bri-Cont = (BN + BM) – (GE + SI); 25BR-44BR = (AN + GV) – (BN + GE) where 25BR = Brahman breed percentage of 25%; 44BR = Brahman breed percentage of 44%.

(1990) and Pringle et al. (1997) reported an increase in LMA per 100 lb carcass weight associated with increases in percentage BR breeding. Calculated LMA per 100 lb carcass weight for 25%- and 44% BR steers in S2LA (1.56 and 1.52 in^2/100 lb, respectively) and S2OK (1.68 and 1.61 in^2/100 lb, respectively) were similar in value. Sherbeck et al. (1995) reported no difference in LMA between 25%- and 50%-BR carcasses.

Marbling score (473 vs 439) and USDA quality grade (11.0 vs 10.4) were greater ($P < 0.05$) for 25%-BR than for 44%-BR influenced steers in S2LA, but were similar between the breed types when harvested on the same day in S2OK, despite very similar average backfat thicknesses between the breed types in both studies (Table 4). Crouse et al. (1989) observed a general decrease in marbling associated with increases in percentage BR breeding. Huffman et al. (1990) reported significantly different marbling scores of small (11) and slight (70) for 25%- and 50%-BR steers, respectively. In that report, 66, 34, and 0% of the 25%-BR steers and 29, 65, and 6% of the 50%-BR steers had carcasses that graded (USDA) choice, select, and standard, respectively. However, Sherbeck et al. (1995) observed no difference in marbling score and USDA quality grade between 25%- and 50%-BR carcasses. Pringle et al. (1997) observed that both marbling score and USDA quality grade decreased with increasing percentage of BR breeding. Warner-Bratzler shear force were similar between 25%- and 44%-BR influenced steers in both S2LA (9.9 vs 10.1 lb) and S2OK (10.9 vs 10.9 lb). Conversely, both Crouse et al. (1989) and Pringle et al. (1997) observed a corresponding increase in shear values as percentage BR breeding increased. Johnson et al. (1990) reported shear values (following a 10-d postmortem aging period) of 9.5 and 10.6 lb for 25%- and 50%-BR carcasses, respectively, and concluded that the former were more tender. Sherbeck et al. (1995) also observed greater shear values for 50%-BR compared to 25%-BR carcasses.

British-Brahman vs Continental-Brahman. In S1, British x BR steers spent 25 fewer days ($P < 0.05$) and weighed 7% less ($P < 0.01$) at harvest than Continental x BR steers (Table 2). In S2LA, BN-sired steers gained at a 36% faster rate ($P < 0.01$) and consequently spent 33 fewer days ($P < 0.01$) on feed than GE-sired steers. However, in S2OK, in which all steers were harvested on the same date within calving season and year, entry weight, feedlot ADG, and harvest weight were similar between BN- and GE-sired steers. The poor performance (i.e., 1.9 lb ADG and 195 days in the feedlot) of the GE-sired steers in the Louisiana environment in the second study was inexplicably not consistent with their performance in S1 and S2OK. Similar slaughter weights for British (AN, Hereford, and Shorthorn) x BR crosses and Charolais x BR crosses (756 and 767, respectively; 22 lb. pooled SE) can be calculated from data presented by Damon et al. (1960).

In S1, carcass weights were 16% less ($P < 0.01$) and LMAs were 10% smaller ($P < 0.01$) for British- than for Continental-BR cross steers (Table 3). However, in S2LA and S2OK, carcass weights, dressing percentages, and LMAs were similar between BN- and GE-sired steers. DeRouen et al. (1992) reported on a long-term (four generations) rotational (2 and 3 breeds) breeding study utilizing AN, Hereford, BR, and Charolais breeds. Two breed rotations (percentages are average breed proportions over four generations) included AN-BR (54% AN and 46% BR), Charolais-BR (54% Charolais and 46% BR), and Hereford-BR (54% Hereford and 46% BR). Three breed rotations included AN-BR-Charolais (34% AN, 30% BR, and 36% Charolais), AN-BR-Hereford (36% AN, 34% Hereford, and 30% BR), and BR-Charolais-Hereford (34% Hereford, 30% BR, and 36% Charolais). Breed effect contrasts in that study included the average of AN-BR and Hereford-BR vs Charolais (2 breed rotation) and the average of AN-BR-Charolais and BR-Charolais-Hereford vs AN-BR-Hereford. In agreement with S1 data, Charolais (i.e., Continental) breeding significantly increased carcass weights in both two- and three-way rotations (DeRouen et al., 1992). Dressing percentages were similar for both British x BR and Charolais x BR (calculated values of 56.9 and 57.3, respectively) in data reported by Damon et al. (1960). Backfat thickness differed ($P < 0.05$) between BN- and GE-sired steers (0.41 vs 0.31 inches) in S2 and then only at the Louisiana location, reflecting perhaps the overall poor performance of GE-sired steers in S2LA. It is doubtful if a contrast between BN- and GE-sired steers in S1 would have produced any meaningful differences between the two groups in terms of carcass weight or dressing percentage. On the other hand, the 1.3 in^2 greater LMA of GE-sired steers likely would have been significant, as would the .06 inch greater backfat thickness of BN-sired steers. In S1, calculated LMA relative to carcass weight was 1.56, 1.55, and 1.55 in^2/100 lb for BN-, BM-, and SI-sired steers and was 1.7 in^2/100 lb for GE-sired steers. Calculated LMA relative to carcass weight for BN- and GE-sired steers were 1.50 and 1.53 in^2/100 lb for S2LA and 1.57 and 1.64 in^2/100 lb for S2OK. Charolais breeding increased LMA in two- and three-breed rotations (DeRouen et al., 1992). In that study, calculated LMA relative to carcass weight was 1.84 and 1.80 in^2/100 lb for two-breed rotations and 1.81

and 1.77 in^2/100 lb for three-breed rotations with and without Charolais breeding, respectively. From the review article by Marshall (1994), British breeds of Angus, Hereford, and Shorthorn (base breeds for Brangus and Beefmaster) had LMA of 1.81 in^2/100 lb carcass weight, whereas the Continental breeds of Gelbvieh and Simmental (base breeds for Gelbray and Simbrah, respectively) had LMA of 1.92 in^2/100 lb carcass weight. These values are in partial agreement with the findings of S1, but not S2LA or S2OK, in that Continental-BR composite breeds had larger actual LMA, but when expressed as in^2/100 lb carcass weight, LMA was similar to the British-BR composite breeds. We can conclude that a clear advantage of one breed type over the other, in terms of these traits, was not consistent across these studies, although BN-sired steers had numerically more fat cover in all of them.

British-BR steers tended ($P < 0.10$) to have lower USDA yield grades than Continental-BR steers in S1, but were similar in terms of marbling score, USDA quality grade, and Warner-Bratzler shear force (Table 4). USDA quality and yield grades, and Warner-Bratzler shear forces were similar between BN- and GE-sired steers in both S2LA and S2OK. Marbling score was greater ($P < 0.05$) for BN- than for GE-sired steers in S2OK, but was similar between the breed types in S2LA. Although not tested, it is likely that both marbling score and USDA quality grade were greater for BN- compared to GE-sired steers in S1. It is worth noting that GE-sired steers in S1 tended to have lower ($P < 0.10$) USDA quality grades and yield grades than SI-sired steers. Charolais breeding lowered marbling scores and increased retail yield in both two- and three-way rotations (DeRouen et al., 1992). O'Conner et al. (1997) reported that Red Brangus had a higher degree of marbling than SI when the cattle were fed to a constant fat thickness end point. DeRouen et al. (1992) reported similar Warner-Bratzler shear forces for two-way breed rotations with and without Charolais breeding, but found that Charolais breeding significantly increased shear values in three-way breed rotations.

Summary. Relative to straightbred AN steers, Brahman-influenced breeds had greater feedlot and carcass weight and required more days on feed to achieve the targeted backfat end point. While the Brahman-influenced carcasses had larger LMA than AN, when expressed relative to carcass weight, they did not differ from AN carcasses. Marbling score was decreased and Warner-Bratzler shear value was increased for Brahman-influenced breeds compared to AN. There was no consistent advantage between 25%- and 44%-Brahman breeding for feedlot weights, carcass weight, and dressing percentage. Longissimus area was smaller for the higher percentage Brahman breeding, but when expressed relative to carcass weight did not appear to differ from the lower percentage Brahman breeding. An increase in percentage Brahman breeding did not increase Warner-Bratzler shear values nor did it consistently decrease marbling score and USDA quality grade. The specific objective of this paper was to compare British-BR and Continental-BR feedlot and carcass data from two Louisiana studies (S1, S2LA, and S2OK). Results of the comparisons of British-BR and Continental-BR for feedlot and carcass traits appear to vary with the specific Continental breeds included in the comparison; however, Continental-BR in general required more feeding days than did British-BR steers. Much of the literature would suggest that carcass weights are increased for Continental-BR compared to British-BR composite breeds. Consistent differences in beef cutability and carcass quality were not observed between British-BR and Continental-BR in the two studies.

Implications

All of the Brahman-influenced breed combinations in the two Louisiana studies produced desirable beef carcasses, with only small differences in cutability and carcass quality. Despite the increase in days on feed and carcass weight for Continental-BR steers, consistent differences in beef cutability and quality were not observed between Continental-BR and British-BR steers in the two studies.

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Reciprocal Differences in Gestation Length and Birth Weight in *Bos indicus/Bos taurus* Crosses

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ABSTRACT: Reciprocal differences in gestation length (GL) and birth weight (BW) were evaluated in 511 calves from 28 full-sib Angus-*Bos indicus* (AB) backcross families produced by embryo transfer. Calves were 3/4 A-1/4 B (Brahman or Nellore) or 3/4 B-1/4 A and were produced by mating F_1 (AB or BA where sire-type is listed first, followed by dam-type) bulls to purebred (A or B) cows; or, by mating purebred (A or B) bulls to F_1 (AB or BA) cows. Calves were born to 1/2 Brahman-1/2 British recipient dams. Backcross calves sired by A bulls and out of BA dams were carried for 289.6 d compared with 284.5 d for calves with AB dams. For calves sired by F_1 bulls out of A dams, GL was 290.4 d when the sire was BA as opposed to 288.4 d for AB sires. For calves from B sires and F_1 dams, GL was 296.1 d in calves from BA dams and 292.4 d for those from AB dams. For calves from F_1 sires and B dams, GL was 291.1 d in calves from BA sires compared with 288.3 d for calves from AB sires. Male backcross calves with AB sires and A dams were 17.6 lb heavier at birth than female calves of this cross, while BA-sired male calves out of A dams were 3.52 lb heavier than females of that cross. Male calves sired by B bulls were 9.68 lb and 10.34 lb heavier than female calves when the dam was AB and BA, respectively. Male calves with AB sires and A dams were 17.82 lb heavier than male calves with A sires and AB dams. *Bos indicus*-Angus-sired male calves out of A dams were 5.72 lb heavier than A-sired male calves with BA dams. *Bos indicus*-sired males with AB dams were 18.48 lb heavier than AB-sired males with B dams, and B-sired male calves with BA dams were 12.76 lb heavier than male calves with BA sires and B dams. Reciprocal differences in BW for female calves were in the same direction as those for male calves; however, none of the differences were of a significant magnitude. These *Bos indicus/Bos taurus* reciprocal differences have been widely reported in natural service calves, and these results for GL and BW are comparable with earlier reports in ET calves. We hypothesize that these reciprocal differences are due to a sex chromosome x autosome interaction and QTL analyses are ongoing.

Key Words: Birth Weight, Gestation Length, QTL, Reciprocal Crosses

Introduction

Reciprocal differences in birth weight and gestation length in *Bos indicus* x *Bos taurus* crosses have been widely reported for natural service calves. Previous studies have also shown that reciprocal differences of similar magnitude occur in embryo transfer calves. Consequently, this difference cannot just be due to a uterine maternal effect, and whatever is responsible for these differences has already occurred by the seventh day of pregnancy. Thallman et al. (1993) proposed mitochondrial inheritance, genomic imprinting, X-linked inheritance with non-random X inactivation, or Y-linked inheritance as possible mechanisms affecting these reciprocal differences. Rohrer et al. (1994) showed source of mitochondria did not account for performance differences between animals. The purpose of this study was to evaluate differences in gestation length and birth weight in reciprocal backcross *Bos indicus/Bos taurus* calves produced by embryo transfer and to detect QTL segregrating between families under a Mendelian inheritance model or with parent-of-origin effects included in the model.

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Materials and Methods

Gestation length (GL, n = 512) and birth weight (BW, n = 511) were evaluated in 28 full-sib families of Angus (A) - *Bos indicus* (B) reciprocal backcross calves produced by embryo transfer. These families were by 16 sires and out of 17 dams representing Angus and *Bos indicus* (Brahman and Nellore) breeds. Eight different mating strategies (Table 1) were used, and resultant progeny were 3/4 A 1/4 B or 3/4 B 1/4 A. Calves were born in spring and fall seasons from 1990 to 1996 at the Texas A&M University Experiment Station at Angleton to recipient dams that were approximately 1/2 Brahman and 1/2 British, and were 3 to 17 years old.

Statistical Methods

Birth weight and GL data were studied through analysis of covariance using the mixed model procedure of SAS (Version 9.0, SAS Inst. Inc., Cary, NC). Independent variables included sex, age of recipient dam, sire-type x dam-type interaction (ST x DT), family nested within ST x DT, the three-way interaction of sex x ST x DT, embryo quality (EQ), embryo stage (ES), and the regression on Julian birth date within season-year combinations (JDAY (birth year BY) x Season)). Family nested within 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. Residuals from these models were used for QTL analysis.

QTL Analysis

A sex averaged linkage map comprising 311 markers (mainly microsatellites) was built for the 29 autosomes and the X chromosome using Crimap V2.4 (Green et al., 1990). Interval mapping was performed under a line cross model using QTL Express (Seaton et al., 2002). QTL effects were examined under both a Mendelian inheritance model and a model that included parent-of-origin effects. Regression coefficients for the QTL additive (a), dominance (d) and(or) imprinting (i) effects were computed every one centimorgan from the estimates of the QTL genotype probability. Threshold values for suggestive and significant linkage were as defined by Lander and Kruglyak (1995). Permutation tests with n = 1000 replicate permutations were performed (Churchill and Doerge, 1994).

Results and Discussion

Gestation Length

The regression on Julian birth date within birth year and season combinations ($P < 0.001$), sex ($P < 0.001$), the two-way interaction of sire type x dam type ($P = 0.008$), and embryo quality ($P = 0.044$) all accounted for variation in gestation length.

GL was 5.1 days longer ($P < 0.05$) for backcross calves sired by A bulls and out of BA dams (289.6 2.16 d) than for calves with AB dams (284.5 2.13 d), where for F_2 animals (AB or BA) sire-type is listed first, followed by dam type. For calves sired by F_1 bulls out of A dams, GL differed only by 2.5 d ($P > 0.10$) when the sire was BA (290.4 2.31 d) as opposed to AB (288.4 2.30 d). Gestation length was 3.7 d longer ($P > .10$) for backcross calves sired by B bulls and out of BA dams (296.1 2.37) than for those out of AB dams (292.4 2.07). For calves sired by F_1 bulls and out of B dams, GL was 3 d longer ($P > 0.10$) when the sire was BA (291.1 2.19) as opposed to AB (288.3 2.28). In both the A and B backcross calves, gestation length was generally longer when the F_1 parent was BA rather than AB (Table 1); however, breed (Brahman vs. Nellore) is partially confounded with the type of F_1 parent. Angus-*Bos indicus* parents (four sires, four dams) had only Brahman influence, while most of the BA F_1 parents had Nellore influence (all three sires and two out of five dams). Nellore-sired calves typically have longer gestation lengths than calves sired by other *Bos indicus* breeds (Paschal et al., 1991; Thrift, 1997).

GL was 2.7 d longer ($P < 0.001$) in male calves (291.2 1.6) than in female calves (288.5 1.5). This difference is comparable to previous studies, in which sex differences from 1.7 to 2.3 d have been reported for *Bos indicus*-influenced calves (Plasse et al., 1968; Gregory et al., 1979; Lemos et al., 1984; Thallman et al., 1993; Herring et al., 1996). Paschal et al. (1991) reported much larger sex differences for calves out of Hereford dams and sired by Grey Brahman, Gir, Indu-Brazil, Nellore, and Red Brahman (7.3, 3.4, 2.2, 6.8, and 4.6 d, respectively).

In this study, GL was shorter for calves whose dams had a higher percentage of *Bos indicus* in relation to the amount of *Bos indicus* in the sire. This is consistent with the findings of Reynolds et al. (1980) and Lemos et al. (1984) in non-ET calves. In reciprocal F_1 Angus-Brahman crosses, BA calves were carried 2.6 d longer than AB (Reynolds et al., 1980). Lemos et al. (1984) showed that in Holstein-Guzera cross calves, GL was longest for calves sired by Guzera bulls and out of F_1 Holstein x Guzera cows (290 and 288 d for male and female calves, respectively).

These results are also consistent with earlier embryo transfer studies. In a small study (n = 25), Baker et al. (1989) reported that in reciprocal F_1 Brahman-Hereford crosses, BH calves were carried longer than HB calves (8 and 10 d longer in Hereford and Brahman recipients, respectively). Thallman et al. (1993) showed that GL was 1.6 and 2.3 days longer for Brahman-sired bull and heifer calves (n = 98) out of Simmental dams than for Simmental sired calves (n = 592) out of Brahman dams.

Birth Weight

Calf sex ($P < 0.001$), the regression on Julian birth date within season and year combinations ($P = 0.007$), the three-way interaction of sire type x dam type x sex ($P = 0.002$), and embryo stage ($P = 0.025$) accounted for variation in BW.

BW for male calves averaged 84.0 lb and female calves averaged 77.4 lb. This 6.6-lb difference between sexes is consistent with numerous other reports of sire breed x calf sex interactions on birth weight, where large sex differences were found in natural service *Bos indicus x Bos taurus* crossbred calves (Cartwright et al., 1964; Notter et al., 1978; Lemos et al., 1984; Comerford et al., 1987; Paschal et al., 1991; Herring et al., 1996; Chase, Jr. et al., 2000). Sexual dimorphism tends to be greater in *Bos indicus*-sired calves out of *Bos taurus* dams with reported differences between bull and heifer calves ranging from 9.7 to 15.4 lb (Notter et al., 1978; Lemos et al., 1984; Paschal et al., 1991; Chase, Jr. et al., 2000), as compared to differences of only 5.7 to 5.9 lb between sexes for *Bos taurus*-sired crossbred calves (Smith et al., 1976; Comerford et al., 1987; Paschal et al., 1991).

Table 1. Least squares means (d) and SE for gestation length

Calf Breeding	Sire Type	Dam Type	n	Gestation Length (days)	Difference[a]
Angus backcross (3/4 A 1/4 B)	A	AB	76	284.5 2.13	-5.1
	A	BA	64	289.6 2.16	(P = 0.043)
	AB	A	68	288.4 2.30	-2.5
	BA	A	59	290.4 2.31	(P = 0.348)
Bos indicus backcross (3/4 B 1/4 A)	B	AB	83	292.4 2.07	-3.7
	B	BA	58	296.1 2.37	(P = 0.149)
	AB	B	48	288.3 2.28	-2.8
	BA	B	56	291.1 2.19	(P = 0.274)

[a] Differences between individuals with an AB parent versus a BA parent for the same type of backcross, where breed of sire is listed first, followed by breed of dam. *P*-values are in parentheses.

Table 2. Least squares means (lb) and SE for birth weight for cross and calf sex combinations

Calf Breeding	Sire Type	Dam Type	Birth Weight males (lb)	n	Birth Weight females (lb)	n	Difference[d] (lb)	*P*-Value
Angus backcross (3/4 A 1/4 B)	A	AB	78.56 4.39[a]	46	75.49 4.66	30	3.07	0.284
	A	BA	77.27 4.60[a]	30	74.84 4.64	33	2.43	0.429
	AB	A	96.36 4.93[b]	34	78.76 4.93	34	17.6	< 0.001
	BA	A	82.89 4.99[ac]	29	79.44 4.96	30	3.45	0.287
Bos indicus backcross (3/4 B 1/4 A)	B	AB	91.60 4.36[bc]	47	81.94 4.48	36	9.66	0.001
	B	BA	90.06 5.24[bc]	22	79.54 4.98	36	10.52	0.003
	AB	B	76.20 5.07[a]	25	73.07 4.90	23	3.13	0.383
	BA	B	77.23 4.79[a]	29	74.90 4.64	27	2.33	0.488

[a-c] Means in the same column with no superscripts in common differ ($P < 0.05$)
[d] Differences between males and females for the same type of cross.

Among A backcross calves with F_1 sires, male calves with AB sires and A dams were 17.6 lb heavier than female calves of this cross ($P < 0.001$), while BA-sired male calves out of A dams averaged only 3.5 lb heavier than females of that cross ($P > 0.25$). Angus backcross calves with F_1 dams exhibited no significant difference in birth weight between male and female calves ($P > 0.25$). Likewise, there was no significant difference between male and female B backcross calves from F_1 sires. However, 3/4 B male calves were 9.7 lb and 10.3 lb heavier than female calves when the dam was AB and BA, respectively (Table 2).

Within sex analysis of reciprocal crosses showed that AB x A male calves were 17.8 lb heavier than A x AB male calves ($P < 0.01$). F_1-sired female calves were only 3.3 lb heavier than A-sired females ($P > 0.50$). When BA was the F_1 parental type, only 5.6 lb separated 3/4 A male calves. Again, the trend was for the calves from sires with more *Bos indicus* influence to be larger than the reciprocal cross ($P > 0.25$). Significant reciprocal differences also existed among 3/4 B male calves. *Bos indicus* x AB males averaged 15.4 lb heavier than AB x B males ($P < 0.01$), and B x BA males averaged 12.8 lb heavier than BA x B ($P < 0.25$). 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 significant. No significant differences in BW were detected by direct comparison of F_1 parental types (AB x A vs. BA x A, etc), with the exception of F_1-sired male calves. In this case, male calves with

AB F_1 sires averaged 13.5 lb heavier at birth than BA-sired male calves ($P < 0.05$). 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 BA natural service calves to average 11 lb heavier than AB 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 11 lb heavier than calves from F_1 sires and B dams. Hereford backcross calves from F_1 sires and H dams were about 11.2 lb heavier than H-sired calves.

Likewise, Baker et al. (1989) found that BH ET calves were 16.3 lb heavier than HB calves when both were produced from B recipients. When H recipients were used, BH calves were 26.2 lb heavier than their HB contemporaries. Thallman et al. (1993) showed that BS bull calves were 30.1 lb heavier at birth than SB bull calves. Brahman-Simmental heifer calves were 16.9 lb heavier at birth than SB heifer calves. In this case, the effect of cross in the bull calves was almost twice the size of the effect in the heifer calves. In the current study, the magnitude of differences in BW between the sexes for the *Bos indicus* backcross calves (B x AB vs. AB x B and B x BA vs. BA x B) was similar to that reported by Thallman et al. (1993), with the effect being about two times larger in males than females. The relationship was not the same in the Angus backcross calves. When comparing A x AB vs. AB x A calves, the effect was 5.1 times larger in male calves than female calves. There was no difference in the size of the effect between male and female calves for the comparison of A x BA vs. BA x A calves.

There is a tendency for calves with a higher percentage of *Bos indicus* in the dam (in relation to the amount of *Bos indicus* in the sire) to have lighter BW, even when produced through embryo transfer. As a result, this difference cannot simply be due to a uterine maternal effect. Whatever is responsible for these differences has already occurred by the seventh day of pregnancy. In addition to the possibility of a maternal effect of ovary, oviduct, and uterus of the donor cow before day seven, Thallman et al. (1993) suggested mitochondrial inheritance, genomic imprinting, X-linked inheritance with non-random X-chromosome inactivation or Y-linked inheritance as possible explanations for the observed reciprocal differences in birth weight. Rohrer et al. (1994) analyzed birth weight for 7,353 registered Brangus calves with breed of cytoplasmic origin fitted as a fixed effect. There was no evidence for an effect of mitochondrial inheritance on performance differences between animals.

Genomic imprinting, or the silencing of either the paternally or maternally inherited gene copy by an epigenetic mechanism, has been demonstrated to affect genes associated with fetal growth and placentation in a number of species, including humans and mice (Reik et al., 2003). In general, paternally expressed (maternally imprinted) genes enhance fetal growth, whereas maternally expressed (paternally imprinted) genes suppress growth. Fifty-seven genes in humans and 69 genes in mice are known to be imprinted (Morrison et al., 2001; www.otago.ac.nz/IGC). Every imprinted gene that has been examined in mice is expressed in the placenta (Reik et al., 2003). To date, six genes have been shown to be imprinted in cattle: IGF2, IGF2 receptor, NNAT, PEG3, GTL2, and XIST (www.otago.ac.nz/IGC).

QTL Analysis

A genome-wide scan for QTL affecting birth weight and gestation length was performed using interval mapping by linear regression under a line cross model (Seaton et al., 2002). The Y-chromosome was not included in the analysis. Under a Mendelian inheritance model, there was suggestive evidence of linkage ($P < 0.05$ chromosome-wise) for three QTL affecting GL and five QTL affecting BW (Table 3). QTL for GL were located on bovine chromosomes (BTA) 4, 6, and 9. All three of these QTL were estimated to have incomplete dominance effects. Birth weight QTL were located on BTA 3, 5, 8, 12, and X. This is the first report of a BW QTL on the X chromosome in cattle. The locations of the QTL on BTA 3 and 5 correspond to BW QTL previously detected under a line cross model in *Bos indicus* x *Bos taurus* families (Casas et al., 2003, 2004; Kim et al., 2003). The QTL on BTA3 and 12 were estimated to have additive effects and those on BTA 5 and X were estimated to have incomplete dominance effects. The QTL on BTA8 was estimated to have a large overdominance effect.

When parent-of-origin effects were included in the model, two suggestive QTL ($P < 0.05$ chromosome-wise) were detected on BTA 6 and 15 for GL (Table 4). Four QTL were detected for BW under this model. The locations of imprinted QTL detected on BTA 3, 8 and X coincide with those detected under the Mendelian model. There is significant evidence for linkage ($P < 0.05$ genome-wise) for the QTL on 8 and X. There is suggestive evidence for linkage ($P < 0.01$ chromosome-wise) for a previously undetected BW QTL on BTA6. For the

QTL on the X chromosome, the estimates were an additive effect of 4.27 1.12 lb, a dominance effect of -1.19 1.12 lb, and an estimated difference in the effect of the heterozygotes of -4.36 1.12 lb, with the heterozygote inheriting the Brahman allele through the male parent having higher BW. Markers flanking the most likely position of the QTL on BTAX are BMS1820 and BM4604. According to Amaral et al. (2002), these markers flank XIST (X-inactive specific transcript), which is known to be paternally imprinted in cattle (Ruddock et al., 2004), thus lending biological significance to these findings. In humans, mutations in the XIST promoter cause familial skewed X inactivation (non-random X inactivation) with preferential use of the paternal X chromosome (Pegoraro et al., 1997). XIST is expressed as early as

Table 3. Most likely position, *F*-statistic values and estimated effects of QTL for birth weight and gestation length that were detected with at least suggestive evidence for linkage under the line-cross model and assuming Mendelian inheritance

Trait[a]	BTA	cM[b]	F[c]	a SE[d]	d SE[e]
BW, lb	3	127	7.15 **	4.58 1.21	0.04 1.21
	5	26	5.50 *	-3.41 1.23	2.16 1.23
	8	27	6.00 *	-1.30 1.34	-4.47 1.34
	12	89	4.76 *	3.15 1.03	0.40 1.03
	X	95	6.11 *	3.70 1.12	-1.12 1.12
GL, days	4	81	5.27 *	1.97 0.72	1.23 0.72
	6	50	4.84 *	2.36 0.86	-1.16 0.86
	9	2	5.10 *	1.52 0.57	-0.92 0.57

[a] BW = birth weight; GL = gestation length
[b] Position at which the F-statistic was maximized
[c] Test statistic, * $P < 0.05$, ** $P < 0.01$ chromosome-wise
[d] QTL genotypic value assigned to Angus homozygotes such that 2a = AA-BB, where AA and BB indicatge Angus and *Bos indicus* alleles at the QTL, respectively.
[e] Heterozygote deviation from QTL homozygote midpoint such that d = 0.5 (AB + BA) - 0.5 (AA + BB).

Table 4. Most likely position, *F*-statistic values and estimated effects of QTL for birth weight and gestation length that were detected with at least suggestive evidence for linkage under the line-cross model and including parent-of-origin effects

Trait[a]	BTA	cM[b]	F[c]	a SE[d]	d SE[e]	i SE[f]
BW, lb	3	114	6.02 **	3.67 1.32	-0.86 1.32	-3.17 1.32
	6	0	5.1 **	2.02 1.54	-2.84 1.54	5.30 1.54
	8	30	7.2 ***	-0.70 1.28	-4.42 1.28	3.98 1.28
	X	108	9.01 ***	4.27 1.12	-1.19 1.12	-4.36 1.12
GL, days	6	50	5.16 *	1.98 0.87	-1.17 0.86	-2.08 0.87
	15	34	3.87 *	0.85 0.77	-1.37 0.77	-2.05 0.77

[a]BW = birth weight; GL = gestation length
[b]Position on the chromosome at which the *F*-statistic was maximized
[c]Test statistic, * $P < 0.05$, ** $P < 0.01$ chromosome-wise, *** $P < 0.05$ genome-wise.
[e]QTL genotypic value assigned to Angus homozygotes such that 2a = AA-BB.
[f]Heterozygote deviation from QTL homozygote midpoint such that d = 0.5 (AB + BA) - 0.5 (AA + BB).
[g]Parent-of-origin effect such that i = AB - BA.

the 8-cell stage in cattle, or within 48 to 72 hours of fertilization (Ruddock et al., 2004). Again, this lends credence to a role for XIST in the observed reciprocal differences in birth weight in embryo transfer calves.

Summary

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. In this study, GL was shorter and BW was lower for calves whose dams had a higher percentage of *Bos indicus* in relation to the amount of *Bos indicus* in the sire. A number of QTL were detected for GL and BW, including a previously unreported imprinted QTL on the X chromosome. XIST is an obvious candidate for this QTL and warrants further study. No single QTL can explain the observed reciprocal

differences in gestation length or birth weight. Genetic background is important and suggests that epistatic interactions between QTL should be investigated.

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Maternal and Fetal Genotype Influences on Fetal Growth

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ABSTRACT: Objectives are to review influences of maternal and fetal genotype on fetal growth and development. Brahman (Br) cows with Br or Charolais (C) fetuses and C cows with Br or C fetuses were used. Indwelling catheters were placed in a uterine artery, uterine vein, umbilical vein, fetal femoral artery, and fetal femoral vein at 220 ± 0.4 d after embryo transfer. Uterine and umbilical blood flows (L/min) and net uptakes of glucose, lactate, α-amino N, urea N, and ammonia N by the gravid uterus, fetus, and uteroplacenta were determined on 227 ± 0.4 d. Cows were killed on 232 ± 0.5 d or 271 ± 0.7 d. Weights of the fetus, fetal membranes, cotyledons, caruncles, and uterus were recorded as were weights of the fetal liver, heart, kidneys, spleen, lungs, stomach complex, intestines, and semitendinosus muscle. Data were analyzed by analysis of variance with breed of cow (CB), breed of fetus (FB), day of gestation (D), and all interactions were included in the model as fixed effects. Uterine blood flow in Br cows with Br (5.01 L/min) or C (4.66 L/min) fetuses was similar, but less ($P < 0.01$) than in C cows with Br (7.14 L/min) or C (9.24 L/min) fetuses, which differed ($P < 0.01$). Umbilical blood flows of C (3.78 L/min) were greater ($P < 0.01$) than those of Br (2.29 L/min) fetuses. Fetal uptake of oxygen, glucose, and α-amino N, gravid uterine uptake of α-amino N, and uteroplacental uptake of glucose were greater for C than for Br fetuses. Gravid uterine oxygen uptake and uteroplacental lactate release were influenced by CB × FB. Fetal weights were influenced ($P < 0.01$) by CB, FB, D, CB × D, and tended ($P = 0.07$) to be influenced by CB × FB × D. Caruncular weights were greater for C than for Br cows ($P < 0.05$) or fetuses ($P < 0.01$) and were greater ($P < 0.05$) at 271 than at 232 d, but FB was the only significant source of variation in cotyledon weight, RNA, DNA, or protein. Results demonstrated that maternal uterine environment influences fetal growth and suggests those influences are mediated, in part, by growth and function of placentomal tissues and uterine blood flow.

Key Words: Blood Flow, Bovine, Placenta

Introduction

It has been recognized for many years that the mother's contributions to her offspring extend beyond her 50% contribution to nuclear DNA. Classic reports of Walton and Hammond (1938), Venge (1950), Hunter (1956), Joubert and Hammond (1958), and Smidt et al. (1967) demonstrated the importance of "maternal uterine environment" on fetal and postnatal growth in the sheep, cow, pig, rabbit, and horse. Results from those studies clearly showed that components of the maternal environment influenced fetal and postnatal growth and development in addition to the maternal contribution to genotype. Gluckman and Liggins (1984) postulated that the fetus rarely expresses its full potential for growth because of constraints imposed by the maternal environment. With this concept in mind, logic would indicate that animals having a greater genetic potential for growth would be constrained to a greater extent than those having a lesser genetic potential for growth in the same uterine environment. This logic is supported by the report of Garrick et al. (1989), which indicated a negative correlation (-0.38) between direct and maternal genetic effects for birth weight in Simmental cattle. Heritabilities for direct and maternal genetic effects on birth weight were 0.40 and 0.13 for male and 0.45 and 0.15 for female calves, respectively. Objectives of the studies reviewed here were to quantify contributions of maternal and fetal genotypes on growth of gravid uterine tissues of the cow during late gestation and to develop further understanding of some of the physiological bases for those effects.

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Materials and Methods

The primary studies being reviewed are those reported by Ferrell (1991a; 1991b). Details of those studies are provided in those publications. Briefly, Charolais cows (1,477 lb, 4 to 6 yr of age) were obtained from the U.S. Meat Animal Research Center (MARC) herds. Brahman cows (1,135 lb, 3 to 8 yr of age) were purchased from commercial sources. Cows were maintained throughout the study on a corn silage-based diet that was provided in sufficient quantities to maintain maternal body weight. Six cows of each breed were selected for use as embryo donors. Those cows were superovulated and bred to bulls of the same breed by artificial insemination.

Embryos were flushed nonsurgically 8 d after mating and transferred to synchronized recipient cows of the opposite breed. Additional Charolais and Brahman cows that had not received superovulation treatment were artificially inseminated with semen from Charolais and Brahman bulls, respectively.

Pregnant cows were moved to an intensive confinement facility at day 190 of gestation for adjustment to the facility and handling. Surgery was performed on 18 cows (six Brahman and four Charolais with Brahman fetuses and four Brahman and four Charolais with Charolais fetuses) at 220 ± 0.4 d after mating. At surgery, indwelling catheters were placed in a fetal femoral artery, fetal femoral vein, umbilical vein, uterine vein, and uterine artery and exteriorized to the flank of the cow. Deuterium oxide was infused into the fetal femoral vein catheter on 227 ± 0.4 d after mating over a 3-h period. Samples of blood were drawn from the other four catheters at 30 min intervals during the infusion. Each sample of blood was analyzed for concentrations of D_2O, oxygen, lactate, and hematocrit. Plasma was harvested and α-amino N, urea N, ammonia N, and glucose were subsequently quantified. Uterine and umbilical blood flows were calculated from D_2O concentrations and net fluxes of oxygen, lactate, α-amino N, urea N, ammonia N, and glucose for the gravid uterus, fetus, and uteroplacental tissues as described previously (Ferrell, 1991b). These cows were killed at the MARC abattoir 232 ± 0.5 d after mating. An additional 16 cows (six Brahman and one Charolais cows with Brahman fetuses, and four Brahman and five Charolais cows with Charolais fetuses) were killed 271 ± 0.7 d after mating.

After each cow was killed, the gravid uterus was removed and weighed. The fetus was removed and fetal weight and sex were recorded. Weights of fetal liver, heart, kidneys, lungs, spleen, digestive tract, and a semitendinosus muscle were recorded. Cotyledons were separated from caruncles, and weights of fetal membranes with cotyledons (chorioallantois) and uterus with caruncles were recorded. Cotyledons and caruncles were dissected from fetal membranes and uterus, respectively, and weights of each of the four resulting tissues were recorded. Numbers of caruncles were determined. Samples of fetal liver, heart kidney, semitendinosus muscle, caruncle, and cotyledon were subsequently analyzed for total RNA, DNA, and protein.

Data were analyzed by analysis of variance as a 2 × 2 (blood flow and metabolite data) or 2 × 2 × 2 (data at slaughter) factorial arrangement. Breed of cow, breed of fetus, and day of gestation were included (as appropriate) in the model as fixed effects. All interactions were evaluated.

Two subsequent studies were conducted with similar methodologies. In the first, Simmental cows were mated to Charolais bulls. Embryos produced were successfully transferred to ¾ Pinzgauer (5), ¾ Brahman (5), or ¾ Sahiwal (2) cows. Catheters were implanted as described by Ferrell (1991b) at approximately 180 or 230 d of gestation. Blood flow and metabolite flux measurements were taken at 187 or 237 d of gestation, and measurements were taken at slaughter at 190 or 240 d. In the second study, Gelbvieh or Pinzgauer cows were mated to Charolais or Longhorn bulls. Surgeries were performed as previously described and blood flow and metabolite flux measurements were taken at approximately 224 and 242 d of gestation.

Results

Uterine blood flow (Table 1) at 227 d of gestation was similar ($P = 0.62$) in Brahman cows regardless of fetal breed (about 4.8 L/min), and lower ($P < 0.002$) than in Charolais cows. Uterine blood flow in Charolais cows was greater ($P < 0.005$) with Charolais (9.24 L/min) than with Brahman (7.18 L/min) fetuses. Umbilical blood flow of Charolais fetuses was greater ($P < 0.005$) than umbilical blood flow of Brahman fetuses, but was similar in Charolais and Brahman cows. Similarly, placental clearance of D_2O was greater for Charolais than for Brahman fetuses, but was not influenced by cow breed.

Uptake of oxygen by the gravid uterus was greater ($P < 0.05$) in Charolais cows with Charolais fetuses than in the other three groups, which were similar. Oxygen uptake by Charolais fetuses was greater than Brahman fetuses, but when scaled by fetal weight (data not shown), no differences were observed. Net oxygen uptake by uteroplacental tissues did not differ significantly. Charolais fetuses in Brahman cows used considerably more oxygen than did uteroplacental tissues, whereas in the other groups, total oxygen consumption of fetuses and uteroplacental tissues was similar.

Uterine glucose uptakes were greatest in Charolais cows with Charolais fetuses and least in cows with Brahman fetuses, Charolais fetuses in Brahman cows were intermediate. Fetal glucose averaged 11% of gravid uterine uptake. Net uptake of glucose by uteroplacental tissues was 2.4-fold greater in cows with Charolais fetuses than in cows with Brahman fetuses.

Net release of lactate from the gravid uterus of cows with fetuses of the opposite breed was observed, whereas in cows with fetuses of the same breed, a smaller release, or net uptake of lactate by the gravid uterus from the maternal circulation, was seen. Fetal net uptake averaged 0.096 mmol/min. Uteroplacental

Table 1. Influence of breed of cow and breed of fetus on uterine and umbilical blood flow, deuterium oxide clearance, and metabolite flux of gravid uterine tissues at 227 d of gestation

	Brahman cow		Charolais cow		
Variable	Brahman fetus	Charolais fetus	Brahman fetus	Charolais fetus	SE
Uterine blood flow, L/min	5.01[a]	4.66[a]	7.18[b]	9.24[c]	0.24
Umbilical blood flow, L/min	2.71[a]	3.65[b]	1.88[a]	3.99[b]	0.23
D_2O clearance, L/min	1.36[a]	2.48[b]	1.46[a]	2.32[b]	0.15
Oxygen uptake, mmol/min					
Gravid uterus	5.71[a]	5.55[a]	5.10[a]	7.76[b]	0.41
Fetus	2.32[a]	3.89[b]	2.27[a]	3.83[b]	0.17
Uteroplacenta	3.48	1.57	2.83	3.93	0.48
Glucose uptake, mmol/min					
Gravid uterus	0.69[a]	1.56[b]	0.83[a]	2.03[b]	0.10
Fetus	0.092[a]	0.136[a,b]	0.098[a]	0.215[b]	0.02
Uteroplacenta	0.61[a]	1.43[b]	0.74[a]	1.82[b]	0.12
Lactate uptake, mmol/min					
Gravid uterus	-0.009[a,b]	-0.602[a]	-0.430[a]	0.158[b]	0.129
Fetus	-0.044	0.142	0.138	0.161	0.087
Uteroplacenta	0.068	-0.960	-0.567	-0.003	0.120
α-amino-N					
Gravid uterus	1.06[a]	3.02[a,b]	1.87[a]	5.01[b]	0.48
Fetus	0.67[a]	0.85[a,b]	0.55[a]	1.62[b]	0.16
Uteroplacenta	0.41[a]	1.93[a,b]	1.32[a,b]	3.39[b]	0.60

[a,b,c]Within a row means without a common superscript letter differ ($P < 0.05$).

net exchange of lactate followed patterns similar to those observed for the gravid uterus.

Gravid uterine uptake of α-amino N was threefold greater in cows with Charolais fetuses (4.02 mmol/min) than in cows with Brahman fetuses (1.46 mmol/min). Fetal uptake was greatest for Charolais fetuses in Charolais cows, intermediate for Charolais fetuses in Brahman cows, and least for Brahman fetuses. Estimated uteroplacental net uptake tended to be greatest for Charolais fetuses in Charolais cows, least with Brahman fetuses in Brahman cows, and intermediate for the other groups.

Uterine and fetal net release of urea N averaged 0.75 ± 0.39 and 0.67 ± 0.12 mmol/min, respectively. Release of N as urea, as percentages of α-amino N uptake, were 27 and 72% for the gravid uterus and fetus, respectively. Net release of urea N from the uteroplacenta was estimated to be 0.10 ± 0.26 mmol/min and did not differ from zero. Although umbilical venous ammonia N concentrations were nearly twice as great as uterine arterial concentrations, mean net release of ammonia N from gravid uterine, fetal, and uteroplacental tissues did not differ from zero and averaged 0.011 ± 0.011, 0.011 ± 0.006, and -0.003 ± 0.012 mmol/min, respectively.

Neither uterine nor umbilical blood flows differed ($P = 0.35$) between Pinzgauer and *Bos indicus* (Brahman and Sahiwal) cows (Table 2) when gestating Charolais × Simmental fetuses. Both uterine and umbilical blood flows were greater ($P < 0.05$) at 237 than at 187 d of gestation. Placental clearance of D_2O, gravid uterine oxygen and glucose uptake, and fetal oxygen uptake followed similar patterns. Net uptake of oxygen by the fetus was 30% of uterine uptake in Pinzgauer cows, but 53% at 187 d and 64% of uterine uptake at 237 d in Zebu cows. Similarly, at 237 d, fetal glucose uptake was 53% of uteroplacental uptake in Pinzgauer cows, but 88% in Zebu cows. Net uptakes of lactate by uterine, fetal, and uteroplacental tissues were seen at 187 d, but at 237 d there was a net lactate release from uteroplacental tissues to both the uterine and fetal circulations.

Few differences due to cow breed and no interactions between cow and sire breed were observed in blood flows or metabolite flux data when Gelbvieh and Pinzgauer cows were mated to Charolais or Longhorn bulls (Table 3). Uterine blood flow tended ($P = 0.07$) to be lower and umbilical blood flow was lower ($P = 0.03$) for Longhorn-sired than for Charolais-sired fetuses. Placental clearance of D_2O and predicted maximum clearance of highly diffusible substances across the placenta followed patterns similar to umbilical and uterine blood flow. This is expected, because clearance rates in a flow limited system are expected to be most strongly associated with the lesser flow, umbilical blood flow. Similarly, fetal oxygen uptake by Charolais-sired fetuses was greater ($P = 0.05$) than for Longhorn-sired fetuses, but fetal oxygen as a proportion of gravid uterine uptake was similar (55%). Net glucose uptake of gravid uterine, fetal, and uteroplacental tissues was seen, but no differences due to cow or sire breed were observed. Fetal glucose was 46% of gravid uterine uptake with Charolais-sired fetuses, but 28% with Longhorn-sired

Table 2. Influence of breed of cow and day of gestation on uterine and umbilical flood flow, deuterium oxide clearance, and metabolite flux of gravid uterine tissues with Charolais × Simmental fetuses

	Pinzgauer cows		*Bos indicus* cows		Probability		
Variable	187 d	237 d	187 d	237 d	Cow breed	Day of gestation	CB × D
Uterine blood flow, L/min	4.23	7.70	4.14	7.89	0.97	0.03	0.91
Umbilical blood flow, L/min	1.24	2.59	1.20	3.51	0.57	0.65	0.54
D_2O clearance, L/min	0.49	1.75	0.88	2.01	0.44	0.03	0.87
Oxygen uptake, mmol/min							
Gravid uterus	3.00	6.01	3.12	7.12	0.65	0.04	0.72
Fetus	0.88	4.46	1.66	4.53	0.56	0.01	0.62
Uteroplacenta	2.01	1.54	1.32	2.32	0.96	0.76	0.42
Glucose uptake, mmol/min							
Gravid uterus	1.00	1.16	0.98	1.75	0.45	0.24	0.43
Fetus	0.28	0.40	0.14	0.69	0.88	0.51	0.67
Uteroplacenta	0.80	0.76	0.84	0.78	0.96	0.93	0.99
Lactate uptake, mmol/min							
Gravid uterus	0.24	-0.54	0.21	-0.31	0.78	0.11	0.71
Fetus	0.16	0.73	0.08	0.74	0.84	0.01	0.82
Uteroplacenta	0.22	-1.27	0.15	-1.00	0.65	0.01	0.46

Table 3. Influence of breed of cow and breeding of sire on uterine and umbilical flood flow, deuterium oxide clearance, and metabolite flux of gravid uterine tissues at 224 or 242 day of gestation

	Cow breed		Sire breed		Probability		
Variable	Gelbvieh	Pinzgauer	Charolais	Longhorn	Cow breed	Sire	Day
Uterine blood flow, L/min	8.43	9.95	10.60	7.77	0.30	0.07	0.97
Umbilical blood flow, L/min	2.87	2.99	3.27	2.59	0.67	0.03	0.01
D_2O clearance, L/min	1.68	1.85	1.96	1.56	0.27	0.02	0.11
Oxygen uptake, mmol/min							
Gravid uterus	6.58	8.67	8.58	6.66	0.09	0.13	0.75
Fetus	4.00	4.36	4.63	3.73	0.38	0.05	0.16
Uteroplacenta	2.37	4.34	3.91	2.80	0.17	0.43	0.53
Glucose uptake, mmol/min							
Gravid uterus	1.11	1.53	1.07	1.56	0.31	0.25	0.07
Fetus	0.49	0.43	0.49	0.43	0.53	0.55	0.09
Uteroplacenta	0.41	1.03	0.50	0.94	0.18	0.34	0.04
Lactate uptake, mmol/min							
Gravid uterus	-0.08	-0.09	-0.11	-0.06	0.89	0.70	0.47
Fetus	0.30	0.25	0.27	0.28	0.30	0.88	0.06
Uteroplacenta	-0.35	-0.40	-0.40	-0.35	0.67	0.71	0.67

fetuses. Lactate was released from uteroplacental tissues to both fetal and uterine circulations, but values did not differ because of dam or sire breed.

At 232 d, weight of neither Brahman nor Charolais fetuses differed with cow breed (Table 4), but Charolais fetuses weighed nearly twice as much as Brahman fetuses. At 271 d, however, Charolais fetuses in Charolais cows (103 lb) weighed 29 lb more than Charolais fetuses in Brahman cows, and Brahman fetuses in Charolais cows (74.7 lb) weighed 10.8 lb more than Brahman fetuses in Brahman cows. Uterine weights were 12 and 15 lb in Brahman cows with Brahman vs. Charolais fetuses, and 15 and 22 lb in Charolais cows with Brahman vs. Charolais fetuses. Placentomal (caruncular + cotyledonary) weights were greater in Charolais than in Brahman cows, greater for Charolais than for Brahman fetuses, and greater at 271 than at 232 d of gestation. Caruncle and fetal membrane weights followed similar patterns, but cotyledon weights differed only because of fetal breed.

At 187 d, weights of Charolais × Simmental fetuses in Pinzgauer (17.7 lb) cows were similar to those in *Bos indicus* (16.5 lb) cows (Table 5), but at 237 d, weights of fetuses in Pinzgauer (64.6 lb) tended to exceed (10.4 lb, $P = 0.11$) weights of those in *Bos indicus* cows. Fetal heart ($P = 0.07$) and gastrointestinal tract ($P = 0.09$) weights followed similar patterns, but few other differences in weight of fetal tissues or uterine tissues were noted. Essentially, all fetal and gravid uterine tissues were heavier ($P < 0.01$) at 237 than at 187 d.

Table 4. Influence of breed of cow, breed of fetus, and day of gestation on weight of gravid uterine and fetal tissues[a]

	Brahman cow				Charolais cow				
	Brahman fetus		Charolais fetus		Brahman fetus		Charolais fetus		
Tissue	232 d	271 d	232 d	271 d	232 d	271 d	232 d	271 d	SE
Gravid uterus, lb	62.4	96.6	96.3	126.3	66.8	112.4	100.8	173.1	2.98
Fetus, lb	29.1	56.2	52.2	74.7	28.4	67.0	49.4	103.4	1.34
Uterus, lb	9.92	14.48	13.51	16.49	12.35	17.85	19.11	24.60	0.44
Fetal membranes, lb	6.44	4.74	10.12	7.50	7.39	6.17	12.50	10.31	0.51
Caruncles, lb	3.95	5.74	5.77	6.45	3.93	6.92	6.54	8.68	0.22
Cotyledons, lb	2.39	2.17	4.50	4.48	2.63	2.32	5.72	5.51	0.22
Fetal tissue, lb									
Liver	1.00	1.26	1.54	1.46	1.17	1.59	1.72	2.09	0.071
Heart	0.194	0.352	0.333	0.465	0.178	0.392	0.311	0.628	0.011
Kidney	0.192	0.234	0.390	0.320	0.187	0.302	0.335	0.463	0.012
Lung	0.681	1.179	1.124	1.766	0.882	1.892	1.011	2.520	0.056
GI tract	1.34	2.16	2.23	2.49	1.22	2.41	2.11	4.09	0.123
Spleen	0.088	0.115	0.172	0.152	0.108	0.130	0.172	0.291	0.011
Semitendinosus	0.064	0.161	0.159	0.218	0.079	0.168	0.132	0.326	0.006

[a]See Ferrell, 1991b for statistical details.

Table 5. Influence of breed of cow and day of gestation on weight of gravid uterine and fetal tissues with Charolais × Simmental fetuses

	Pinzgauer cows		*Bos indicus* cows		Probability		
Variable	187 d	237 d	187 d	237 d	Cow breed	Day	CB × D
Gravid uterus, lb	61.9	118.2	48.5	112.9	0.32	0.001	0.65
Fetus, lb	17.6	64.6	16.5	54.2	0.11	0.001	0.19
Uterus, lb	8.05	13.23	8.73	12.19	0.92	0.03	0.61
Fetal membranes, lb	5.89	6.39	6.66	11.44	0.06	0.08	0.15
Caruncles, lb	3.29	6.29	3.34	6.26	0.99	0.03	0.97
Cotyledons, lb	2.22	3.79	2.26	4.00	0.65	0.001	0.74
Fetal tissue, lb							
Liver	0.772	2.019	0.688	1.631	0.30	0.001	0.50
Heart	0.137	0.445	0.121	0.346	0.07	0.001	0.17
Kidney	0.137	0.293	0.128	0.304	0.97	0.001	0.59
Lung	0.520	1.521	0.439	1.360	0.29	0.001	0.71
GI tract	0.542	3.228	0.414	2.198	0.09	0.001	0.17
Spleen	0.073	0.192	0.060	0.174	0.56	0.002	0.94
Semitendinosus	0.049	0.134	0.055	0.134	0.86	0.002	0.92

Discussion

Collectively, these data show that fetal genotype is a primary component in the regulation of fetal growth. This conclusion is supported by observations that Charolais fetuses weighed nearly twice as much as Brahman fetuses at 232 d regardless of cow breed. Also, in a uterine environment presumed to be capable of supporting high rates of fetal growth, Charolais fetuses weighed 36.4 lb more than Brahman fetuses at 271 d.

These data also show that the uterine environment of the dam contributes to differences in fetal growth and development, particularly during late gestation. Weights of Charolais × Simmental fetuses gestating in *Bos indicus* and Pinzgauer dams were similar at 187 d, but those in *Bos indicus* dams grew about 20% slower between 187 and 237 d, resulting in a numerical difference of 10.4 lb at 237 d. Constraint of fetal growth was more evident when Charolais fetuses developing in Charolais vs. Brahman cows were compared at later stages of gestation. At 232 d, weights of Charolais fetuses in the two breeds of cows was similar, but at 271 d, Charolais fetuses in Charolais cows weighed 28.7 lb more than those in Brahman cows, reflecting a difference in rate of weight gain of 1.39 vs. 0.57 lb/d during that 39 d interval. It is evident that fetal growth may be constrained by the maternal uterine environment, particularly during late stages of gestation.

Although weights of Brahman fetuses were similar in Brahman and Charolais cows at 232 d,

apparent rate of growth during the ensuing 39 d was 0.71 vs. 0.99 lb/d, resulting in Brahman fetuses in Brahman cows weighing 10.8 lb less than those in Charolais cows. These observations support the hypothesis that fetal growth may be constrained by the uterine environment, even in the "normal" situation. These observations are consistent with those reported by Garrick et al. (1989), which indicated a negative correlation (-0.38) between direct and maternal genetic effects for birth weight in Simmental cattle. They also reported that heritabilities for direct and maternal genetic effects on birth weight were 0.40 and 0.13 for male and 0.45 and 0.15 for female calves, respectively, supporting our suggestion that constraint of fetal growth by the uterine environment is likely to be greater in fetuses that have a greater genetic potential for growth.

Components of the uterine environment most often suggested as having major contributions to differences in fetal growth include perfusion and functional capacity of the placenta. Metabolite fluxes across gravid uterine tissues primarily reflect blood flows or perfusion rates. These have been discussed more extensively in previous reports (Ferrell, 1991a; 1991b). Caruncle and cotyledon weights, uterine and umbilical blood flows, and deuterium clearance rates across the placenta are considered indices of functional capacity of the placenta. Expression of uterine blood flow relative to weight of the fetus and uteroplacental tissues indicated that uteroplacental perfusion in Brahman cows with Brahman fetuses and Charolais cows with Charolais fetuses was similar, but greater than observed in Brahman cows with Charolais fetuses, and less than observed in Charolais cows with Brahman fetuses. Uterine blood flows relative to caruncular tissue weight were 1.31, 1.49, 0.86, and 1.86 (SE = 0.10) L/min/lb for those groups, respectively, indicating that maternal perfusion of the uteroplacenta, and likely caruncular tissues, differed among the four groups. These observations indicate that circulatory systems of Brahman and Charolais cows responded to differing degrees with regard to uterine blood flow, to stimuli from the fetus or conceptus and that maternal perfusion of uteroplacental tissues differed substantially as a result. Results with Charolais × Simmental fetuses in Pinzgauer or *Bos indicus* cows were consistent with those results.

In contrast to uterine blood flow, umbilical blood flow was primarily related to fetal genotype and was not influenced significantly by cow breed in any of the studies discussed herein. Umbilical blood flow was positively related to fetal weight. Umbilical blood flow relative to cotyledon weight was similar in Pinzgauer and *Bos indicus* cows at 187 d, but greater in *Bos indicus* cows at 237 d. Similarly, umbilical blood flow relative to cotyledon weight was greater in Brahman cows than in Charolais cows at 227 d. Deuterium oxide clearance followed similar patterns. It is suggested that these results are indicative of a mechanism whereby the fetus may compensate for differences in maternal perfusion of caruncular tissue and/or differences in placental exchange area by altered rates of perfusion of the tissues available for exchange.

Summary

Data have been presented to show that fetal growth is primarily a function of fetal genotype; however, it is evident that the ability of the fetus to express its full growth potential is frequently constrained to varying degrees by the maternal uterine environment, especially during later stages of gestation. Maternal constraint of fetal growth appears to be, in part, mediated by perfusion and function of uteroplacental tissues. Consequences of restricted placental development early in gestation may not become evident until late in gestation or during the postnatal period. There is some evidence that fetal tissues may be differentially affected by maternal constraint, possibly because of differing priorities, or simply timing of development. In addition, the effects of maternal constraint may not be fully reflected by birth weight or tissue weight alone and may have consequences beyond the perinatal period.

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Evaluation of the F_1 Crosses of Five *Bos indicus* Breeds With Hereford for Birth, Growth, Carcass, Cow Productivity, and Longevity Characteristics

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ABSTRACT: Birth, growth, carcass, and cow productivity traits were evaluated in cattle out of Hereford cows and by Angus, Gray Brahman, Gir, Indu-Brazil, Nellore, and Red Brahman bulls. Angus-sired calves had the shortest and Nellore the longest ($P < 0.05$) gestations (282 and 294 d, respectively); others ranged from 289 to 291 d. Angus-sired calves had lower ($P < 0.05$) birth weight (70.0 lb) than all except Gir crosses (72.6 lb), which were lightest ($P < 0.05$) of the Zebu crosses; Indu-Brazil crosses (86.0 lb) were heavier ($P < 0.05$) than all except Red Brahman crosses (82.3 lb). Red Brahman and Gray Brahman crosses had higher ($P < 0.05$) weaning weight (472 and 468 lb) than Gir and Angus crosses (435 and 437 lb); Indu-Brazil and Nellore crosses were intermediate. Yearling weight off pasture was lowest for the Angus crosses (509 lb) and was higher ($P < 0.05$) for Red Brahman and Gray Brahman crosses (597 and 594 lb) than for Nellore, Indu-Brazil, and Gir crosses (568, 561 and 549 lb). Yearling hip height was lowest ($P < 0.05$) for the Angus crosses (43.3 in). Among the Zebu crosses, Nellore crosses (47.9 in) were taller ($P < 0.05$) than Gir crosses (46.8 in); others were intermediate. Feedlot gain for steers did not differ ($P > 0.05$) by breed and ranged from 3.23 lb/d in Gir crosses to 3.52 lb/d in Gray Brahman and Indu-Brazil crosses. Marbling score was highest ($P < 0.05$) for Angus crosses (Sm 10); among Zebu crosses, marbling did not differ ($P > 0.05$) and ranged from Sl 45 to Sl 59. Carcass weight was higher ($P < 0.05$) for Red Brahman (676 lb) than for Angus crosses (607 lb); others were intermediate. Ribeye area did not differ ($P > 0.05$) and ranged from 11.7 to 12.0 in^2. Yield grade was lower ($P < 0.05$) for Indu-Brazil crosses (2.3) than for Gray Brahman crosses (2.8); others were intermediate. Crossbred cows were bred to different breeds of bulls in different years; breed of service sire was confounded with year. Birth weight for calves out of Angus-sired cows (86.6 lb) was heavier ($P < 0.1$) than for those out of Gir and Nellore crosses (76.6 and 80.7 lb); others were intermediate. Weaning weight for calves out of *Bos indicus* cross cows did not differ ($P > 0.10$) and ranged from 562 to 574 lb; all were heavier ($P < 0.001$) than those out of Angus-sired cows (499 lb). Cow weight at 7 yr of age was higher ($P < 0.1$) for Indu-Brazil, Red Brahman and Gray Brahman crosses (1258 to 1288 lb) than for Angus crosses (1146 lb); others were intermediate. All *Bos indicus* crosses were taller ($P < 0.05$) at the hip at 7 yr than Angus crosses (49.1 in). Indu-Brazil-sired cows (54.4 in) were taller ($P < 0.05$) than Gir crosses (52.7 in); others were intermediate. Calf crop weaned for Nellore crosses (96%) was higher ($P < 0.1$) than for Indu-Brazil, Angus and Red Brahman crosses (81, 83 and 86); Gray Brahman and Gir crosses were intermediate (88 and 92). Survival (under the culling policy practiced) to 14 yr was higher ($P < 0.05$) in Nellore crosses (80%) than in Indu-Brazil (33%) and Red Brahman crosses (43%). Angus, Gray Brahman, and Gir crosses were intermediate (53, 53 and 73%).

Key Words: Beef Cattle, *Bos indicus*, Brahman, Breed Differences, Gir, Indu-Brazil, Lifetime Production, Nellore

Introduction

In 1980, 1981, and 1982 *Bos indicus* cattle from Brazil were imported into the United States through the Harry S. Truman Import Center at Fleming Key, FL. Bulls and heifers of the Gir, Indu-Brazil, Nellore, and Guzerat breeds were imported. These were the first legal importations of Indian or Brazilian breeds of *Bos indicus* cattle into North America since the 1946 importation from Brazil. This study was initiated in 1980 with the purchase of Hereford heifers with the objective of comparing the productivity of the imported breeds, Gir, Indu-Brazil, and Nellore, with each other and with the American Gray Brahman and American Red Brahman from crosses out of Hereford cows. Only two Guzerat bulls were imported, and they were in the 1982 importation after the first matings for this project had been completed, so the Guzerat breed was not included in the study.

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Results from this study for birth and weaning characters were reported by Paschal et al. (1991). Differences for post-weaning growth and carcass characters were reported by Paschal et al. (1995), and differences for cow productivity and longevity were reported by Riley et al. (2001a and 2001b).

Materials and Methods

This research was initiated at the USDA Blacklands Research Center at Riesel, TX, in 1981 and was continued at the Texas Agricultural Research Center at McGregor from 1985 to present. Starting in late December 1981, Hereford cows that had previously produced at least one calf were artificially inseminated to Angus (n = 10), Gray Brahman (n = 11), Gir (n = 6), Indu-Brazil (n = 10), Nellore (n = 10), and Red Brahman (n = 10) bulls.

The 10 Angus bulls included 6 from the R.L. Hruska U.S. Meat Animal Research Center at Clay Center, NE, and 4 from the USDA Subtropical Agricultural Research Station at Brooksville, FL. These sources were chosen in an attempt to represent the type of Angus bulls used in commercial herds at the time, but the bulls were more moderate (smaller) in frame size than the Angus cattle that were popular in many purebred herds at that time.

The 11 Gray Brahman and 10 Red Brahman bulls were selected from both commercial artificial insemination (AI) services and purebred herds and represented major bloodlines of these breeds. The 6 Gir, 10 Indu-Brazil, and 10 Nellore bulls were selected from the 1980 and 1981 importations from Brazil. The six Gir bulls were the only imported Brazilian Gir bulls available; the Indu-Brazil and Nellore bulls were representative of the type and bloodlines of the importations.

Of the *Bos indicus* breeds evaluated, the Nellore (called the Ongole in India) and Gir are Indian breeds that are maintained as pure breeds in Brazil; since the time of the importation, a small number of purebred Nellore herds have been maintained in the United States. The Indu-Brazil breed was developed in Brazil from cattle imported from India; the Gray Brahman and Red Brahman breeds were developed in the United States from cattle imported from India and Brazil (Sanders, 1980).

These bulls were mated by AI to Hereford cows from 1981-82 to 1984-85. Matings were started in late December each year; calving was from October to early January. The Hereford cows were from 15 different sources in Central Texas. Some were polled and some were horned (dehorned); some were purebred and some were grade.

All the F_1 calves were weaned in late June at about 7 (from approximately 6 to 9) mo of age. At weaning, the calves were held in pens for weaning and preconditioning for 7 to 10 d and then returned to warm-season perennial pasture. All calves (steers and heifers) were on pasture until mid-November, when the steers were put in feedlot pens and the heifers were placed on oat pasture.

The steers were fed a ration containing ground grain sorghum, cottonseed hulls, and cottonseed meal plus an ionophore. They were fed from November to April, for 120 to 135 d, depending on the year. All carcass data were collected by personnel of the Texas A&M University Meat Science and Technology Center at College Station. Average age at slaughter was 504 d.

All heifers were bred to calve in the spring to have their first calves at about 2.5 yr of age. Since one of the advantages of *Bos indicus* cross females is their ease of calving, all heifers were bred to Charolais bulls for their first calf to provide a challenge for calving difficulty. They were then maintained in a spring calving season throughout their lives and were bred to various breeds of bulls, depending on the year; in a given year, cows were all bred to the same bulls. Breed of service sire was confounded with year.

The *Bos indicus* breeds evaluated in this study were known to differ greatly in the characteristics of their udders; in fact, the udder problems, combined with the poor nursing instinct in many straight *Bos indicus* calves, make some of these breeds unacceptable under extensive ranching conditions, even in the tropics. Since nursing behavior of calves is adversely affected by cold (or even cool) weather, this problem in straightbreds is even a larger problem in subtropical and temperate environments. At least some producers recognized that Brahman x Angus F_1 cows typically had fewer and less severe udder problems than Brahman x Hereford F_1 cows; however, at the initiation of this study, there was little information about how the F_1 crosses of these breeds (the five *Bos indicus* breeds evaluated in this study) with the Hereford would differ in their udder characteristics and whether these differences would be large enough to affect the survival of their calves.

The F_1 cows calved from about February 10 to May 10 of each year. Various measurements and scores of udders and teats of the F_1 cows were taken as soon after calving as possible. Riley et al. (2001b) discussed the system used for evaluating and scoring udders.

Starting in 1996, when the F_1 cows were from 11 to 14 yr of age, incisor condition was evaluated in the fall at the time of palpation for pregnancy, by assignment of one of three scores: solid mouths had no teeth loose or missing, broken mouths had one or

more teeth loose or missing, and smooth mouths had no incisors remaining. In the analysis reported in this paper, mouth score was analyzed as a binary trait of 14-yr-old cows, where smooth mouths were assigned a value of zero and both broken and solid mouths were assigned a value of one.

Calves out of the F_1 cows were weaned in October or November, depending on the year. Cows were culled for severe injuries, poor health, or at least two failures to have or wean a calf until they were about 14 yr of age. In some cases, cows were kept that did not meet these criteria; in most of these cases, these were cows that had lost a calf and were diagnosed as pregnant. In later years, cows were culled after one failure to have or wean a calf, regardless of their previous record. Cows were also culled if udders and/or teats were so large or pendulous that it was apparent that future calves would be unable to nurse without assistance. Fraction of cows remaining in the herd to 14 yr of age (which was the age of the youngest cows at the time of the analysis that is reported in this paper) was evaluated under the actual and three imposed culling procedures. The first imposed culling procedure (Method A) was removal of a cow after two failures to wean a calf. In Method B, a cow was removed after her first failure to have a calf; in Method C, cows were removed after the first failure to wean a calf.

The traits evaluated in this study are the result of both additive and non-additive (heterotic) effects; that is, differences between two breeds (as evaluated in their F_1 crosses with Hereford) are due to both breed differences (additive effects) and differences in the amount of heterosis that the two breeds express with Hereford. The heterosis expressed in a cross between a *Bos indicus* and a *Bos taurus* breed is about twice (Cundiff et al., 1989) or even three times as high (Koger, 1980) as that between pairs of *Bos taurus* breeds.

Data were analyzed by mixed model procedures; sire breed of the F_1s was the major effect of concern in all analyses. Sire within breed was considered a random effect and was used to test for differences in sire breeds. More details about the models used to analyze specific characters were reported by Paschal et al. (1991, 1995) and Riley et al. (2001a, 2001b).

Results and Discussion

Birth and Weaning Characters of F_1 Calves

Least squares means and standard errors for birth and weaning characters of F_1 calves are presented by breed of sire in Tables 1 and 2, respectively. Gestations of the various *Bos indicus*-sired F_1 crosses were from 7 to 12 days longer than those of the Angus-Hereford crosses. This is consistent with other published results (e.g., Gregory et al., 1979). Among the *Bos indicus*-sired F_1 crosses, Nellore crosses had the longest ($P < 0.05$) gestations, which is consistent with results from straightbred cattle in India (Sharma and Prabhu, 1968) and Brazil (Villares and de Abreu, 1949). There was a significant breed of sire by sex interaction for gestation length; the difference in gestation length between bull and heifer calves was larger in all of the *Bos indicus*-sired F_1 crosses than in the Angus-Hereford crosses. The largest differences between bulls and heifers were in the Gray Brahman- and Nellore-sired calves, where the bull calves were carried 7.3 and 6.8 d longer, respectively, than the heifer calves.

The breed of sire by sex of calf interaction was included in the final model for birth weight ($P = 0.29$) because of the importance of this interaction and because the results are consistent with other published results. Least squares means for birth weight in bull and heifer calves differed by 5.7 lb in Angus crosses; in the *Bos indicus*-sired F_1 crosses, birth weight differences between bulls and heifers ranged from 10.8 lb in Gir crosses to 15.4 lb in Nellore crosses.

Because of the close association between birth weight and dystocia and the threshold nature of dystocia, breeds with larger differences between the sexes for birth weight can experience more dystocia than would be expected from the average birth weight of the breed. This can be even more of a problem in *Bos indicus*-sired F_1s, where the variance of birth weight in bull calves has been found to be larger than in heifer calves of the same breeding or in bull or heifer calves of straight *Bos indicus* or *Bos taurus* breeding (Riley and Sanders, 1999). In the study reported here, the breed of sire by sex of calf interaction ($P > 0.4$) was not used in the final analysis of dystocia, but most of the dystocia was in bull calves, and, therefore, the largest within-breed sex differences in dystocia frequency were in the breeds with the most dystocia. Of the calves requiring assistance, excluding abnormal presentations, 20 of 25 were bulls; of the 25 requiring assistance, 10 of the 25 required mechanical assistance (calf puller), and all 10 were bulls.

The sire breed differences for the linear birth measurements (cannon bone length and heart girth) are fairly consistent with what would be expected from the birth weight differences. One apparent exception is that the cannon bone lengths in the Gir and Nellore crosses are longer than might have been expected from their birth weights. The average heart girth in Nellore crosses was also more than might have been expected from their birth weights.

The lower weaning weight of the Angus-Hereford crosses compared to the Gray Brahman and Red Brahman crosses is consistent with published results (e.g., Gregory et al., 1979). The lower weaning weight of the Gir crosses compared to the Nellore and Indu-Brazil sired calves is consistent with results from straightbreds in Brazil (e.g., Veiga et al., 1949).

The breed of sire by sex of calf interaction was not significant for weaning weight, but, with the exception of the Indu-Brazil crosses, the sex differences were larger in the *Bos indicus*-sired calves than in the Angus crosses. When evaluated with a model that included the breed by sex interaction, the steer calves were 41.1, 33.9, 9.5, 37.2, and 37.0 lb heavier than the heifers in the Gray Brahman, Gir, Indu-Brazil, Nellore, and Red Brahman crosses, respectively. In the Angus crosses, the steers were 16.1 lb heavier than the heifers.

The sire breed differences for weaning hip height are consistent with the averages for cannon bone length at birth. All of the *Bos indicus* sired crosses were not only taller at weaning than the Angus crosses, but also taller in relation to their weaning weights; this is especially apparent in the Gir crosses, which were slightly lighter ($P > 0.05$) than the Angus crosses but 2.7 inches taller. Among the *Bos indicus* crosses, the Nellore and Indu-Brazil crosses were taller in relation to their weaning weights than the Red, and, especially, the Gray Brahman crosses.

More details for birth and weaning characters were reported by Paschal et al. (1991).

Postweaning Growth and Size Characters of F_1 Crosses

Least squares means and standard errors for postweaning pasture growth and size characters of steers and heifers and feedlot growth and size characters of steers are presented by breed of sire in Tables 3 and 4, respectively. The yearling (off pasture) weights were taken in the fall at an average age of 355 d. The feeding period ended in April at an average age of 504 d. Note that the pasture growth was evaluated during the summer months while grazing warm-season perennial pasture, and the feedlot growth was evaluated during the winter months.

The (summer) pasture growth rate for the Angus crosses was less ($P < 0.05$) than for any of the *Bos indicus* crosses, but the (winter) feedlot growth rate did not differ ($P > 0.05$) between the Angus crosses and any of the *Bos indicus* crosses. The higher weight gains of the *Bos indicus* crosses on (summer) pasture would appear to represent both their tolerance of the summer weather and their use of the summer forages. The pasture gain of the Indu-Brazil crosses was slightly less than that of the Gir and Nellore crosses and significantly less than that of the Gray Brahman and Red Brahman crosses; feedlot gain for the Indu-Brazil crosses was as high or higher ($P > 0.05$) than that of any of the crosses. The lower pasture gains of the Indu-Brazil crosses may represent some lack of adaptation to the pasture conditions and/or their inability to consume enough forage to meet their nutritional requirements.

The Red Brahman and Gray Brahman crosses were both significantly heavier than the Angus and Gir crosses for weaning weight (steers and heifers), yearling weight (also steers and heifers), and weight at the end of the feeding period (steers). The Nellore and Indu-Brazil crosses were intermediate in weight at all three of these ages.

There was a very close correspondence between both the yearling (steers and heifers) and final feedlot height (steers) with the weaning hip height and cannon bone length at birth. Note that the Nellore crosses were as tall or taller (never significantly taller than the Indu-Brazil or Red Brahman crosses) than any of the other crosses at weaning, yearling age, and at the end of the feeding period. All five of the *Bos indicus* crosses were significantly taller than the Angus crosses at all three ages; the Nellore, Indu-Brazil, and Red Brahman crosses were significantly taller than the Gir crosses at all three ages.

While the *Bos indicus* crosses were all significantly taller than the Angus crosses at all three of these ages, in all but one case, their difference from the Angus crosses increased with the increase in age. This single exception was in the difference between the Gray Brahman crosses and the Angus crosses, where the difference was 3.9 inches at both the time of the yearling measurement and at the end of the feeding period.

To illustrate this increase in the difference, the Red Brahman crosses were 3.7 inches taller than the Angus crosses for weaning height, 4.3 inches taller for yearling height, and 4.7 inches taller at the end of the feedlot period. The increases in the difference from the Angus from weaning to the end of the feeding period were 0.6, 1.0, 0.7, 0.9, and 1.0 inches for the Gray Brahman, Gir, Indu-Brazil, Nellore, and Red Brahman crosses, respectively. These increases in the difference from the Angus crosses are consistent with the observed tendency for *Bos indicus* cattle to increase in frame score (by either the Missouri or the BIF system) with increasing age.

More details for postweaning growth and size characters were reported by Paschal et al. (1995).

Carcass Characteristics of F_1 Steers

Least squares means and standard errors for carcass characters of F_1 steers are presented by breed of sire in Tables 5. The Red Brahman and Gray Brahman crosses had significantly heavier carcasses than the Angus crosses; other crosses were intermediate.

The Angus crosses had significantly higher marbling scores than any of the *Bos indicus* crosses. Although there were no significant differences in marbling score among the *Bos indicus* crosses, the higher ($P > 0.05$) marbling score of the Nellore crosses is consistent with more recent unpublished observations of both purebred Nellore and Nellore crosses.

Although the Indu-Brazil crosses did not differ significantly from the other *Bos indicus* crosses for most (the only exception was that they were significantly lighter in carcass weight than the Red Brahman crosses) of the factors affecting yield grade (ribeye area in relation to carcass weight, adjusted fat thickness, and estimated percent of kidney, pelvic, and heart fat), they had an advantage ($P > 0.05$) for all of the factors, and, consequently, had a lower (leaner, or more desirable) average yield grade ($P < 0.05$) than the other *Bos indicus* crosses. More details for carcass characteristics were reported by Paschal et al. (1995).

Maternal Characteristics of F_1 Cows

Least squares means and standard errors for percentage occurrence of calving difficulty in F_1 first calf (2.5 years of age) heifers (all bred to Charolais bulls) are presented by breed of sire of the heifers in Tables 6. The occurrence of calving difficulty was 50% in the Angus cross heifers, which was much higher (not significantly higher than in the Gray Brahman cross heifers) than that in any of the *Bos indicus* cross heifers. As discussed by Riley et al. (2001a), these differences in dystocia in F_1 *Bos indicus* cross heifers compared to straight British heifers are consistent with published results. Since there was almost no calving difficulty among older cows (three years of age and older), calving difficulty was only evaluated in heifers.

Least squares means and standard errors for birth weight and weaning weight of calves out of F_1 cows are presented by breed of sire of the cows in Tables 6. Average birth weight for calves out of Angus x Hereford cross cows was from 4.7 to 10 lb heavier than for calves out of the various *Bos indicus* cross cows, although only significantly heavier than those out of Gir and Nellore cross cows. Of course, this is consistent with the well-known tendency for *Bos indicus* and *Bos indicus* crossbred cows to have lighter calves at birth than *Bos taurus* cows, when they are bred to the same sires (e.g., Roberson et al., 1986).

Among the *Bos indicus* crossbred groups, the Gir and Nellore cross cows had calves with the lightest average birth weights (only the difference between calves out of Gir and Red Brahman cross cows was significant). The Gir and Nellore crosses also had the lowest average birth weights as F_1 calves (Table 1). Calves from the Gir cross cows had an adjusted birth weight of 76.6 lb, which was 4.9 lb lower than the average of the calves out of the four other *Bos indicus* groups. As calves, the F_1 Gir crosses had an adjusted average birth weight of 72.6 lb, which was 10.1 lb lower than the average of the four other *Bos indicus* group means.

The sex of calf x sire breed of cow interaction ($P = 0.242$) was included in the model for weaning weight. Steer calves were 44.4, 41.8, 32.3, 39.6, and 35.4 lb heavier than the heifer calves out of the Gray Brahman, Gir, Indu-Brazil, Nellore, and Red Brahman cross F_1 cows, respectively. Steers calves out of the Angus sired cows were 18.0 lb heavier than the heifers.

Average weaning weight for calves out of the Angus sired cows was less ($P < 0.001$) than those from cows of any of the *Bos indicus* sire breeds; there were no significant difference among those out of any of the *Bos indicus* crossbred groups. As discussed by Riley et al. (2001a), these differences in weaning weight in calves out of F_1 *Bos indicus* cross cows compared to those out of straight British cows is consistent with published results.

More details for birth and weaning characteristics of calves out of F_1 cows were reported by Riley et al. (2001a).

Cow Size

Least squares means and standard errors for seven-year-old cow weights and hip heights are presented by sire breed of cow in Table 7. The Angus sired cows had lighter ($P < 0.10$) adjusted weights as seven year olds than any of the crossbred groups except the Gir and Nellore crosses. All of the *Bos indicus* crossbred groups were taller ($P < 0.05$) than the Angus crosses. Among the *Bos indicus* crosses, the Indu-Brazil crosses were significantly taller than the Gir crosses; all others were intermediate. More details for size of F_1 cows were reported by Riley et al. (2001a).

Udder Characteristics

Least squares means and standard errors for teat length, teat diameter, and udder support score are presented by breed of sire of the cow in Table 8. Teat

length is a problem if the bottom of the teat is too low for the calf to reach (or find) shortly after birth. Calves almost always have to reach down to nurse; short teats are easier for calves to reach and, except in extreme cases, are easier to nurse. Teat size increases with the age of the cow, at least up to a point, so that

Table 1. Least squares means and standard errors for F_1 birth characters by sire breed (n = 290)

Sire breed	Gestation length, d	Calving ease[a]	Birth weight, lb.	Cannon bone length, in.	Heart girth, in.
Angus	282 ± 1[b]	0.05 ± 0.05	70.0 ± 1.5[b]	10.5 ± 0.08[b]	28.2 ± 0.2[b]
Gray Brahman	291 ± 1[c]	0.13 ± 0.04	81.6 ± 1.3[c]	11.5± 0.08[c]	29.5± 0.2[c]
Gir	289 ± 1[c]	0.06 ± 0.04	72.6 ± 1.5[b]	11.4 ± 0.08[c]	28.7± 0.2[c]
Indu-Brazil	290 ± 1[c]	0.22 ± 0.05	86.0 ± 1.5[d]	11.9 ± 0.08[e]	29.8± 0.2[c]
Nellore	294 ± 1[d]	0.14 ± 0.04	80.7 ± 1.3[c]	11.8 ± 0.08[de]	29.9± 0.2[c]
Red Brahman	290 ± 1[c]	0.08 ± 0.04	82.3 ± 1.3[cd]	11.6± 0.08[cd]	29.4± 0.2[c]

[a]Calving ease score as follows: 0 = no assistance; 1 = assisted birth.
[b,c,d,e]Means within a column with no superscripts in common differ ($P < 0.05$).

Table 2. Least squares means and standard errors for F_1 weaning characters by sire breed (n = 260)

Sire breed	Weaning weight, lb.	Weaning hip height, in.
Angus	437.1 ± 8.6[a]	39.9 ± 0.28[a]
Gray Brahman	468.4 ± 8.1[bc]	43.2 ± 0.24[bc]
Gir	435.2 ± 7.9[a]	42.6 ± 0.24[b]
Indu-Brazil	451.2 ± 8.6[ab]	43.8 ± 0.28[c]
Nellore	453.9 ± 7.7[abc]	43.8 ± 0.24[c]
Red Brahman	471.7 ± 7.9[c]	43.6 ± 0.24[c]

[a,b,c]Means within a column with no superscripts in common differ ($P < 0.05$).

Table 3. Least squares means and standard errors for F_1 yearling (steers and heifers) growth characters (off pasture) by sire breed (n = 245)

Sire breed	Postweaning gain, lb./day	Yearling weight, lb.	Yearling hip height, in.
Angus	0.48 ± 0.04[a]	509.1 ± 9.2[a]	43.3 ± 0.24[a]
Gray Brahman	0.86 ± 0.02[c]	594.4 ± 8.4[c]	47.2 ± 0.24[bc]
Gir	0.81 ± 0.04[bc]	548.7 ± 8.8[b]	46.8 ± 0.24[b]
Indu-Brazil	0.77 ± 0.04[b]	560.8 ± 11.0[b]	47.6 ± 0.28[cd]
Nellore	0.79 ± 0.02[bc]	567.6 ± 7.9[b]	47.9 ± 0.20[d]
Red Brahman	0.86 ± 0.02[c]	596.9 ± 8.1[c]	47.6 ± 0.20[cd]

[a,b,c,d]Means within a column with no superscripts in common differ ($P < 0.05$).

Table 4. Least squares means and standard errors for feedlot growth characters of F_1 steers by sire breed (n = 125)

Sire breed	Average daily gain, lb./day	Final weight, lb.	Final height, in.
Angus	3.45 ± 0.13	1030.5 ± 23.3[a]	48.2 ± 0.35[a]
Gray Brahman	3.52 ± 0.13	1099.3 ± 24.0[bc]	52.1 ± 0.35[bc]
Gir	3.23 ± 0.13	1038.2 ± 22.4[a]	51.9 ± 0.35[b]
Indu-Brazil	3.52 ± 0.13	1081.7 ± 24.4[abc]	52.8 ± 0.35[cd]
Nellore	3.30 ± 0.13	1056.2 ± 22.7[ab]	53.0 ± 0.35[d]
Red Brahman	3.45 ± 0.13	1124.2 ± 22.0[c]	52.9 ± 0.32[cd]

[a,b,c,d]Means within a column with no superscripts in common differ ($P < 0.05$).

Table 5. Least squares means and standard errors for carcass characters of F_1 steers by sire breed (n = 124)

Sire breed	Carcass weight, lb.	Marbling score[a]	Ribeye area, in^2	Yield grade
Angus	606.8 ± 14.5[b]	410.2 ± 12.0[c]	11.9 ± 0.34	2.5 ± 0.1[bc]
Gray Brahman	660.2 ± 14.5[cd]	347.7 ± 12.2[b]	11.7 ± 0.36	2.8 ± 0.1[d]
Gir	632.7 ± 12.8[bc]	349.6 ± 11.0[b]	12.0 ± 0.37	2.7 ± 0.1[cd]
Indu-Brazil	632.3 ± 15.0[bc]	344.5 ± 12.5[b]	12.0 ± 0.36	2.3 ± 0.1[b]
Nellore	642.8 ± 13.9[bc]	358.9 ± 11.5[b]	11.7 ± 0.33	2.7 ± 0.1[cd]
Red Brahman	676.3 ± 13.4[d]	345.5 ± 11.2[b]	11.9 ± 0.33	2.7 ± 0.1[d]

[a]Marbling: 300 = Sl^{oo}; 400 = Sm^{oo}; etc.
[b,c,d]Means within a column with no superscripts in common differ ($P < 0.05$)

Table 6. Least squares means and standard errors for occurrence (%) of calving difficulty for first-calf 2-yr-olds (n = 112), birth weight (n = 1139) and weaning weight (n = 1119) (lb) of calves out of F_1 cows through 1999

Breed of cow's sire	Occurrence (%) of calving difficulty	Birth weight, lb.	Weaning weight, lb.
Angus	50.3 9.2[a]	86.6 1.7[a]	499.4 9.1[d]
Gray Brahman	19.7 7.9[ab]	81.4 1.5[abc]	565.6 8.0[e]
Gir	14.8 9.4[b]	76.6 1.7[c]	562.2 8.7[e]
Indu-Brazil	12.4 8.6[b]	81.8 1.7[abc]	563.4 8.8[e]
Nellore	4.8 7.4[b]	80.7 1.5[bc]	566.3 8.0[e]
Red Brahman	8.4 7.7[b]	81.9 1.6[ab]	574.3 8.4[e]

[a-c]Means in the same column with no superscripts in common differ ($P < 0.10$).
[d-e]Means in the same column with no superscripts in common differ ($P < 0.001$).

Table 7. Weight (lb.) and height (in.) and standard errors of seven year old F_1 cows by sire breed (n = 108)

Sire breed	Palpation weight	Hip height
Angus	1145.5 ± 35.1[e]	49.1 ± 0.41[c]
Gray Brahman	1288.3 ± 32.1[d]	53.2 ± 0.35[ab]
Gir	1184.5 ± 38.5[de]	52.7 ± 0.43[b]
Indu-Brazil	1258.1 ± 30.9[d]	54.4 ± 0.37[a]
Nellore	1209.0 ± 31.0[de]	53.6 ± 0.33[ab]
Red Brahman	1270.7 ± 30.7[d]	53.5 ± 0.34[ab]

[a-c] Means in the same column with no superscript in common differ ($P < 0.05$).
[d-f] Means in the same column with no superscript in common differ ($P < 0.10$).

excessive teat length is usually a bigger problem in older cows; breakdown of the structure of the udder can be associated with larger increases in teat size. Teat length as reported in Table 8 is the average length of all four teats shortly after calving; the means were adjusted for teat distension to account for whether a teat had been nursed and the degree, if any, of swelling of the teat. These are the adjusted averages across the age of the cow from 2 to 14 yr of age. Teat length was also analyzed for length of individual teats and for the length of the shortest teat, and the breed differences are in general agreement with the results reported in Table 8 for average teat length. Riley et al. (2001b) reported adjusted averages for teat length and other udder characteristics by age of cow.

Average teat length was longest ($P < 0.05$) for the Indu-Brazil crosses and shortest for the Nellore crosses (only significantly shorter than the Indu-Brazil crosses). Indu-Brazil crosses had the longest teats of the *Bos indicus* crosses as 2 yr olds (not significantly longer than the Red Brahman crosses), and teat length of the Indu-Brazil and Gray Brahman crosses increased the most with age. The Angus crosses had the longest teats as 2 yr olds (not significantly longer than Indu-Brazil crosses) but had the smallest increase with age. The Nellore crosses had the shortest average teat length at all ages (not significantly shorter in some cases) and had the least increase in teat length of the *Bos indicus* crosses. Although only significantly shorter than the Indu-Brazil crosses at most ages, the Gir crosses had the second shortest average teat length of the *Bos indicus* crosses at all ages.

Teat diameter is a problem if the teat is too large for the calf to get it in its mouth without assistance. Averages for teat diameter followed similar trends as teat length, with the smallest values in the Nellore and Gir crosses and largest values in the Indu-Brazil crosses.

Udder support scores were assigned to assess the strength of udder attachment, with a higher score representing a tighter attachment and a lower score representing a more pendulous udder. Breakdown of the structure of the udder with increased age is associated with a decrease in udder support score. The strength of udder attachment and teat length (in addition to the height of the cow) determine how low the calf must reach to nurse.

The Indu-Brazil crosses had the most pendulous udders at all ages (Riley et al., 2001b). The Angus crosses had the highest udder support scores as 2, 3, and 4 yr olds although not significantly higher than Nellore crosses at any age), but had the largest decreases with age. From age 7 and older, the Nellore crosses had the highest udder support scores (not significantly higher in all cases), with the least decrease with age (Riley et al., 2001b).

More details for udder characteristics of F_1 cows were reported by Riley et al. (2001b).

Reproduction and Calf Survival

Least squares means and standard errors for pregnancy rate, calf crop born, calf crop weaned, and survival of calves from F_1 cows through 14 yr of age are presented by breed of sire of the cow in Table 9. The sire breed of cow x age interaction was important ($P < 0.05$) for pregnancy rate. Pregnancy rates of the Angus and Indu-Brazil crosses decreased the most with increasing age and both had some tendency to fluctuate between high pregnancy rates at one age and relatively low rates at the next age. Riley et al. (2001a) presented adjusted means for pregnancy rates for breed of sire x age combinations for these cows. Pregnancy rate for the Nellore crosses was highest and was significantly higher than that of the Angus crosses. Pregnancy rates of the Gray Brahman and Gir crosses were also higher ($P < 0.05$) than that of the Angus crosses.

As expected, calf crop born closely followed the pattern for pregnancy rates, and was higher ($P < 0.10$) for Nellore and Gray Brahman crosses than for Angus crosses.

The sire breed of cow x age interaction was important ($P < 0.05$) for survival rate of calves out of F_1 cows. Riley et al. (2001a) reported adjusted averages for calf survival by age of cow. As heifers, Angus crossbred cows had lower ($P < 0.10$) calf survival rates than Nellore, Gir, and Indu-Brazil crosses; however, they were not significantly lower than any of the *Bos indicus* crossbred groups at later ages. Remember that 50.3% of the Angus sired heifers had difficulty with their first calves (Table 6). All (four) of the calf deaths for calves out of Angus cross heifers were from difficult calvings (remember

that all heifers were bred to Charolais bulls for their first calves).

Indu-Brazil crossbred cows had the lowest overall rate of calf survival and lower rates than most breeds from age 5 to 14 (Riley et al., 2001a). Half of the 10 calf deaths of calves out of Indu-Brazil cross cows, which were 11 yr of age or older, were recorded as unable to nurse without assistance. In contrast, although the Nellore crosses were not significantly different from the Gir crosses at any age and were not significantly different from the other crosses at all ages, they were at or near the top at all ages; only one calf out of a Nellore cross cow was unable to nurse without assistance, and that cow died

Table 8. Least squares means and standard errors for udder characteristics through 14 years of age (n = 1200) and mouth scores (n = 116) of 14 year old F_1 cows

Sire breed	Teat length, in, (SE[a] = 0.15 in)	Teat diameter, in, (SE[a] = 0.05 in)	Udder support score[b] (SE[a] = 0.16)	Mouth score[c] (SE[a] = 0.06)
Angus	2.28[e]	1.02[gh]	4.78[fg]	0.65[e]
Gray Brahman	2.30[e]	1.09[gh]	4.79[fg]	0.95[d]
Gir	2.11[e]	1.02[gh]	4.63[gh]	0.92[d]
Indu-Brazil	2.95[d]	1.34[f]	4.16[h]	1.01[d]
Nellore	1.87[e]	0.95[h]	5.06[f]	1.01[d]
Red Brahman	2.21[e]	1.10[g]	4.51[gh]	0.99[d]

[a]Average standard error across all sire breeds
[b]Higher scores reflect stronger (tighter) attachment.
[c]Analyzed as a binary trait, where smooth = 0 and broken or solid = 1.
[d-e]Means in the same column with no superscripts in common differ ($P < 0.05$).
[f-h]Means in the same column with no superscripts in common differ ($P < 0.10$).

Table 9. Least squares means (%) and standard errors for pregnancy rate (n = 1275), calf crop percentages (n = 1217), and calf survival (n = 1142) of F_1 cows through fourteen years of age

Sire breed	Pregnancy Rate	Calf crop born	Calf survival rate[a]	Calf crop weaned
Angus	87.4 2.1[c]	86.7 2.5[e]	96.3 2.3[b]	83.3 3.1[c]
Gray Brahman	96.4 1.8[b]	95.6 2.2[d]	92.3 1.9[bc]	88.4 2.7[bc]
Gir	96.0 2.0[b]	94.6 2.4[de]	96.8 2.2[b]	91.5 3.0[bc]
Indu-Brazil	91.0 1.9[bc]	92.8 2.3[de]	87.1 2.1[c]	81.0 2.8[c]
Nellore	97.0 1.5[b]	97.1 1.9[d]	98.9 1.8[b]	96.1 2.4[b]
Red Brahman	93.8 1.8[bc]	92.7 2.2[de]	93.0 2.0[bc]	86.0 2.7[c]

[a]Evaluated as a trait of the cow.
[b-c]Means in the same column with no superscripts in common differ ($P < 0.05$).
[d-e]Means in the same column with no superscripts in common differ ($P < 0.10$).

Table 10. Least squares means (%) and standard errors for fractions of F_1 cows remaining in the herd to age fourteen under actual and imposed culling[a]

Sire breed	Actual	Method A	Method B	Method C
Angus	52.8 ± 12.8[bc]	45.4 ± 12.4[de]	18.8 ± 12.0[e]	21.2 ± 9.8[e]
Gray Brahman	53.4 ± 11.0[bc]	36.5 ± 12.4[e]	31.4 ± 10.1[e]	18.4 ± 8.2[e]
Gir	72.6 ± 13.2[bc]	64.4 ± 12.4[de]	44.2 ± 11.9[de]	39.7 ± 9.8[de]
Indu-Brazil	33.1 ± 11.5[c]	31.1 ± 11.1[e]	33.1 ± 10.8[de]	19.3 ± 8.8[e]
Nellore	80.3 ± 10.2[b]	78.9 ± 9.7[d]	68.8 ± 9.4[d]	54.0 ± 7.7[d]
Red Brahman	43.2 ± 10.8[c]	37.0 ± 10.4[e]	38.5 ± 10.1[de]	14.1 ± 8.2[e]

[a]Records culled using:
Method A – Culled after two failures (failure to calve or wean a calf) in two separate years
Method B – Culled after first failure to calve
Method C – Culled after first failure to wean a calf
[b-c]Means in the same column with no superscripts in common differ ($P < 0.05$).
[d-e]Means in the same column with no superscripts in common differ ($P < 0.10$).

Table 11. Simple means (%) for F_1 cow survival to various ages under actual culling through 2003

Sire breed	To age 14	To age 15	To age 16	To age 17	To age 18[a]	To age 19[b]
Angus	33	20	13	0	0	0
Gray Brahman	43	24	19	10	0	0
Gir	73	47	40	27	13	0
Indu-Brazil	16	11	5	0	0	0
Nellore	76	60	36	24	17	13
Red Brahman	43	33	14	14	0	0

[a] For the age groups that were (or would have been) 18 yr of age or older
[b] For the age groups that were (or would have been) 19 yr of age

Table 12. Percentage of cows remaining and removed of original number in each sire breed group (through 1999)

Sire breed of cow	Orig. no.	% remaining	Reprod. failure[a]	Udder[b]	Struct. unsound[c]	Other[d] and unk.[e]	Cancer eye	Calving diff[f]
Angus	15	13.3	53.3	0	13.3	6.7	6.7	6.7
Gray Brahman	21	19.1	28.6	33.3	0	4.8	4.8	9.5
Gir	15	40.0	6.7	20.0	6.7	6.7	20.0	0
Indu-Brazil	19	5.3	21.1	63.2	0	0	0	10.6
Nellore	25	60.0	24.0	0	0	4.0	8.0	4.0
Red Brahman	21	23.8	28.6	19.1	4.8	14.3	4.8	4.8
Total	116	28.5	26.7	22.4	3.5	5.4	6.9	6.0

[a]Reproductive failure category includes cows that were culled for failing to calve or wean a calf.
[b]Udder category includes cows culled for structurally bad udders, mastitis problems, and/or inadequate milk production.
[c]Structurally unsound category includes cows that were culled because of injury or physical condition that would prevent proper function.
[d]Other includes 2 yr old Gray Brahman cow that had uterine prolapse and calf was stillborn; cow was sold; Gir cow had laminitis and was sold; 14 yr old Nellore cow died from apparent respiratory problems.
[e]Unknown category includes one missing cow and three deaths.
[f]Calving category includes one death and one cull related to caesarean section births and five deaths that occurred close to calving date or projected calving date that seemed to be related to calving.

within a few days after calving. Although not evaluated statistically, it appears to be clear that the high calf survival rate in calves out of Nellore cross cows and the low rate of those out of Indu-Brazil crosses were due, in large part, to the teat and udder characteristics of the cows (Table 8).

The sire breed of cow x age interaction was also important ($P < 0.10$) for calf crop weaned. Since calf crop weaned is totally determined by calf crop born and calf survival, and since the Nellore cross cows were highest for both calf crop born and calf survival, they also had the highest calf crop weaned (96.1%); significantly higher than that of the Indu-Brazil, Angus, and Red Brahman crossbred cows. Calf crop weaned for Nellore and Gir crossbred cows ranked as highest or near highest for all age groups (Riley et al., 2001a).

Although Gray Brahman and Red Brahman crosses were lowest for calf crop weaned as heifers and lowest of the *Bos indicus* crosses as three year olds, they had acceptable (> 89%) calf crop weaned percentages from 4 to 9 yr of age. Calf crop weaned was acceptable (> 89%) for Indu-Brazil cross cows through 4 yr of age and at 6 yr of age but was lowest of all breed groups at age 5 and at all ages from 7 to 14.

More details for reproductive characters of F_1 cows and survival of calves out of F_1 cows were reported by Riley et al. (2001a).

*Mouth Score*s

Least squares means and standard errors for mouth score of 14-yr-old cows are presented by breed of sire of the cow in Table 8. The Angus sired cows had a lower ($P < 0.05$) adjusted mouth score (higher occurrence of smooth mouths) than the other sire breed groups. Riley et al. (2001b) also reported the results of an analysis of this same data where both smooth and broken mouths were assigned values of zero and solid mouths were assigned values of one. In that analysis, the adjusted mean for the Angus crosses

(0.13) was also less ($P > 0.10$) than (i.e., lower occurrence of solid mouths) that of any of the Bos indicus crosses (0.32 to 0.57 in the Gray Brahman and Red Brahman crosses, respectively).

Productive Longevity of F_1 Cows

Fraction of cows remaining in the herd to 14 yr of age (which was the age of the youngest cows at the time of the analysis) was evaluated under the actual and three imposed culling procedures. Least squares means and standard errors under these four different culling procedures are presented by cow's breed of sire in Table 10.

The Nellore crossbred cows had the largest fraction remaining in the herd at 14 yr of age (survival rate) under all four culling procedures. Under actual culling, the survival rate of 80.3% for the Nellore crossbred cows was significantly larger than that of the Indu-Brazil and Red Brahman crossbreds (33.1 and 43.2%). Under the imposed culling Method A (a cow's record removed after second failure to wean a calf), the rate for the Nellore crosses (78.9%) was significantly different from that of the Indu-Brazil, Gray Brahman, and Red Brahman crossbreds (31.1, 36.5, and 37.0%, respectively). Under imposed Method B (record removed after first failure to have a calf), the rate for the Nellore crosses (68.8%) was significantly different from that of the Angus and Gray Brahman crosses (18.8 and 31.4%). Under Method C (record removed after first failure to wean a calf), the rate for the Nellore crosses (54.0%) was significantly different from that of the Red Brahman, Gray Brahman, Indu-Brazil, and Angus crosses (14.1, 18.4, 19.3, and 21.2%, respectively).

The Gir crosses had the second highest fraction remaining in the herd under all four culling procedures and were not significantly lower than the Nellore crosses or significantly higher than any of the breed groups under any of the four culling procedures.

Simple means (%) for F_1 cow survival to various ages under actual culling, through 2003, are presented by cow's breed of sire in Table 11. The advantages in productive longevity of the Nellore and Gir crossbred cows continued at least through 17 yr of age.

The percentages of Nellore and Gir crosses remaining in the evaluation herd until 14 yr of age under culling Method C (54.0 and 39.7%, respectively, Table 10) clearly demonstrate the major reason that these two breed groups had their advantages in productive longevity under all four culling procedures. That is, these values represent the percentages of the original cows of these breed groups that had perfect weaning records through 14 yr of age. Table 12 gives the reasons for removal from the herd through the year 1999 by breed of sire of the cow. An individual cow may have been removed for more than one reason, especially in the later years of this project. The reason for removal is especially difficult to distinguish when a cow loses a calf because of an udder problem that prevents the calf from nursing without assistance; cows were removed for udder problems only if it appeared to be certain that future calves would be unable to nurse without assistance. In spite of these difficulties, an earnest attempt using all available written records and objective scores was made to assign cows to the category that best represented the reason for their removal.

Reproductive failure included cows that were culled for failure to conceive, calve, or wean calves more than one time in the majority of the project and one time in the very latest years of the project. This category was the leading cause for removal (26.7% of original 116 cows). Note, however, that although the Nellore crosses had the highest and Indu-Brazil crosses the lowest performance for calf crop weaned (Table 9), a higher proportion of Nellore than Indu-Brazil crosses were designated as having been culled for reproductive failure. Udder problems were the second leading cause for removal (22.4% of the original cows) and, since cows were removed for udder problems only if it appeared certain that future calves would be unable to nurse without assistance, it seems to be appropriate to compare the combined proportions that were removed for either reproductive failure or udder problems. When combined in this way, the fractions removed for reproductive failure or udder problems were 24, 26.7, 47.7, 53.3, 61.9, and 84.3% in the Nellore, Gir, Red Brahman, Angus, Gray Brahman, and Indu-Brazil crosses, respectively.

Most (65%) of the 83 cows that had died or were culled from the project by 1999 were 12 yr of age or older (Riley at al., 2001b) when they died or were culled. Since all of the cows were beyond 12 yr of age in 1999, all remaining cows were older than 12 yr of age when they left the herd. Therefore, 75% of the original 116 cows were 12 yr old or older when they died or were culled from the evaluation herd.

Most (all but 7) of the 31 cows that had been culled for reproductive failure by 1999 were 12 yr of age or older (Riley at al., 2001b).

As with reproductive failure, most of the cows that had been culled for udder problems by 1999 were 12 yr of age or older (Riley at al., 2001b). More of the Indu-Brazil crosses (63% of the original 19 cows) were culled for udder problems than any other breed group; also, more of the Indu-Brazil crosses were culled for udder problems before 12 yr of age than any other group. None of the Nellore or Angus sired cows were culled for udder problems.

Although the proportions of Nellore and Gir crossbred cows that remained in the herd to 14 yr of age (and later ages) were the highest of the breed groups in the study, the proportions that were removed by 1999 for cancer eye were highest in these two breed groups (8 and 20% for the Nellore and Gir crosses, respectively). Part of the higher incidence of cancer eye in these breed groups may have been simply that a larger proportion stayed in the evaluation herd long enough to develop the condition. However, another apparent cause is that, when crossed with the Hereford, the genes for spotting (and/or speckling) that are carried by these two breeds give a higher proportion of F_1 crosses with the "full" Hereford pattern. Of course, cancer eye is well known to be a bigger problem in straight Hereford cattle than in other breeds.

More details for productive longevity characteristics of F_1 cows were reported by Riley et al. (2001b).

Summary

The Brahman by British F_1 cow can be considered the standard for cow productivity in the southern and southwestern United States (as well as in many other tropical, subtropical, and warm temperate areas). Crosses of both the Gray Brahman and the Red Brahman with the Hereford performed well in this study. However, the Gir- and, especially, the Nellore-Hereford F_1 cows had even higher productivity.

Although not all differences were significant, compared to the Brahman crosses (both Gray and Red), the Gir and Nellore crosses had lower birth weights in F_1 calves, higher marbling scores and similar yield grades in F_1 steer carcasses, lower mature cow weights in F_1 cows, lower birth weights in calves out of F_1 cows, similar weaning weights in calves out of F_1 cows, more desirable udders and higher reproductive rates in F_1 cows, higher survival rates in calves out of F_1 cows, and higher levels of productive longevity in F_1 cows.

By contrast, the Indu-Brazil crossbreds were markedly inferior in many aspects of performance and productivity to the other *Bos indicus* crosses in this study. Compared to these four other crosses (Gray Brahman, Red Brahman, Gir, and Nellore by Hereford crosses), the Indu-Brazil crosses (again, not all differences were significant) had higher birth weights and more calving difficulty in F_1 calves, lower postweaning average daily gain on pasture of F_1 calves, and lower marbling scores in F_1 steer carcasses, distinctly inferior udders and lower reproductive rates in F_1 cows, lower survival rates in calves out of F_1 cows, and lower levels of productive longevity in F_1 cows.

The Gir, and especially the Nellore, should be given serious consideration for incorporation into commercial crossbreeding programs and for use in composite breed development. Disposition was not measured experimentally in this study, but research and breed improvement efforts are needed to improve the disposition of the Nellore breed and its crosses.

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Evaluation of Brahman and Tropically Adapted *Bos taurus* Breeds In the Humid Subtropics

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ABSTRACT: Classic studies conducted in the 1960s between Brooksville, Florida, and Miles City, Montana, clearly established the presence of genotype by environment interactions. Those researchers concluded that the advantages of local over introduced lines were large enough to be of great economic significance in commercial beef production. While providing an ideal environment for all cattle is an unrealistic expectation, performance can be greatly enhanced by selecting cattle that have the genetic capacity to perform under harsh climates. Environment, however, is not simply related to geography or climate but also includes nutrition, disease, and the endemic pest load. Brahman cows of small, medium, and large frames were bred to bulls with similar frame size. Weaning rate was considerably lower for large frame first-parity and second-parity dams compared to small and medium frame dams. This was caused by poor calf survivability for large frame first-parity dams and to low conception for large frame second-parity dams. Weaning rates did not differ among frame sizes in third or greater-parity dams. Although the Brahman is undoubtedly adapted to the tropics, there are tropically adapted *Bos taurus* breeds that may offer other attributes for southern U.S. cattle production. In crossbreeding studies between Senepol and Hereford, significant levels of heterosis were observed for preweaning calf performance and feedlot performance of steers. Breed types did not differ for USDA yield and quality grades or Warner Bratzler shear force. A more recent study evaluated maternal and reproductive performance of Brahman x Angus, Senepol x Angus, and Tuli x Angus cows. Tuli x Angus cows had similar calf crop born and weaned as Brahman x Angus cows. Reproductive and maternal performance of Tuli x Angus cows was comparable to Brahman x Angus cows except for calf weaning weight and some calving difficulty. More recent studies have evaluated the Romosinuano, a tropically adapted *Bos taurus* breed native to Colombia. These recent studies showed that Romosinuano bulls and heifers reach puberty at relatively young ages similar to Angus. Currently a diallel breeding scheme among Angus, Brahman, and Romosinuano is being conducted.

Key Words: Cattle Breeds, Subtropics, Adaptation

Introduction

Compatability between beef cattle type (e.g., breed) and the environment is critical in harsh environmental zones such as the subtropics. In the United States, this zone represents 153 million acres of land, of which 27 million acres are grazing lands, on which approximately 30% of the U.S. beef herd is located. Climate-mandated dependence on warm-season grasses and lack of significant grain production limit beef cattle producers in this region largely to the cow-calf segment of the beef cattle industry. In the United States, sources of cattle germplasm with adaptation to warm climates, including subtropical Florida, are primarily limited to the American Brahman and derivative breeds. Crossbreeding research has consistently documented higher levels of heterosis or hybrid vigor in *Bos indicus* x *Bos taurus* cows compared to *Bos taurus* x *Bos taurus* cows, and the F1 Brahman cow is the standard of comparison in the South. Purebred Brahman, however, are required to generate these F1s and have been criticized for poor reproductive and feedlot performance, aggressive temperament, and low newborn calf survivability. Additionally, researchers have reported inferior carcass traits and palatability of beef from carcasses that have a high percentage of Brahman breeding. Consequently, there is a need to assess the feasibility of selection programs, including carcass selection programs, within the Brahman breed. Additionally, there are breeds of cattle from other regions of the world that are adapted to tropical environments that have not been characterized under U.S. conditions. Priority should be given to the characterization and evaluation of tropically adapted *Bos taurus* breeds that have potential for improving marketability and increasing production efficiency, especially for reproductive traits. Breeds offer convenient packages for the transfer of new or improved

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genetics/traits/genes. To be successful, a new breed must perform favorably in crossbreeding situations and potentially in the development of composite(s). No breed excels in all traits. Therefore we have focused our breed evaluations on tropically adapted *Bos taurus* breeds that included the Senepol, Tuli, and, most recently, the Romosinuano.

Genotype by Environment Interaction

An important component of efficient beef production is to ensure optimal compatability between the cattle and their environment. This is particularly important in stressful environments such as the subtropics and tropics. Environment, however, is not simply related to geography or climate (temperature, humidity), it also includes nutrition (forages, minerals, supplements) and disease and the endemic pest load. A classic example was provided by Butts et al. (1971), Koger et al. (1979), Burns et al. (1979), and Pahnish et al. (1983, 1985). They reported results from a study where Hereford cattle from Florida (Line 6) were exchanged with Hereford cattle from Montana (Line 1). These herds were maintained in Brooksville, Florida, and Miles City, Montana. Over the 11 years of the project that were reported on, it is obvious that pregnancy and weaning rates fluctuated from year to year (Table 1; Koger et al., 1979). Mean pregnancy rates in Montana for Hereford of Montana origin were 81% and of Florida origin were 83%. However, pregnancy rates in Florida for Hereford of Montana origin were 64% and of Florida origin were 86%. This line x environment interaction was evident for most of the traits that were studied and is commonly referred to as genotype by environment interaction. Mean weaning rate in Montana for Hereford of Montana origin was 73% and of Florida origin was 76% and in Florida Hereford of Montana origin was 59% and of Florida origin was 80%. In Table 2 pregnancy rate, calf survival, and weaning rates are presented (Koger et al., 1979). Clearly the pregnancy and weaning rates are lowest in Florida for Herefords of Montana origin (72 and 65%, respectively). Differences were observed between lines for both pregnancy rate and weaning rate and both were greater for Hereford of Florida origin than of Montana origin. Location also affected pregnancy and weaning rates with both being greater in Montana than in Florida. What is most striking about these data, however, is that there was a 6.7% advantage in pregnancy rate and a 6.1% advantage in weaning rate for local over introduced cattle.

Another indicator of cow productivity that includes reproductive efficiency and maternal traits is annual production per cow calculated as the product of weaning rate x 205-day weight (Table 3; Burns et al., 1979). These data are from the same project that was just discussed. Clearly the 205-day weight (366.2 lb) and annual production per cow (238.1 lb) were the lowest in Florida for Herefords of Montana origin. Interestingly, birth weights were smaller in Florida for both Herefords that originated in Montana and Florida. Thus, birth weights were affected by location as well as line and origin. Calf 205-d weight was not influenced by line but was heavier in Montana than in Florida. In fact there was a 35.1 lb advantage for local cattle over introduced cattle in 205-d weaning weight. This combined with weaning rate led to a 48.9 lb advantage in annual production per cow for the local over the introduced cowherd. Those researchers indicated that "the advantages of local over introduced lines were large enough to be of great economic significance in commercial beef production." They concluded that the results should be considered in "commercial cattle production, performance testing, interregional exchange of seedstock, and sources of semen for AI in different environments."

Table 1. Annual pregnancy and weaning rates of two lines of Hereford in two locations[a]

Location and line[b]	Year											Mean
	64	65	66	67	68	69	70	71	72	73	74	
	Pregnancy rate, %											
Montana												
M line 1	89	84	63	81	65	85	90	83	79	85	82	81
F line 6	82	78	87	73	89	94	96	88	73	73	77	83
Florida												
M line 1	83	36	83	78	72	85	59	39	73	44	55	64
F line 6	90	90	84	80	93	81	82	77	98	94	83	86
	Weaning rate, %											
Montana												
M line 1	83	70	57	77	60	73	86	76	68	83	69	73
F line 6	79	69	81	68	82	87	92	78	69	65	67	76
Florida												
M line 1	83	36	71	78	71	75	59	31	58	33	55	59
F line 6	79	86	75	74	86	78	75	75	90	91	66	80

[a]From Koger et al., 1979.
[b]Montana Line 1 (M line 1) and Florida Line 6 (F line 6).

Table 2. Reproductive performance of two lines of Hereford at two locations[a]

Item	No. of matings	Pregnancy rate, %	Calf survival, %	Weaning rate, %
Subgroups[b]				
M line 1 in MT	948	81.6	90.3	73.7
F line 6 in MT	526	82.8	91.9	76.1
M line 1 in FL	1007	72.0	90.3	65.0
F line 6 in FL	464	86.5	92.1	79.7
Line				
M line 1	1995	76.8	90.3	69.4
F line 6	990	84.7	92.0	77.9
P <		0.01	ns	0.01
Location				
MT	1474	82.2	91.1	74.9
FL	1471	79.3	91.2	72.3
P <		0.01	ns	0.01
Origin				
Local	1412	84.1	91.2	76.7
Introduced	1533	77.4	91.1	70.6
Difference		6.7	0.1	6.1
P <		0.01	ns	0.01

[a]From Koger et al., 1979.
[b]Montana Line 1 (M line 1) and Florida Line 6 (F line 6).

Table 3. Reproductive performance of two lines of Hereford at two locations[a]

Item	No. of calves born	Birth weight, lb	205-day weight, lb	Production per cow, lb
Subgroups[b]				
M line 1 in MT	727	81.1	435.4	321.0
F line 6 in MT	405	77.2	403.2	306.9
M line 1 in FL	677	63.9	366.2	238.1
F line 6 in FL	363	65.7	403.9	321.9
Line				
M line 1	1995	72.5	400.8	279.5
F line 6	990	71.4	403.7	314.4
P <		0.05	ns	----
Location				
MT	1474	79.1	419.3	313.9
FL	1471	64.8	385.1	280.0
P <		0.01	0.01	----
Origin				
Local	1412	73.4	419.8	321.4
Introduced	1533	70.5	384.7	272.5
Difference		2.9	35.1	48.9
P <		0.01	0.01	----

[a]From Burns et al., 1979.
[b]Montana Line 1 (M line 1) and Florida Line 6 (F line 6).

A more recent example of genotype by location interaction was reported between Brooksville, Florida, and Clay Center, Nebraska (Olson et al.,1991). Crossbred *Bos taurus* heifers and *Bos indicus* x *Bos taurus* heifers were born and weaned in Nebraska, and one-half were then raised in Nebraska and the other one-half in Florida. For this discussion the contrasts of location, genotype (*Bos indicus* [Brahman and Sahiwal] x *Bos taurus* cows vs *Bos taurus* x *Bos taurus* cows), and location x genotype are pertinent. There was a 9.0% higher pregnancy rate in Nebraska than Florida (Table 4); crossbred *Bos indicus* cows had a 3.8% higher pregnancy rate than crossbred *Bos taurus* cows; however, pregnancy rate of crossbred *Bos indicus* cows was influenced more ($P < 0.06$) in Florida (5.8%) than in Nebraska (1.8%). The percentage of unassisted calvings was 4.6% higher in Florida than Nebraska and crossbred *Bos indicus* cows had a higher percentage of unassisted calvings than crossbred *Bos taurus* cows. Some of these differences were due to heifers first calving in Nebraska as two-yr-olds vs in Florida as three-yr-olds. There was a significant location x genotype interaction for unassisted calvings, and this was explained by a greater advantage for crossbred *Bos indicus* cows in Nebraska, where the prevalence of calving difficulty was greater. Calf survivability was greater in Florida than in Nebraska and numerically was equivalent to the advantage in unassisted calving rate in Florida. This advantage in Florida, however, was greater for first calf heifers that were about 1 yr older in Florida than in Nebraska. Calf survival was not significantly influenced by genotype or location x genotype. Birth weight was 17.6 lb heavier in Nebraska than Florida and 7.5 lb heavier for calves from crossbred *Bos taurus* cows than crossbred *Bos indicus* cows. There was, however, a genotype by location interaction due to a greater reduction in birth weight from Nebraska to Florida for calves from crossbred *Bos taurus* cows (19.8 lb) than crossbred *Bos indicus* cows (15.2 lb). Weaning weights were 34.4 lb heavier in Nebraska than Florida and were 54.9 lb heavier for calves from crossbred *Bos indicus* cows than crossbred *Bos taurus* cows; however, weaning weights of calves were heavier from crossbred *Bos taurus* cows in Nebraska than in Florida, whereas weaning weights were similar for calves from crossbred *Bos indicus* cows in Nebraska and Florida. The researchers also reported that calf weaning weight per cow exposed was 354 lb and 459 lb for crossbred *Bos taurus* and crossbred *Bos indicus* cows in Florida, respectively, and 441 lb and 476 lb in Nebraska, respectively.

These studies clearly demonstrate the importance of matching cow type to the environment, particularly in more stressful environments. With respect to the subtropical location, both studies had adapted vs non-adapted cows: in the first study, local vs introduced Hereford cattle and in the second study adapted (*Bos indicus* crossbred cows) vs unadapted (*Bos taurus* crossbred cows) cows. Many of the results were consistent among studies; however, it is clear that our understanding of the mechanisms responsible for genotype by environment interactions is largely deficient. A greater understanding of the

Table 4. Linear contrasts of location (L), breed group (BG), and location x breed group for reproductive and maternal traits of crossbred beef cows[a]

Contrast	Pregnancy rate, %	Unassisted calving, %	Calf survival,%	Birth weight,lb	Weaning weight, lb
Nebraska – Florida	0.090***	-0.046***	-0.046***	17.6***	34.4***
Bos indicus cross – *Bos taurus* cross	0.038***	0.085***	0.010	-7.5***	54.9***
L x BG	-0.039[x]	0.082***	-0.010	-4.6***	-55.8***

[a]From Olson et al., 1991.
***P < 0.001.
[x]P < 0.10.

physiological and genetic mechanism responsible for genetic by environment interactions and/or adaptability is needed.

Effect of Frame Size on Reproductive and Maternal Performance of Brahman Cattle

Another important consideration in matching the cow to the environment involves the mature size of the cow in relation to the nutritional environment that is primarily forage based. At Brooksville, Florida, a relatively long-term breeding study was conducted that involved breeding small, medium, and large frame Brahman cows to Brahman bulls of similar frame size (Menchaca et al., 1996; Vargas et al., 1998, 1999, 2000). In that study, weaning rate was considerably lower for large frame first-parity (46.2%) and second-parity (38.3%) dams compared to medium frame first (74.3%)- or second-parity (59.8%) dams and small frame first (75.0%)- or second-parity dams (64.9%, Table 5; Vargas et al., 1999). Weaning rates did not differ among frame sizes in third- or greater-parity dams. Therefore, the question then becomes what was responsible for the decreased weaning rates in the large frame first- and second-parity dams? For the first-parity dams, calf survival rate was significantly lower for large frame (47.9%) than either small (80.7%) or medium (83.4%) frame dams. This difference in calf survivability explains the decreased weaning rate observed for large frame first-parity dams. Calf survivability did not differ among frame sizes for second- or third- or greater-parity dams. In second-parity dams, calving rate was significantly lower for large frame (41.0%) dams compared to either small (65.8%) or medium (69.0%) frame dams. The stage of production, which consists of raising their first calf and becoming pregnant with their second calf, is a critical and stressful time in the subtropics. Thus, the lower weaning rate observed in large frame second-parity dams was caused by low calving rates. There were no differences in calving rate among frame sizes in first-parity dams. Interestingly, calving rates were higher for small frame (93.5%) than either medium (78.5%) or large (79.8%) frame third-or greater-parity dams. This would suggest that from a pregnancy perspective, the small frame cow was superior to the other frame sizes. Production per cow, however, addresses the sum of the components that we have discussed, as well as calf weaning weight. For both first- and second-parity, large frame dams had significantly lower production per cow than either small or medium frame cows which did not differ from each other. For third- or greater-parity dams, there was no statistical difference among frame sizes in production per cow.

Development of replacement heifers is also critical to the economic efficiency of a beef cattle operation. In the context of matching cow size to the environment, it is important to consider sire selection for use on the cowherd because in most instances heifer calves will be selected as herd replacements. In addition to the differences in productivity observed among the frame size groups of Brahman cows there were also ramifications observed in saving heifer calves as replacements. Large frame heifers were 39 days older than small frame heifers and 46 days older than medium frame heifers at puberty.

Table 5. Reproductive performance of small, medium, and large frame Brahman[a]

Item	First-parity dams	Second-parity dams	Third or greater-parity dams
Weaning rate, %			
Small	75.0[b]	64.9[b]	71.8
Medium	74.3[b]	59.8[b]	68.5
Large	46.2[c]	38.3[c]	75.8
Survival rate, %			
Small	80.7[b]	97.5	77.6
Medium	83.4[b]	88.1	86.9
Large	47.9[c]	93.9	95.7
Calving Rate			
Small	93.5	65.8[b]	93.5[b]
Medium	88.5	69.0[b]	78.5[c]
Large	97.3	41.0[c]	79.8[c]
Weaning weight, lb			
Small	424.8[b]	422.0	439.2[b]
Medium	476.8[c]	422.8	448.2[b]
Large	498.2[c]	427.5	509.7[c]
Production / cow, lb			
Small	315.9[b]	268.5[b]	310.0
Medium	356.9[b]	254.4[b]	331.4
Large	226.8[c]	177.5[c]	389.8

[a]From Vargas et al., 1999.
[b,c]Means with a different superscript letter within a column and item differ (P < 0.05).

When managed in a defined breeding season, these differences can be important, even if breeding to calve first as 3 yr olds.

Genetic Control of Tenderness in Brahman Cattle

In 1994 a study at Brooksville, Florida, was initiated to investigate the genetic control of tenderness in Brahman cattle. This was originally designed as a five-year progeny test but was extended for two additional years to participate in the National Cattlemen's Beef Association (NCBA)-Carcass Merit Project for the Brahman breed. Brahman cows from the Brooksville herd were bred to registered Brahman bulls that were borrowed from breeders or were produced at Brooksville. Some bulls were used in multiple years in order to link data among years. A total of 27 bulls and over 500 progeny were evaluated (Riley et al., 2002, 2003a,b). The mean and heritability for some carcass traits were: average daily gain 2.4 lb./day and 0.64, harvest weight 978 lb. and 0.47, fat thickness 0.52 inches and 0.63, carcass weight 625 lb. and 0.55, dressing percent 63.8% and 0.77, loin eye area 11.2 square inches and 0.44, yield grade 3.1 and 0.71, marbling score 324 (Slight) and 0.44, and quality grade 526 (Select) and 0.47 (Table 6; Riley et al., 2002). The estimated heritabilities for carcass traits were moderate to large. The levels of heritability estimates observed for marbling score and USDA quality grade indicate that these traits would be very responsive to selection within the Brahman breed. The mean and heritability for some palatability traits were: Warner-Bratzler shear force 12.3 lb. and 0.14 (day 7), 11.6 lb. and 0.14 (day 14), 10.6 lb. and 0.06 (day 21); and taste panel tenderness 4.9 and 0.11 (Table 6; Riley et al., 2003a). Taste panel means for tenderness are based on a scale of 1 (extremely tough) to 8 (extremely tender). In contrast to the heritabilities for carcass traits, the heritabilities for palatability traits, including tenderness, were low (below 0.15). These results indicate that the use of selection for improvement of palatability traits including tenderness may be a slow process. Selection complemented with the use of post slaughter technologies to enhance tenderness may give quicker results for these traits.

These data, and the data we collected for the NCBA-Carcass Merit Project, provided the impetus for the development of carcass EPDs for the Brahman breed. Data from Brooksville, Florida, Louisiana State University, Texas A&M University, and American Brahman Breeders Association (ABBA) sponsored programs all contributed to this work. The recently published Brahman Herd Improvement Records (BHIR) 2004 Performance Summary includes EPDs for hot carcass weight, fat thickness, ribeye area, marbling score, percent retail yield, and Warner-Bratzler shear force (Franke et al., 2004).

The DNA from the Brooksville Brahman study was used to evaluate the association of molecular markers (called single nucleotide polymorphisms, SNPs) at the diacylglycerol O-acyltransferase 1 (*DGAT1*), Thyroglobulin (*TG*), and micromolar calcium activated neutral protease (*CAPN1*) genes with carcass and palatability traits (Casas et al., 2005). In previous studies, *DGAT1* was associated with milk yield and milk fat in dairy cattle and possibly with fat deposition in beef cattle; however, there was no significant association between *DGAT1* and any carcass or palatability traits in our study. In previous studies, *TG* was associated with marbling score in beef cattle. In our study, *TG* was associated with fat thickness and loin muscle area, but not marbling score. The *CAPN1* gene was of interest because in earlier studies it has been associated with tenderness in *Bos taurus* beef cattle. We used five SNPs (markers) for CAPN1, but only one was associated with tenderness, three were associated with hump height, and one was not associated with any trait. These results suggest that molecular marker data developed in *Bos taurus* cattle may not be appropriate for *Bos indicus* cattle and that appropriate additional markers will need to be developed.

Table 6. Unadjusted means, standard deviations (SD), and estimates of heritability for feedlot, carcass, and tenderness traits of Brahman cattle[a]

Trait	Mean	SD	Heritability
Average daily gain, lb	2.43	0.38	0.64
Hip height, in	53.1	2.61	0.67
Slaughter weight, lb	978.0	122.80	0.47
Shrink, %	3.37	1.34	0.26
Adj. fat thickness, in	0.53	0.15	0.63
Hot carcass weight, lb	624.8	83.38	0.55
Dressing percentage	63.8	2.27	0.77
Loin muscle area, in^2	11.25	1.20	0.44
KPH fat, %	2.29	0.67	0.46
Yield grade	3.08	0.56	0.71
Marbling score[b]	323.8	57.19	0.44
Quality grade[c]	526.0	42.87	0.47
Shear force, day 7, lb	12.3	4.26	0.14
Shear force, day 14, lb	11.6	3.75	0.14
Shear force, day 21, lb	10.6	3.55	0.06
Panel tenderness[d]	4.93	0.72	0.11
Calpastatin activity, mg/g	2.69	1.17	0.07

[a]From Riley et al., 2002, 2003a.
[b]200 to 299 = Traces; 300 to 399 = Slight; 400 to 499 = Small.
[c]400 to 499 = Standard; 500 to 599 = Select; 600 to 699 = Choice.
[d]Panel tenderness measured on a scale from 1 to 8; 1 = extremely tough, 4 = slightly tough, 5 = slightly tender, 8 = extremely tender.

In summary, moderate to high levels of heritability were observed for carcass traits including marbling score and USDA quality grade in Brahman cattle. Low levels of heritability were observed for palatability traits including tenderness in Brahman

cattle. Selection for improvement in carcass traits should make good progress; however, selection for improvement in palatability traits may be slow. The EPDs for carcass traits of Brahman cattle are now available from ABBA and are published in the 2004 Performance Summary. Analysis of Brahman DNA revealed some associations between gene markers and fat thickness, loin muscle area, and tenderness. Results suggest that molecular markers developed in *Bos taurus* cattle may not be applicable for *Bos indicus* cattle.

Evaluation of Senepol Cattle

Senepol cattle were imported to Brooksville, Florida, from St. Croix U.S. Virgin Islands in 1982. Most of the early research was to increase numbers of Senepol cows in order to conduct a diallel breeding design with Senepol and Hereford (Mujica et al., 1997; Chase et al., 1998). At that time, it had been shown that levels of heterosis were less in progeny from *Bos taurus* x *Bos taurus* crosses than in *Bos indicus* x *Bos taurus* crosses; however, it was not clear what levels of heterosis would be expected in the subtropics when one of the two *Bos taurus* breeds was tropically adapted. Results from the Senepol and Hereford diallel study indicated that direct heterosis was 3.5% for birth weight and 5.1% for 205-d adjusted weaning weight (Table 7; Chase et al., 1998). Senepol maternal breed effects were 4.2 lb for birth weight ($P < 0.10$) and 83.6 lb for 205-d adjusted weaning weight ($P < 0.01$). Levels of direct heterosis, Senepol maternal breed effects, and Hereford direct breed effects were significant for most feedlot performance traits of steer calves fed to a common endpoint (Table 8; Chase et al., 1998). Levels of heterosis were small and nonsignificant for most carcass traits (Table 9). Breeds did not differ for USDA yield and quality grades, and direct heterosis was not significant for Warner-Bratzler shear force. Thus, these data indicate significant levels of heterosis for preweaning and feedlot performance between Senepol and Hereford cattle. Although these levels of heterosis are somewhat lower than would be expected from *Bos indicus* x *Bos taurus* crosses, the Senepol breed appears to offer tropical adaptation with acceptable carcass traits, including tenderness.

Numerous physiological studies were conducted with Senepol cattle at Brooksville, Florida. Early work established that Senepol cattle and their crosses were heat tolerant; on hot days their rectal temperatures were lower than *Bos taurus* cattle and similar to or lower than Brahman (Hammond and Olson, 1994; Hammond et al., 1996). Further studies deduced that the short or slick hair coat characteristic of Senepol cattle was also associated with an ability for slick Senepol cattle to maintain lower rectal temperatures during hot days than normal haired Senepol cattle (Olson et al., 2003). Breeding studies and evaluations of Holstein – Senepol crossbreds are now being conducted to determine the influence of slick hair coat on milk production and reproductive performance in dairy settings. Furthermore, we are conducting genome scans to identify markers associated with the slick hair coat phenotype. Other studies conducted with Senepol at Brooksville included research on physiology of bulls (Chase et al., 1993, 1997; Chenoweth et al., 1996a,b), heifers (Kamwanja et al., 1994; Simpson et al., 1998; Williams et al., 2002) and cows (Alvarez et al., 2000; Landaeta-Hernandez, et al., 2002, 2004; Paula-Lopes et al., 2003).

Evaluation of Crossbred Senepol, Tuli, and Brahman Cattle

Most commercial cattle production in the subtropics is based on crossbred Brahman cows. At Brooksville, Florida, we developed a F1 crossbred cowherd about 10 years ago. Over two-years we bred the Angus cowherd to Brahman, Senepol, and Tuli sires using AI (Chase et al., 2000). Crossbred heifers appeared to be heat tolerant (Hammond et al., 1998). Age at first conception (or puberty) did not differ among the F1 crossbred heifers and was 15.5 mo for Brahman x Angus, 15.6 mo for Senepol x Angus, and 15.3 mo for Tuli x Angus heifers (Table 10). There were, however, large differences in body weight at first conception among the breed types. This is in contrast to bulls where breed type differences in both age and body weight were observed at puberty (Chase et al., 2001). Angus bulls were used to breed the heifers for their first calf and Charolais bulls were used for second and subsequent calves. For first-parity, there were no statistical differences among breedtypes in age at first-calving, percentage of normal births, or calf survival (Table 11; Chase et al., 2004). For second and later parities, calf crop born was higher for Brahman x Angus (89.0%) and Tuli x Angus (94.7%) than Senepol x Angus (76.9%) cows. This indicated that, under the conditions of this experiment, the reproductive efficiency of the Brahman x Angus and Tuli x Angus cows was superior to that of the Senepol x Angus cows. The percentage of normal births was higher for Brahman x Angus (98.7%) than Tuli x Angus (91.6%) cows when bred to Charolais bulls. Calf survival was higher for Brahman x Angus (96.2%) than Tuli x Angus (91.1%) cows. Calf crop weaned (or net calf crop) was higher for Brahman x Angus (86.1%) and Tuli x Angus (86.5%) than Senepol x Angus (70.2%) cows. Thus, the relatively high calf crop born for the Tuli x Angus cows was tempered by relatively more difficult births

Table 7. Direct heterosis effects for preweaning growth traits of Hereford (H x H), Senepol (S x S), Hereford x Senepol (H x S),and Senepol x Hereford (S x H) calves[a]

Trait	H x H	H x S	S x S	S x H	Heterosis[b]
Birth weight, lb	69.2	78.3	75.6	74.1	3.7*(3.5%)
Weaning age, d	221	207	206	216	-2 (0.03%)
Adj. weaning wt, lb[c]	410.0	522.5	496.0	438.7	28.4** (5.1%)
Avg. daily gain, lb	1.66	2.17	2.04	1.78	0.12**(5.4%)

[a]From Chase et al., 1998.
[b]0.5[(H x S + S x H) – (H x H + S x S)].
[c]Adjusted to 205 d.
*P < 0.05.
**P < 0.01.

Table 8. Direct heterosis effects for feedlot performance of Hereford (H x H), Senepol (S x S), Hereford x Senepol (H x S), and Senepol x Hereford (S x H) steers[a]

Trait	H x H	H x S	S x S	S x H	Heterosis[b]
Initial age, d	272	260	254	263	-1.3 (0.5%)
Initial body wt., lb	434.3	573.2	482.8	465.2	60.8**(13.2%)
Final body wt., lb	831.1	996.5	939.2	886.2	54.9**(6.4%)
Avg. daily gain, lb	3.04	3.00	2.36	2.98	0.28**(10.6%)
Days on feed	130	139	195	142	-22*(-13.6%)
Daily intake, lb	17.0	19.6	17.4	18.3	0.8**(9.9%)
Gain/feed, lb	0.40	0.34	0.30	0.37	0.005 (1.7%)

[a]From Chase et al., 1998.
[b]0.5[(H x S + S x H) – (H x H + S x S)].
*P < 0.05.
**P < 0.01.

Table 9. Direct heterosis effects for carcass traits of Hereford (H x H), Senepol (S x S), Hereford x Senepol (H x S), and Senepol x Hereford (S x H) steers[a]

Trait	H x H	H x S	S x S	S x H	Heterosis[b]
Hot carcass wt., lb	513.7	617.3	608.5	542.3	19.0 (3.4%)
Adj. fat thickness, in	0.42	0.44	0.40	0.41	0.015(3.6%)
Ribeye area, in^2	10.3	11.5	10.8	10.8	0.63* (6.0%)
KPH fat, %	1.9	2.1	2.7	2.2	-0.15(-6.5%)
Yield grade	2.5	2.6	2.8	2.5	-0.09(-3.4%)
Marbling score[c]	370	381	370	369	5.3 (1.4%)
Quality grade[d]	567	574	562	570	7.2 (1.3%)
W-B shear force, lb	10.6	9.5	9.9	11.7	0.22 (2.2%)

[a]From Chase et al., 1998.
[b]0.5[(H x S + S x H) – (H x H + S x S)].
[c]300 = slight, 400 = small.
[d]500 = Select, 600 = Choice.
*P < 0.05.

Table 10. Puberty in Brahman x, Senepol x, and Tuli x Angus heifers

Item	Brahman x Angus	Senepol x Angus	Tuli x Angus
No. of heifers	42	34	50
Age at puberty, mo	15.5	15.6	15.3
Weight at puberty, lb***	765	719	679

*** P < 0.001.

Table 11. Reproductive performance of Brahman x, Senepol x, and Tuli x Angus cows (from Chase et al., 2004)

Item	Brahman x Angus	Senepol x Angus	Tuli x Angus
First-parity, Angus-sired calves			
Age at first calving, days	752.5	751.3	743.2
Normal births, %	90.3	88.4	93.7
Calf survival, %	88.4	90.9	90.5
Weaning weight, lb	470.7[a]	429.7[b]	422.2[b]
Second- and later-parities, Charolais-sired calves			
Calf crop born, %	89.0[a]	76.9[b]	94.7[a]
Normal births, %	98.7[a]	93.3[ab]	91.6[b]
Calf survival, %	96.2[x]	91.2[xy]	91.1[y]
Calf crop weaned, %	86.1[a]	70.2[b]	86.5[a]
Weaning weight, lb	592.8[a]	540.1[b]	514.6[c]
Weaning weight per cow exposed, lb			
3- through 8-year-olds	516.3[a]	381.5[c]	461.0[b]

[a,b,c]Means with a different superscript letter in a row differ (P < 0.05).
[x,y]Means with a different superscript letter in a row differ (P < 0.10).

and lower calf survivability. Charolais-sired calf weaning weights were heaviest from Brahman x Angus (592.8 lb) cows, lightest for Tuli x Angus cows (514.6 lb) and intermediate for Senepol x Angus (540.1 lb) cows. However, when weaning weight was expressed as weaning weight per cow exposed (for 3- to 8-yr-old cows), the heaviest was from the Brahman x Angus (516.3 lb), the lightest from the Senepol x Angus (381.5 lb), and intermediate from the Tuli x Angus (461.0 lb) cows. The advantage of Brahman x Angus cows over Tuli x Angus cows in weaning weight per cow exposed was therefore due to the heavier calf weaning weights because calf crop weaned was similar between Brahman x Angus and Tuli x Angus cows. However, maintenance costs of the cow are also important to consider in overall efficiency. As 7 yr olds, the Brahman x Angus cows were the heaviest (1239 lb), the Tuli x Angus cows were the lightest (1130 lb), and the Senepol x Angus cows were intermediate (1186 lb). Therefore, when cow size is also considered, the overall efficiency of the Tuli x Angus cows becomes closer to that of the Brahman x Angus cows. This is significant because there are few examples of F1 crosses that can compete with Brahman x Angus or Brahman x Hereford F1 crosses in the subtropics of the United States. An additional factor that needs to be addressed is longevity of Tuli vs Brahman crosses because historically Brahman crosses have excellent longevity and hence lifetime productivity.

Characterization and Evaluation of the Romosinuano

The Romosinuano is a tropically adapted, criollo beef breed native to Colombia. Romosinuanos are purported to be highly fertile, and they are noted for their longevity, docile temperament, and combining ability with *Bos indicus*. A Romosinuano base herd was established at Brooksville through embryo importations from Costa Rica (upgraded herd) and Venezuela (purebred herds). Although progeny from these importations are phenotypically similar, microsatellite analyses have revealed differences at the DNA level (Brenneman et al., 2001). In our early research with Romosinuano, we confirmed their heat tolerance (Hammond et al., 1996) and observed that both bulls (Chase et al., 1997) and heifers reached puberty at slightly older ages than Angus but at younger ages than Brahman (Chase et al., 1998). Currently, we are conducting a three-breed diallel using Angus, Brahman, and Romosinuano cows. In addition to producing the three purebreds, six crossbreds (reciprocal crosses; e.g., Angus x Brahman and Brahman x Angus) are produced each year. This diallel design is necessary to estimate heterosis or hybrid vigor. Preliminary data indicate that for preweaning and weaning traits, levels of heterosis between Romosinuano and Angus were about 6%, Romosinuano and Brahman were about 9%, and Brahman and Angus were about 10% of the purebred averages (Riley et al., 2004). Heifer calves are being developed, and age at first conception will be determined. Steer calves are shipped to Oklahoma, backgrounded on wheat pasture, and finished in the feedlot. Carcass data and loin samples are collected, and tenderness will be evaluated. Preliminary data suggest that the Romosinuano has an acceptable rib eye area and USDA quality grade (Coleman et al., 2004; Phillips et al., 2004). Heifers from this project (purebreds and crossbreds) will be used to develop a cowherd to evaluate reproductive and maternal performance of these breed types.

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Lifetime Performance and Efficiency of F_1 Tropically Adapted Beef Cattle Breeds x Angus in Semiarid Rangeland

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ABSTRACT: Lifetime performance (growth, pregnancy, lactation, and longevity records through 7 calf crops) was evaluated for 252 F_1 cows: 93 Brahman Angus, 73 Senepol Angus and 86 Tuli Angus F_1 females born in February-April and weaned in October of 1992-1995. All females were bred to calve at 2 yrs of age and maintained on south Texas rangeland. A total of 1,471 calf records were evaluated: 468 collected before maturity (first three calf crops sired by Hereford bulls); 1,005 after maturity (four calf crops sired by Bonsmara, Braunvieh, Tuli, Wagyu bulls used in certain yrs stratified across all F_1 breeds). Birth dates and weights (only for first calf) and weaning measurements: weights, palpated pregnancy rates, BCS, and frame score were recorded. F_1's were supplemented with 20% C.P at 2-3 lb/female/d for 100 days each winter. Females were not culled until after the third parity and then only if they were dry in the fall and palpated open. The model for F_1 preweaning performance was $\hat{Y}$= yr, day of age, sire breed, age of dam, and sire breed x yr; for F_1 productivity was $\hat{Y}$= yr, pregnancy status, sire breed, sire breed x yr. Calving difficulty and pregnancy data were analyzed with the model: $\hat{Y}$= yr, sire breed (chi-square). Lifetime production efficiency for the Brahman-, Senepol-, and Tuli-Angus F_1's was 40.7, 38.7, and 42.3 lb weaned calf/100 lb female exposed. Even though Tuli F_1's weaned smaller (P<0.05) calves than Brahman F_1's (494.3 vs 532.4), they had higher (P<0.05) reproductive rates as 2 yr olds (75.6 vs 61.3) and as 3 yr olds (73.1 vs 68.5) and had smaller (P<0.05) mature weights (994 vs 1120 at 5.5 yr), and thus had higher (P<0.05) lifetime efficiencies. Senepol F_1's had higher (P<0.05) calving difficulty than Brahman and Tuli F_1's (16.2 vs 8.7 and 9.5% having difficulty) and thus weaned a (P<0.05) lower calf crop and had lower (P<0.05) reproductive rates in their second parity than Tuli F_1's.

Key Words: Angus, Brahman, Crossbred Cattle, Efficiency, Senepol, Tropically Adapted, Tuli

Introduction

Beef cattle breeds have been developed on every continent encompassing tropical environments. Some breeds are evolutionarily distinct and genetically distinctive. Each has been selected to be productive in specific environments, but the physiological processes by which they express their adaptation may differ. The ultimate proof of adaptation is in lifetime brood cow productivity. Hypotheses concerning physiological adaptation to environment can most expeditiously be done by evaluating distinctive genetics under the same environment, observing relative success in the animal's ability to manage the inherent aggregated stresses. Little has been reported on the lifetime productivity of tropically adapted breeds compared under one environment. The purpose of this experiment was to evaluate lifetime performance and efficiency on arid, subtropical south Texas rangeland of crossbred cows derived from three breeds that originated in different tropical environments.

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Experimental Procedures

Lifetime performance (growth, pregnancy, calf performance, and longevity records through seven calf crops) was evaluated for 252 F_1 cows. Ninety-three Brahman (Bos indicus), 73 Senepol (Bos taurus), and 86 Tuli (Bos taurus africanus [Sanga]) F_1 females were produced from Angus cows artificially inseminated to bulls available in the United States during 1992-1995 (Holloway et al., 2002). Experimental females were produced by artificially inseminating Angus females from two long-term local herds from south and west Texas to 12 Brahman, 9 Senepol, and 7 Tuli bulls selected to represent bulls in common commercial use. Females were born during February through April of each year from 1992-1995. The average calving date was March 23. Experimental females were weaned in October of each year at about 7 mo of age. All females were bred to calve at 2 yr of age. Thereafter, they were managed in the same production system as their dams. A total of 1,471 calf records were evaluated for seven calf crops from these females. Four hundred sixty-eight calving records were collected from the females before maturity (first

three calf crops sired by Hereford bulls). One thousand five calf records were evaluated from three calf crops after maturity. Birth dates and weights (only for first calf), weaning weights, and visual body condition score (BCS, 1=thin, 9=fat, Long et al., 1979), and frame score (1=small, 9=large, expanded scale from Lowman et al., 1976) were recorded.

Experimental females were maintained on south and south-central Texas rangeland for their productive lives (birth and early growth on the Rio Grande Plains Experimental Ranch near Spofford and mature life at the Harris Ranch, Kline [29^0 2' N, 100^0 14' W, elevation 853 ft, mean annual rainfall 22.5 in, range of 16.8 to 24.9 in, maximum temperature 37.8°C, minimum temperature 14.3°C]). They were supplemented according to commonly accustomed practice with 20% C.P. commercially available supplement[2] or equivalent (2-3 lb/female/d for about 100 d during winter). They were also allowed free access to a commercially available trace mineralized salt.[1] The management of all animals was similar for each year of the study (1992-2004) except for 1996. Because of severe drought conditions, we were forced to de-stock the rangeland from May 15 to November 15. During that time, experimental females were moved 180 miles north to the Texas Agricultural Experiment Station at McGregor. After this short period of time, experimental females were returned to south Texas rangeland. Cattle grazed extensively managed "mixed-brush" rangeland characterized by relatively sparse herbage with an over-story of shrubs that inhibited free movement of animals over the landscape (Holloway et al., 1993). Although cattle on this rangeland at times consume certain shrub species, shrubs do not usually compose much of the diet except during drought conditions (Launchbaugh et al., 1990). Prominent grass species were sideoats grama (*Bouteloua curtipendula*), red grama (*B. trifida*), buffalograss (*Buchloe dactyloides*), curly mesquite (*Helaria belangeri*), pink pappas (*Pappophorum bicolor*), Wrights threeawn (*Aristida wrightii*), and bristlegrass (*Seteria leucopila*). Prominent forb species were common ragweed (*Ambrosia artemisifolia*) and Texas croton (*Croton texensis*). Prominent shrubs included honey mesquite (*Prosopis glandulosa* var. *glandulosa*) and *Acacia* species including twisted acacia (*A. tortuosa*), blackbrush (*A. rigidula*), and guajillo (*A. berlandieri*). Although herbage allowance was not measured during each year, and growing conditions varied from year to year, in general the herbage allowance was estimated to be in the range of 800 to 1,400 lb DM per 100 lb of animal body weight. This environment represents about 25 million ac of land in south Texas and northern Mexico and, to a lesser extent, much of the rangeland in the semi-arid to arid zone of west Texas, and eastern New Mexico.

Experimental F_1 females were bred to calve first at two years of age, calving February through April for each of seven parities. Birth weights and calving difficulty scores (1=no difficulty, 2=assistance required, 3=born dead) were recorded for the first parity only. After calving was complete each year (May), calves were fitted with individual ID ear tags, experimental females were paired with their calves, and experimental female weight, BCS, and frame scores were taken. Each year at weaning, experimental females and calves were weighed and BCS and frame scores taken. Experimental females were rectally palpated for pregnancy at time of weaning. Frame scores were no longer taken after the third parity. No female was culled until after the third parity. After the third parity, cows were culled if they were palpated open or failed to wean a live calf. Breeding was by natural service each year in multi-sire herds. Breeding season each year was April 15 to July 15. For the first three calf crops, Hereford bulls were used, for the fourth and fifth calf crops, more than one breed of bull was used (fourth: Bonsmara and Braunvieh, and fifth: Bonsmara, Tuli and Wagyu). For the fourth calf crop, 12 bulls (6 - Braunvieh and 6 - Bonsmara) were placed with all of the experimental females across the ranch. For the fifth calf crop, cows were stratified by breed and allotted to multi-sire pastures so that equal numbers of cows of each experimental breed were exposed to each breed of sire. Each breed of sire was represented in each breeding unit in equal proportions. As a result, the calves born represented all experimental breeds being studied bred to all breeds of sire. For the sixth and seventh calf crop, all cows were stratified by breed and allotted to multi-sire pastures and bred to Bonsmara bulls.

Least square means for the performance response variables were computed using GLM of SAS (SAS, 1990). The model for experimental female weaning measurements (weight, BCS, and frame score) was $\hat{Y}$= day of age, breed of sire, age of dam, and breed of sire x year; The model for succeeding experimental female weights, BCS, frame scores, and weight gains was $\hat{Y}$= year, pregnancy status, breed of sire, breed of

[1]Trace mineralized salt composition: 33% NaCl, 11% Ca, 8% P, 1.9% Mg, 1.3% K, .4% Mn, .5% Zn, .8% Fe, .1% Cu, 1,564,000 IU/kg of vitamin A, and 1,100 IU/kg of vitamin D3.

sire x year. Since in 1996 experimental females were maintained under different conditions than in other years, all variables that included data from 1996 or were subsequent to 1996 were analyzed both with 1996 data and without. The only variable influenced by the data from McGregor was the yearling weight measurement. Thus, year 1996 was excluded from statistical analyses for yearling weight, BCS, frame score, and weight gains calculated with yearling weight, but were included for the analysis of all other variables. Performance data for the first three calf crops was analyzed with the model: $\hat{Y}$= calf sex, year, sire breed of dam, sire breed of dam x year, all years included for the other parities. Performance data for next four calf crops was analyzed with the model: $\hat{Y}$= calf sex, sire of calf, year, sire breed of dam, sire breed of dam x year. Statistical differences between means were determined with *t* tests (Steel and Torrie, 1980). Proportion of first calf females having difficulty calving and pregnancy data were analyzed by the chi-square statistic through the CATMOD procedure (SAS, 1990) with the model: $\hat{Y}$= year, breed of sire.

This experiment was part of a larger study designed to evaluate these breeds across the southern United States and Nebraska, ranging from hot, humid conditions (Overton, TX [Browning et al., 1995], Brooksville, FL [Chase et al., 2000], and Tifton GA [Baker, 1996]) to semi-arid conditions (El Reno, OK; Clay Center, NB [Cundiff et al., 1998] and McGregor, TX [Herring et al., 1996]), to arid conditions (Uvalde, TX [Holloway et al., 2002], and Las Cruces, NM [Winder and Bailey, 1995]). Because the experiment at Brooksville, FL, (Chase et al., 2000) was quite similar to the one presented here, having the same F_1 experimental crosses, the same sires represented, and having the same calving season, inferences as to genotype x environment interactions will be drawn and direct comparisons will be made as to sire breed performance.

Results and Discussion

Experimental female growth

Growth patterns of experimental F_1 females are shown in Table 1. As reported by Chase et al. (2000) and Holloway et al. (2002), Brahman crossbred females were 19.8 lb heavier, had 1.7 units greater frame score, and were 0.3 units lower in BCS than either Senepol or Tuli crossbred females. Senepol and Tuli crossbred females were similar at weaning. These differences persisted until after the females were pregnant with their first calf (1.5 yr of age, Table 1). From then until the end of the experiment, Brahman cross females were heavier, had higher frame scores, and were either similar to or greater than Senepol and Tuli crosses in BCS. Brahman crossbred females were later maturing, larger cows than Senepol and Tuli crosses. Senepol and Tuli crosses were similar in growth pattern, both being relatively early maturing and small to moderate in mature size.

Performance

Performance of Hereford crossbred calves for the first three calf crops is reported in Table 2. Hereford crossbred calves from Brahman F_1 females, however, grew 20% faster from birth to weaning ($P<0.0001$) than their counterparts, and thus weaned 49 lb heavier ($P<0.0001$) than calves from the Senepol and Tuli F_1's, Hereford crossbred calves from first-calf Brahman F_1 females had only slight advantages in condition, but had 0.9 units more frame than the calves from the other two breed types, which were similar in these respects. Results for the second parity were similar as the first, with calves from Brahman crossbred females weaning 42.7 lb heavier ($P=0.008$) with 0.3 units more ($P=0.06$) condition and 0.7 units more ($P=0.0004$) frame than calves from the other breed types. For the third parity, greater advantages were noted for calves out of Brahman F_1 females than calves of the other two breeds. The advantage was 58.3 lb ($P=0.0004$) for weaning weight, 0.3 units ($P<0.006$) for BCS, and 0.6 units ($P=0.01$) for frame. Hereford crossbred calves from Senepol and Tuli crossbred females were similar ($P>0.1$) in weaning weight, condition, and frame size for the first three calf crops.

As an average of parities 4-7, calves from Brahman F_1 cows had 44 lb heavier weaning weights ($P<0.05$) and 0.6 units greater frame scores ($P<0.05$) than calves from the other two cow breed types. Calves from Senepol and Tuli F_1 cows had similar weaning weights for all parities except for the seventh when calves from Senepol F_1's were 11 lb heavier ($P<.05$) than calves from Tuli F_1's. Calves from Brahman F_1 cows tended to have greater frame scores and BCS, but, for BCS, the differences between breed types declined in later parities.

Reproduction

At the first palpation (Table 4) at 1.5 yr of age, Brahman F_1 females were least likely to be palpated

Table 1. Growth patterns of tropically adapted F_1 females[a].

	Breed of Sire			
Variable	Brahman	Senepol	Tuli	Probability > F
Weaning weight, lb	346 ± 4[b]	330 ± 4[c]	322 ± 4[c]	< 0.0001
Weaning BCS	4.2 ± 0.07[b]	4.5 ± 0.07[c]	4.5 ± 0.06[c]	0.006
Weaning frame	6.2 ± 0.07[b]	4.4 ± 0.07[c]	4.5 ± 0.07[c]	< 0.0001
Yearling weight, lb	551 ± 8[b]	481 ± 10[c]	518 ± 9[d]	< 0.0001
Yearling BCS	4.9 ± 0.09[b]	4.7 ± 0.10[b]	4.8 ± 0.10[b]	0.1
Yearling frame	5.8 ± 0.13[b]	4.1 ± 0.14[c]	4.3 ± 0.13[c]	< 0.0001
Weight at 1.5 years of age	743 ± 12[b]	662 ± 14[c]	676 ± 12[c]	< 0.0001
BCS at 1.5 years of age	5.2 ± 0.07[b]	4.9 ± 0.08[cd]	5.1 ± 0.08[d]	0.01
Frame at 1.5 years of age	6.5 ± 0.10[b]	4.7 ± 0.11[cd]	4.8 ± 0.11[d]	0.0001
Gain from weaning to yearling,	0.90 ± 0.03[b]	0.73 ± 0.04[c]	0.79 ± 0.04[c]	0.004
Gain from yearling to 1.5 years,	0.99 ± 0.06[b]	0.90 ± 0.07[bc]	0.81 ± 0.06[c]	0.08
Gain from weaning to 1.5 years,	0.88 ± 0.03[b]	0.77 ± 0.03[c]	0.77 ± 0.03[c]	0.002
Weight at 2.5 years, lb	897 ± 28[b]	815 ± 34[c]	779 ± 13.23[c]	< 0.0001
BCS at 2.5 years, lb	4.6 ± 0.27[b]	3.9 ± 0.32[c]	3.7 ± 0.28[c]	0.002
Frame at 2.5 years, lb	6.8 ± 0.20[b]	4.8 ± 0.23[c]	4.8 ± 0.20[c]	< 0.0001
Weight at 3.5 years, lb	1010 ± 25[b]	958 ± 29[c]	890 ± 25[d]	< 0.0001
BCS at 3.5 years	5.1 ± 0.34[b]	5.2 ± 0.40[b]	4.9 ± 0.34[b]	0.7
Frame at 3.5 years	6.6 ± 0.21[b]	4.4 ± 0.26[c]	4.5 ± 0.22[c]	< 0.0001
Weight at 4.5 years, lb	1005 ± 20[b]	924 ± 22[c]	915 ± 18[c]	< 0.0001
BCS at 4.5 years	4.4 ± 0.17[b]	4.0 ± 0.19[b]	4.3 ± 0.16[b]	< 0.0001
Weight at 5.5 years, lb	1120 ± 17[b]	1036 ± 19[c]	994 ± 18[d]	< 0.0001
BCS at 5.5 years	5.0 ± 0.15[b]	4.7 ± 0.17[b]	4.6 ± 0.16[b]	< 0.0001
Weight at 6.5 years, lb	1170 ± 15[b]	1087 ± 17[c]	1014 ± 15[d]	< 0.0001
BCS at 6.5 years	5.5 ± 0.13[b]	4.8 ± 0.15[c]	5.1 ± 0.13[d]	< 0.0001
Weight at 7.5 years, lb	1118 ± 14[b]	1019 ± 17[c]	1016 ± 15[c]	< 0.0001
BCS at 7.5 years	4.6 ± 0.12[b]	3.7 ± 0.14[c]	4.1 ± 0.13[d]	< 0.0001
Weight at 8.5 years, lb	1232 ± 14[b]	1164 ± 16[c]	1087 ± 14[d]	< 0.0001
BCS at 8.5 years	6.1 ± 0.12[b]	5.2 ± 0.14[c]	5.2 ± 0.12[c]	< 0.0001

[a] Least square means from the models: Weaning weight, BCS, Frame = day of age, breed of sire, age of dam, sire x year (all years included); Succeeding weights, condition scores, and frame scores, and gains = year, pregnancy status, breed of sire, sire x year (year 96 excluded from yearling weight, and gains calculated with yearling weight, but included for all other variables).

[b,c,d] Means within row with a different superscript differ ($P < 0.05$) according to *t* tests.

pregnant (61% pregnant) with Tuli and Senepol F_1's having pregnancy rates of 75%. Perhaps because 39% of the Brahman F_1 females failed to calve the previous year, after their first pregnancy, Brahman F_1's responded by having similar to better pregnancy rates than both Senepol and Tuli F_1's. Senepol F_1's had the lowest pregnancy rates compared to Brahman and Tuli F_1's except in parities 1 and 3. For parity 1, Senepol F_1's had pregnancy rates equal to Tuli F_1's but in parity 2, Senepol F_1's had the lowest pregnancy rate. This was possibly due to the high percent of difficult births experienced by Senepol F_1's (Table 6) in parity 1. Bellows et al. (1978) reported lower subsequent reproduction for cattle experiencing difficult births. Senepol F_1's had the lowest number of live calves at birth and lowest percent weaned until the sixth and seventh parity. Tuli and Brahman F_1's were similar in percent live calves born and percent weaned (Table 4).Table 5 presents the number and total percent of F_1's that calved each year for the first three calf crops. Tuli F_1's had the best record in calving for three calf

Table 2. Performance as immature females (growth of Hereford crossbred calves)[a].

Parity	Variable[d,e]	Sire Breed of Dam: Brahman	Senepol	Tuli	Probability > F
1	Birth Weight, lb	74.5 ± 1.76[b]	79.15 ± 1.63[c]	73.19 ±1.46[b]	0.02
	Weaning Weight, lb	385 ± 11[b]	331 ± 11 [c]	349 ± 9[c]	0.0001
	Preweaning ADG, lb/d	1.85 ± 0.04[b]	1.52 ± 0.05 [c]	1.57 ± 0.04[c]	0.0001
	Weaning BCS	4.2 ± 0.14[b]	3.7 ± 0.14[c]	3.9 ± 0.12[bc]	0.2
	Weaning Frame	5.5 ± 0.14[b]	4.4 ± 0.15[c]	4.7 ± 0.12[c]	0.0001
2	Weaning Weight, lb	485 ± 11[b]	433 ± 14 [c]	452 ± 11[c]	0.008
	Weaning BCS	4.8 ± 0.10[b]	4.4 ± 0.13[c]	4.6 ± 0.10[bc]	0.06
	Weaning Frame	5.3 ± 0.13[b]	4.5 ± 0.15[c]	4.7 ± 0.14[c]	0.0004
3	Weaning Weight, lb	534 ± 13[b]	468 ± 16[c]	482 ± 13[c]	0.0004
	Weaning BCS	5.1 ± 0.10[b]	4.8 ± 0.12[c]	4.7 ± 0.10[c]	0.006
	Weaning Frame	5.4 ± 0.17[b]	4.6 ± 0.21[c]	4.9 ± 0.17[c]	0.01

[a] Least square means from the model: Birth weight, weaning weight, BCS and frame score = calf sex, year, sire breed of dam, sire breed of dam x year.
[b,c] Means within row with a different superscript differ ($P < 0.05$) according to t tests (Chi square test for percent having difficulty calving in parity 1).
[d] BCS = Body condition score, 1 to 9 with 9 being fattest.
[e] Frame score, 1 to 9 with 9 having the most frame.

Table 3. Performance as mature cows[a].

Parity	Variable[d,e]	Sire Breed of Dam: Brahman	Senepol	Tuli	Probability > F
4	Weaning Weight, lb	531 ± 22[b]	500 ± 21[b,c]	485 ± 20[c]	0.0217
	Weaning BCS	4.94 ± 0.21[b]	4.87 ± 0.20[b]	4.83 ± 0.19[b]	0.5078
	Weaning Frame	5.42 ± 0.22[b]	4.66 ± 0.21[c]	4.87 ± 0.20[c]	0.0003
5	Weaning Weight, lb	578 ± 18 [b]	531 ± 21[c]	545 ± 21[c]	0.0081
	Weaning BCS	5.20 ± 0.21[b]	4.99 ± 0.24 [b]	5.10 ± 0.24[b]	0.5031
	Weaning Frame	5.67 ± 0.23[b]	5.01 ± 0.27[c]	4.91 ± 0.26[c]	<0.0001
6	Weaning Weight, lb	578 ± 25 [b]	538 ± 23[c]	540 ± 23[c]	0.0128
	Weaning BCS	5.29 ± 0.24[b]	4.90 ± 0.23[c]	5.10 ± 0.22[b,c]	0.0563
	Weaning Frame	5.86 ± 0.36[b]	5.21 ± 0.34[c]	5.11 ± 0.33[c]	0.0013
7	Weaning Weight, lb	644 ± 22[b]	626 ± 21[b]	615 ± 21[b]	0.1529
	Weaning BCS	5.46 ± 0.27	5.46 ± 0.26[b]	5.59 ± 0.25[b]	0.7097
	Weaning Frame	6.07 ± 0.31[b]	5.65 ± 0.29[b,c]	5.23 ± 0.28[c]	0.0006

[a] Least square means from the model: Weaning weight, weaning BCS and weaning frame score = calf sex, year, sire breed of calf, sire breed of dam, sire breed of dam x year.
[b,c] Means within row with a different superscript differ ($P < 0.05$) according to t tests.
[d] BCS = Body condition score, 1 to 9 with 9 being fattest.
[e] Frame score, 1 to 9 with 9 having the most frame.

crops with Brahman and Senepol F1's being similar but about 7% lower than Tuli F1's.

Calving difficulty at two years of age

Calves born to first calving Senepol F_1 females were 5.3 lb heavier at birth than calves born to the other two breeds (P=0.02, Table 2). Calves from Senepol F_1 females were also much more likely (P=0.0027) to experience difficulty at parturition, having 29.2% difficult births as compared to 16.7% and 5.6% difficult births for calves from Tuli and Brahman F_1 females, respectively (Table 6). This was in agreement to results reported by Browning et al. 1995).

Table 4. Reproduction of tropically adapted crossbred females[a].

	Parity	Breed of Sire		
		Brahman	Senepol	Tuli
Percent of females declared pregnant	1	61.29	75.34	75.58
	2	68.54	66.15	73.08
	3	84.44	83.87	83.54
	4	94.59	81.13	84.29
	5	85.33	75.93	88.41
	6	86.44	86.36	91.94
	7	100.00	78.95	98.21
Percent of females declared pregnant having live calves at birth (only for parity = 1)	1	84.21	76.36	86.15
Percent of females declared pregnant in the fall having a weaning record	1	78.95	63.64	78.46
	2	85.00	78.57	82.46
	3	92.11	80.77	89.39
	4	90.00	86.05	88.14
	5	90.63	82.50	86.89
	6	92.16	91.89	91.23
	7	95.45	96.67	94.55

[a] Chi Square Analysis: Proportion declared pregnant = sire of dam *(P*=0.06(parity 1) 0.65 (parity 2) 0.99 (parity 3) 0.07 (parity 4) 0.17 (parity 5) 0.56 (parity 6) 1.0 (parity 7)).

Table 5. Number of (Percent) F_1 females having perfect calving records for the first three calf crops[a].

Sire Breed	Year of birth	Calves weaned, n	Total cows, n
Brahman	92	4	17
	93	5	15
	94	5	18
	95	2	43
Total		(17.20 %)	93
Senepol	92	5	15
	93	3	12
	94	5	23
	95	3	23
Total		(21.92 %)	73
Tuli	92	8	19
	93	7	13
	94	3	22
	95	9	32
Total		(31.39 %)	86

[a] Chi square analysis: Proportion having 3 calves = year *(P* = 0.1 (parity 1) 0.0001 (parity 2) 0.6 (parity 3)) sire *(P* = 0.09 (parity 1) 0.9 (parity 2) 0.6 (parity 3)).

Table 6. Proportion of first calf F_1 females having difficulty calving[a].

	Sire Breed		
Year	Brahman	Senepol	Tuli
92	0 (0/6	30 (3/10)	17 (2/12)
93	0 (0/8)	44 (4/9)	0 (0/10)
94	0 (0/15)	7 (1/15)	0 (0/15)
95	12 (3/25)	43 (6/14)	35 (8/23)
Total	5.6 (3/54)	29.2 (14/48)	16.7 (10/60)

[a] Chi square analysis: Calving difficulty = year ($P < 0.01$), sire breed ($P = 0.0027$).

Table 7. Production efficiency of F_1 females (lb weaned calf/100 lb cow exposed[a].

	Sire Breed of Dam			
Parity	Brahman	Senepol	Tuli	Probability > F
1	24.25 ± 2.68	23.06 ± 3.06	30.95 ± 2.74	0.1046
2	33.30 ± 2.80	28.43 ± 3.30	36.33 ± 3.00	0.2099
3	42.01 ± 2.43	35.79 ± 2.93	42.60 ± 2.60	0.1669
4	45.93 ± 2.21	41.45 ± 2.58	43.14 ± 2.24	0.3999
5	43.42 ± 2.20	43.46 ± 2.60	43.88 ± 2.30	0.9880
6	46.11 ± 2.18	45.81 ± 2.53	47.84 ± 2.13	0.7878
7	49.86 ± 2.05	53.16 ± 2.23	51.26 ± 1.83	0.5541
Mean	40.69	38.73	42.29	

[a] Least square means from the model: Efficiency = parity, sire breed of dam.

Efficiency

The efficiency of production as measured by lb of calf weaned/100 lb of cow exposed was lowest for parity 1 and increased gradually until parity 7 (Table 7). For the first and second parity, efficiency tended to be highest for Tuli F_1's, least for Senepol, and intermediate for Brahman. For the third parity, however, efficiency appeared similar between Tuli and Brahman F_1's, but lower for Senepol crosses. Efficiency for fourth, fifth, sixth, and seventh parities was similar for the three F_1 breed types. However efficiency increased by approximately 5% from the fourth to the seventh parities and was greater than 51% for the Senepol and Tuli F_1's for the seventh parity, while Brahman F_1's had an efficiency of 49.85% in the seventh parity. As an average of seven calf crops, Tuli F_1's had the highest efficiency, being 1.6% greater than Brahman and 3.6% greater than Senepol F_1's.

Implications

The use of tropically adapted breeds in south Texas and semi-arid rangeland has merit. Brahman x Angus crosses excel and are typically the standard for comparison in south Texas. Tuli x Angus crosses proved to be well adapted to south Texas. They compared favorably and in most circumstances were more productive and efficient than Brahman and Senepol crosses. Brahman x Angus females always produced the heaviest weaning weights compared to Senepol and Tuli crosses. Senepol x Angus crosses were the least adapted to south Texas and only began to perform comparable to the Brahman and Tuli crosses in later parities. Calving difficulty for the first calf may have influenced subsequent performance of the Senepol x Angus. The smaller size, earlier maturing rate, and the resulting higher reproductive rate at an early age for Tuli crosses provided an early advantage over Brahman crosses, even though Brahman crosses produced consistently heavier calves.

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Evaluation of the F_1 Crosses of the Tuli, Boran, and Brahman with Hereford and Angus for Birth, Growth, Carcass, Cow Productivity, and Longevity Characteristics

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ABSTRACT: Birth, weaning, growth, carcass, tenderness, and cow productivity traits were evaluated in cattle born in 1992 and 1993 out of multiparous Hereford and Angus cows and by Tuli, Boran, and Brahman bulls. Average gestation lengths did not differ ($P > 0.05$) by sire breed and were 287, 290, and 289 days for the Tuli-, Boran-, and Brahman-sired calves. Tuli-sired calves had the lowest ($P < 0.05$) birth weight (80.0 lb) and Brahman crosses the highest (96.8 lb; $P < 0.05$); Boran crosses averaged 88.6 lb. All three sire groups also differed ($P < 0.05$) for cannon bone length at birth and ranked the same as for birth weight (11.2, 11.6, and 12.2 in for the Tuli, Boran, and Brahman crosses, respectively). Brahman-sired calves had the highest ($P < 0.05$) weaning weight (516 lb); Boran and Tuli crosses did not differ (478 and 460 lb). All three crosses differed ($P < 0.05$) for weaning hip height and ranked the same as for cannon bone length at birth (42.8, 43.4, and 45.6 in). Feedlot gain for steers was highest ($P < 0.05$) for Brahman crosses (2.93 lb/day) and did not differ between Tuli and Boran crosses (2.60 and 2.46 lb/day). Marbling score was higher ($P < 0.05$) for Tuli (Slight 51) than for Brahman crosses (Slight 24); Boran crosses were intermediate (Slight 45). Carcass weight was highest ($P < 0.05$) for Brahman crosses (685 lb) and did not differ between Tuli and Boran crosses (608 and 601 lb, respectively). Ribeye area and yield grade did not differ and ranged from 11.2 to 11.6 in^2 in Boran to Brahman and from 3.0 to 3.2 in Tuli and Brahman crosses, respectively. Warner-Bratzler shear force was lower ($P < 0.05$) for Tuli (7.3 lb) than for Boran crosses (8.3 lb); Brahman crosses were intermediate (7.9 lb). Breed of service sire was confounded with year. Birth weight for calves out of crossbred cows did not differ and ranged from 77.4 to 78.3 lb in calves out of the Boran and Tuli cross cows. Calves out of all three groups of cows differed ($P < 0.05$) for weaning weight (511, 481, and 450 lb for those out of Brahman, Boran, and Tuli crosses, respectively). Mature cow weight was highest ($P < 0.001$) for the Brahman crosses (1322 lb); the Boran (1130 lb) and Tuli crosses (1128 lb) did not differ ($P > 0.10$); simple means for condition score were 5.9, 6.2, and 5.6 for the Brahman, Boran, and Tuli crosses, respectively. Calf crop weaned percentage was 88.1 2.1, 85.3 1.8, and 83.4 1.7 for the Boran, Tuli, and Brahman crosses. Percentages of cows remaining in the herd in 2004 were 69, 50, and 51 for the Boran, Tuli, and Brahman crosses, respectively.

Key Words: Beef Cattle, Boran, Brahman, Breed Differences, Lifetime Production, Tuli

Introduction

In the late 1980s, frozen embryos of the African breeds Tuli and Boran were imported into Australia. In 1991 semen from bulls that resulted from these embryos was available for importation into the United States. As part of a collaborative effort that included three Texas Agricultural Experiment Station locations, two USDA locations, and experiment stations in two other states, Hereford and Angus cows at the McGregor station were artificially inseminated to bulls of the Tuli, Boran, and Brahman breeds, with the objective of comparing the productivity of these two African breeds to each other and to that of the American Brahman.

Results from this study for birth and weaning characters were reported by Herring et al. (1996). Differences for cow productivity were reported by DuCoing (2002).

Materials and Methods

Starting in May 1991, both Hereford and Angus cows were artificially inseminated to Tuli (n = 9), Boran (n = 8), and Brahman (n = 15) bulls. Matings were made in May and June in both 1991 and 1992. The Tuli and Boran bulls were all of the bulls that were available from Australia at the time. The Brahman bulls included both gray and red bulls and were selected from both commercial artificial

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insemination services and purebred herds and represented major bloodlines of these breeds.

The Tuli is a Sanga breed that was developed in Rhodesia (now Zimbabwe) from indigenous cattle of the region. The Boran is a shoulder humped Zebu breed that was developed as a beef breed in Kenya from cattle from Somalia. The Brahman breed was developed in the United .States from cattle imported from India and Brazil (Sanders, 1980).

The F_1 calves were weaned in October at about 7 mo (from about 6 to about 8 mo) of age. At weaning, the steers were placed on feed at the McGregor station. The heifers were developed on pasture with supplementation.

The steers were fed on a ration containing ground grain sorghum, cottonseed hulls, and cottonseed meal plus a vitamin-mineral premix. The steers born in 1992 were killed at an average age of about 400 d; those born in 1993 were fed about 45 days longer and were killed at about 445 d of age. All carcass data were collected by personnel of the Texas A&M University Meat Science and Technology Center at College Station.

The heifers were exposed by natural service to Angus bulls to calve in the spring to have their first calves at about 2 yr of age. All cows were bred to Brangus bulls for their second calves. The cows in the older group (those born in 1992) were also bred to Brangus bulls for their third calves; starting with that breeding season (i.e., 1995, when the cows born in 1992 were 3 and those born in 1993 were 2 yr old), all cows of both ages were bred to the same bulls in any given year. Different breeds of sires were used in different years, and breed of sire was confounded with year.

The F_1 cows calved from about February 10 to May 10 of each year. Their calves were weaned in October or November, depending on the year. Cows were culled for severe injuries, poor health, or at least two failures to have or wean a calf. Cows were also culled if udders and/or teats were so large or pendulous that it was apparent that future calves would be unable to nurse without assistance.

In the fall of 2004, at the time of palpation for pregnancy diagnosis, incisor condition of F_1 cows was evaluated by assignment of mouth scores. Initially, five scores were assigned, but these were consolidated into three scores. For these three scores, solid mouths had no teeth loose or missing, broken mouths had one or more teeth loose or missing, and smooth mouths had no incisors remaining (or the few remaining were small and badly deteriorated). Mouth score was analyzed as a binary trait of the remaining cows (11 or 12 yr of age, depending on year of birth) in two different ways. In the first case, smooth mouths were assigned a value of zero and both broken and solid mouths were assigned a value of one. In the second case, both smooth and broken mouths were assigned a score of zero and solid mouths were assigned a value of one.

The traits evaluated in this study are the result of both additive and non-additive (heterotic) effects; that is, differences between two breeds (as evaluated in their F_1 crosses with Hereford and Angus) are due to both breed differences (additive effects) and differences in the amount of heterosis that the two breeds express with the Hereford and Angus.

Data were analyzed by mixed model procedures; sire breed (i.e., sire breed of the F_1) was the major effect of concern in all analyses, and sire within breed was considered a random effect and was used to test for differences in sire breeds. More details about the models used to analyze specific characters were reported by Herring et al. (1996) and Ducoing (2002).

Results and Discussion

Birth and Weaning Characters of F_1 Calves

Least squares means and standard errors for birth and weaning characters of F_1 calves are presented by breed of sire in Table 1. There were no significant differences among sire breeds for gestation length of their calves, although there was a trend for both the Boran- and Brahman-sired calves to be carried longer than the Tuli-sired calves. As discussed by Herring et al. (1996), this is consistent with published results, where *Bos indicus*-sired calves out of *Bos taurus* cows are consistently carried longer than straight *Bos taurus* calves.

Brahman-sired calves had the highest values ($P < 0.05$) and Tuli crosses the lowest values ($P < 0.05$) for both cannon bone length and birth weight. A breed of sire by sex of calf interaction ($P = 0.07$) was present for birth weight. Differences in average birth weight between bull and heifer calves were 13.0, 9.9, and 6.2 lb, respectively, for Brahman-, Boran-, and Tuli-sired calves. As discussed by Herring et al. (1996), the large differences between sexes for birth weight in the Brahman and Boran (*Bos indicus)* sired calves out of *Bos taurus* cows are consistent with published results.

As with the size characters at birth, Brahman-sired calves had the highest values ($P < 0.05$) for both weaning weight and weaning hip height; Tuli-sired calves had the lowest values for weaning weight and hip height, although their average weaning weight was not significantly less than that of the Boran-sired calves. As discussed by Herring et al. (1996), the heavier weaning weight of the Brahman- than the Tuli-sired calves is consistent with results in southern Africa.

Table 1. Least squares means and standard errors for F_1 birth (n = 308) and weaning (n = 291) characters by sire breed

Sire breed	Gestation length, d	Birth weight, lb.	Cannon bone length (at birth), in	Weaning weight, lb.	Weaning hip height, in.
Boran	289.7 ± 1.2	88.6 ± 1.8[b]	11.6 ± 0.06[b]	477.6 ± 8.1[b]	43.4 ± 0.20[b]
Brahman	288.6 ± 0.9	96.8 ± 1.5[a]	12.2 ± 0.06[a]	515.5 ± 7.5[a]	45.6 ± 0.20[a]
Tuli	286.8 ± 1.1	80.0 ± 1.8[c]	11.2 ± 0.06[c]	460.0 ± 7.7[b]	42.8 ± 0.20[c]

[a,b,c]Means within a column with no superscripts in common differ ($P < 0.05$).

Table 2. Least squares means and standard errors for feedlot growth characters of F_1steers by sire breed (n = 142)

Sire breed	Average daily gain, lb/day	Final weight, lb	Final height, in
Boran	2.46 ± 0.07[b]	983.0 ± 14.7[b]	49.8 ± 0.28[b]
Brahman	2.93 ± 0.07[a]	1,110.8 ± 15.8[a]	53.5 ± 0.28[a]
Tuli	2.60 ± 0.07[b]	999.5 ± 15.8[b]	49.8 ± 0.28[b]

[a,b]Means within a column with no superscripts in common differ ($P < 0.05$).

Table 3. Least squares means and standard errors for yearling characters of F_1 heifers by sire breed (n = 139)

Sire breed	Yearling weight, lb (SE[a] = 11 lb)	Hip height, in (SE[a] = 0.3 in)	Condition score (SE[a] = 0.08)	Pelvic height, cm (SE[a] = 0.12 cm)	Pelvic area, cm^2 (SE[a] = 3.6 cm^2)
Boran	631.2[c]	46.9[c]	5.53[b]	14.6[c]	154.7[c]
Brahman	683.5[b]	49.4[b]	5.09[c]	15.0[b]	165.6[b]
Tuli	615.3[c]	46.5[c]	5.33[b]	14.4[c]	153.1[c]

[a]Average standard error across all sire breeds.
[b,c]Means within a column with no superscripts in common differ ($P < 0.05$).

Table 4. Least squares means and standard errors for carcass and tenderness characters of F_1 steers by sire breed (n = 142)

Sire breed	Carcass weight, lb	Marbling score[a]	Ribeye area, in^2	Yield grade	Warner-Bratzler shear force, lb
Boran	601.0 ± 9.0[c]	344.5 ± 9.5[bc]	11.2 ± 0.22	3.1 ± 0.16	8.3 ± 0.31[b]
Brahman	685.1 ± 10.3[b]	323.9 ± 9.3[b]	11.6 ± 0.22	3.2 ± 0.14	7.9 ± 0.31[bc]
Tuli	607.6 ± 10.3[c]	351.0 ± 10.3[c]	11.5 ± 0.26	3.0 ± 0.17	7.3 ± 0.33[c]

[a]Marbling: 300 = $Slight^{00}$, 400 = $Small^{00}$, etc.
[b,c]Means within a column with no superscripts in common differ ($P < 0.05$).

Postweaning Growth and Size Characters of F_1 Crosses

Least squares means and standard errors for feedlot growth and size characters of F_1 steers and yearling characters of F_1 heifers are presented by breed of sire in Tables 2 and 3, respectively. Feedlot average daily gain was higher ($P < 0.05$) for Brahman-sired steers (2.93 lb/day) than for Tuli- (2.6 lb/day) or Boran-sired steers (2.46 lb/day), which did not differ ($P > 0.05$).

As with birth and weaning weight, final feedlot weight was heaviest ($P < 0.05$) in the Brahman crosses (1110.8 lb). However, although the Boran crosses were heavier ($P < 0.05$) than the Tuli crosses at birth and slightly (but not significantly) heavier at weaning, the Tuli-sired steers (999.5 lb) were slightly (not significantly) heavier than the Boran crosses (983 lb) at the end of the feedlot period.

Consistent with cannon bone length at birth and weaning hip height, the Brahman-sired steers were taller ($P < 0.05$) at the end of the feeding period (53.5 in) than the Boran or Tuli crosses (49.8 in for both).

In F_1 heifers (Table 3), the Brahman crosses were larger ($P < 0.05$) for yearling weight, yearling height, pelvic height, and pelvic area than both the Boran and Tuli crosses, which did not differ ($P > 0.05$). When yearling height was included in the statistical models for pelvic height and pelvic area, no differences among sire breeds were observed for the pelvic size character, indicating that the differences among pelvic measurements were reflections of skeletal size differences.

Condition score for the Boran-sired heifers (5.53) did not differ ($P > 0.05$) from that of the Tuli crosses (5.33), which were both higher ($P < 0.05$) than that of the Brahman crosses (5.09).

Carcass and Tenderness Characteristics of F_1 Steers

Least squares means and standard errors for carcass and tenderness characters of F_1 steers are

presented by breed of sire in Table 4. As with all live measurements of size, carcass weight was heaviest ($P < 0.05$) for Brahman-sired steers (685 lb). Carcass weight in Tuli- (608 lb) and Boran-sired steers (601 lb) did not differ ($P > 0.05$).

Average marbling score was higher ($P < 0.05$) in Tuli- (Slight 51) than in Brahman-sired carcasses (Slight 24). Boran crosses (Slight 45) were intermediate.

Warner-Bratzler shear force (a measure of tenderness representing the amount of force required to cut a core of cooked steak) was significantly lower (more desirable) in steaks from Tuli crosses (7.3 lb) than in those from Boran crosses (8.3 lb); Brahman crosses were intermediate (7.9 lb).

There were no differences ($P > 0.05$) in ribeye area, even though carcass weight was significantly heavier for the Brahman crosses. If ribeye area is expressed as ribeye area per cwt of carcass weight, the values for the Tuli, Boran, and Brahman crosses are 1.89, 1.86, and 1.69 in^2/cwt, respectively. There were also no significant differences in average yield grade among the three sire breeds.

More details about birth, weaning, yearling carcass, and tenderness characters in the F_1 crosses were reported by Herring et al. (1996).

Maternal Characteristics of F_1 Cows

Least squares means and standard errors for birth weight and weaning weight of calves out of F_1 cows are presented by breed of sire of the cows in Table 5. There were no significant differences in birth weight in calves out of the three types of crossbred cows, even though all three crosses differed in birth weight as F_1 calves.

Weaning weight was highest ($P < 0.05$) for calves out of Brahman-sired cows (511.1 lb). Calves out of Boran-sired cows (481.4 lb) were heavier ($P < 0.05$) than those out of Tuli crosses (449.5 lb).

The least squares means reported in Table 5 were calculated from a model that did not include the breed of cow by sex of calf interaction, but Ducoing (2002), in an analysis that included calves through the 2001 calf crop, reported that the breed of sire of cow by sex of calf interaction was significant. In calves out of Brahman-sired cows, the steer calves were 32.6 lb heavier than the heifers. The sex difference in calves out of the Boran and Tuli crossbred cows were 18.9 and 18.3 lb, respectively. Riley et al. (2001a) reported that weaning weights in steer calves out of F_1 *Bos indicus*/Hereford cows were from 32.3 to 44.4 lb heavier than heifer calves of the same cross, but, in calves out of Angus/Hereford cows, the sex difference was only 18.0 lb.

Cow Size

Least squares means and standard errors for mature cow weight and simple means for body condition score are presented by sire breed of cow in Table 6. These were weights taken in 2000, when the cows born in 1993 were 7 and those born in 1992 were 8 yr old. The Brahman-sired cows were heavier ($P < 0.001$) than the Boran and Tuli crosses (almost 200 lb heavier). The simple mean for condition score was highest for the Boran crosses and lowest for the Tuli crosses.

If the weaning weights of calves out of F_1 cows (Table 5) are expressed as a fraction of the average weight of the F_1 cows (Table 6), the values for calves out of the Boran, Tuli, and Brahman crossbred cows are 0.426, 0.398, and 0.387, respectively.

Calf Crop Born and Weaned by F_1 Cows

Least squares means and standard errors for calf crop born and calf crop weaned, through 2003, are presented by breed of sire of the cow in Table 7. There were no significant differences for these reproductive characters, but values for both calf crop born and calf crop weaned were highest for the Boran-sired cows and lowest for the Brahman crosses.

More details about size, maternal and reproductive characters of F_1 cows were reported by Ducoing (2002).

Mouth Scores and Productive Longevity of F_1 Cows

Simple means for mouth scores and percentages of cows remaining in the herd in 2004 are presented by breed of sire of the cow in Table 8. When incisor condition was scored as a zero for smooth mouths and one for either broken or solid mouths, the simple means were much higher for both the Boran (1.0; i.e., none of the Boran crosses were scored as smooth) and the Brahman (0.96) than for the Tuli crosses (0.75). When both smooth and broken mouths were scored as zero and only solid mouths were scored as one, the breed groups of cows ranked the same, with simple means of 0.74 (i.e., 74% were scored as having solid mouths), 0.71, and 0.38, again, with the Boran and Brahman crosses having much higher fractions than the Tuli crosses. The cows were either 11 or 12 yr of age at the time these mouth scores were taken, depending on their year of birth.

Riley et al. (2001b) reported mouth scores at 14 yr of age in five types of F_1 *Bos indicus*/Hereford crossbred cows compared to F_1 Angus/Hereford crosses. In that study, when smooth mouths were scored as zero and both solid and broken mouths were scored as one, the least squares mean for the Angus crosses was 0.65; least squares means for

Table 5. Least squares means and standard errors for birth weight (n = 1,032) and weaning weight (n = 965) (lb) of calves out of F_1 cows through 2003

Breed of cow's Sire	Birth Weight (n = 1032)	Weaning Weight (n = 965)
Boran	77.4 1.2	481.4 6.8[b]
Brahman	78.2 0.88	511.1 5.3[a]
Tuli	78.3 1.0	449.5 5.9[c]

[a-c]Means in the same column with no superscript in common differ ($P < 0.05$).

Table 6. Least squares means and standard errors for mature F_1 cow palpation weight (lb) and simple means for condition score by sire breed of cow (n = 124)[a]

Breed of cow's Sire	Palpation Weight	Condition Score
Boran	1,130.1 21.3[c]	6.2
Brahman	1,321.8 16.3[b]	5.9
Tuli	1,128.4 18.0[c]	5.6

[a]Means in the year 2000, when the cows born in 1993 were 7 and the cows born in 1992 were 8 years of age.

[b,c]Means within a column with no superscripts in common differ ($P < 0.001$).

Table 7. Least squares means and standard errors for calf crop percentages through 2003

Breed of cow's sire	Calf crop % born (n = 1,155)	Calf crop % weaned (n = 1,143)
Boran	92.4 1.7	88.1 2.1
Brahman	89.0 1.4	83.4 1.7
Tuli	90.6 1.4	85.3 1.8

Table 8. Simple means for mouth scores and cows remaining in the herd through 2004 for F_1 cows

Sire breed	Mouth score[a]	Mouth score[b]	% of original cows remaining in 2004
Boran	1.00	0.74	69
Brahman	0.96	0.71	51
Tuli	0.75	0.38	50

[a]Analyzed as a binary trait, where smooth = 0 and broken or solid = 1.

[b]Analyzed as a binary trait, where smooth or broken = 0 and solid = 1.

the *Bos indicus* crosses ranged from 0.92 to 1.01. When both smooth and broken mouths were scored as zero and only solid mouths were scored as one, the least squares mean for the Angus crosses was 0.13 and the means for the *Bos indicus* crosses ranged from 0.32 to 0.57.

Percentage of cows remaining in the herd in 2004 (simple means), under the culling procedure that has been practiced, was much higher for the Boran crosses (69%) than that of either the Brahman (51%) or Tuli (50%) crosses.

Summary

The two African breeds, Tuli and Boran, when crossed with the Angus and Hereford, produced crossbred cows that were more moderate in size than the American Brahman. Results from this study indicate that the Boran/British F_1 crossbred female is at least as productive as the Brahman/British F_1 cross, and, under the culling policy practiced, has a longer productive life. The Tuli crossbred cows weaned significantly lighter calves than the Boran crosses, had similar (or lower) reproductive rates, and appear to have a shorter productive life.

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Performance of Tropically Adapted Breeds in a Temperate Environment: Calving, Growth, Reproduction and Maternal Traits

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ABSTRACT: Results will be reviewed from an analysis of data for 8,484 calves produced in the Germplasm Evaluation Program at MARC. Although the analysis involved progeny of 27 sire breeds, this report focuses on comparisons among progeny sired by tropically adapted breeds including Nellore (Ne) and Longhorn (Lh) in Cycle IV (1986-1990); Brahman (Bh), Boran (Bo), and Tuli (Tu) in Cycle V (1992-1994); and Beefmaster (Be), Brangus (Br), Bonsmara (Bm), and Romosinuano (Ro) in Cycle VIII (2001-2002). Hereford (H) and Angus (A) sires provided ties for pooling data over cycles for least squares analyses using a model that included random effects for sire in breed and fixed effects for sire breed, dam breed, sex, cow age, birth year, and sire breed-dam breed interaction. Data obtained on three-way cross progeny by Red Poll (Cycle IV and V) sires for unassisted calvings, birth weight, and weaning weight were similarly analyzed. *Bos indicus*-sired progeny had heavier birth weights and required more assistance at calving than progeny of other breeds; however, birth weights were significantly heavier for progeny of H- and A-sired females than for those by other breeds, and Ne, Bh, and Lh females required less assistance at calving than those by other breeds. Growth rates, primarily during summer months, to weaning ages were greater for Bh- and Ne-sired progeny than in Bo-, A-, and H-sired progeny, which was in turn greater than in Tu- or Lh-sired progeny. However, weights at yearling ages (400 or 550 d), affected primarily by growth rate during winter months, were heavier for progeny of Be, Br, A, and H sires than Ne, Bo, and Bh sires, which were in turn heavier than for progeny of Ro, Tu, or Lh sires. Age at puberty was significantly younger for Lh, Tu, Br, Be than for Ne- and Bm-sired females, intermediate for Ro and Bo, which were not significantly different from any other breed except A and H, which were youngest. Progeny of Bh- and Ne-sired females were heavier at weaning than those of other tropically adapted breeds and A and H sires.

Keywords: Beef cattle, Breeds, Tropically adapted

Introduction

Results have shown that *Bos indicus X Bos taurus* F_1 cross cows (e.g., Brahman, Sahiwal, and Nellore F_1 crosses out of Hereford and Angus dams) were exceptionally productive (Cundiff et al., 1993) and efficient as cows (Green et al., 1991), especially in subtropical regions of the United States (Olson et al. 1991). However, as proportion *Bos indicus* inheritance increased in crosses, meat tenderness and marbling were reduced (Koch et al., 1982; Crouse et al., 1989; Wheeler et al., 1996; Wheeler et al., 2001); postweaning gain and feed efficiency have been reduced during winter months (Cundiff et al., 1984: Souza et al., 1993), and age at puberty increased, limiting conception rate in some instances in yearling heifers (Gregory et al., 1979; Freetly and Cundiff, 1997; Thallman et al., 1999). As a result of these antagonisms, Brahman-influenced cattle have experienced serious discounts in the beef industry (Thrift and Thrift, 2005). These antagonisms and discounts have sparked interest in considering other breeds that have evolved in the tropics as an alternative source of tropically adapted germplasm for crossbreeding or composite breeding programs. After embryo transfer technology was developed in the mid-1980s, it was possible to sample germplasm from previously inaccessible regions of the world because pathogens could be removed as part of the standard embryo transfer protocol (Acree et al., 1991). As a result of embryo transfer technology, a number of tropically adapted breeds have been introduced into the United States, including Nellore from Brazil, Tuli originating in Zimbabwe (sampled via semen from Australia), Boran from Zambia (sampled via semen from Australia), Bonsmara from South Africa, and Romosinuano originally developed in Colombia but sampled from Venezuela. Thus, cooperative research efforts were initiated to characterize these breeds of cattle in crosses with *Bos taurus* dams (usually Hereford, Angus, Hereford-Angus crosses) at research stations in subtropical (Florida, Georgia, Texas, Louisiana, and Oklahoma) and temperate (MARC, Clay Center, Nebraska) regions of the United States, results from which are reported in these proceedings. This specific report will review results from this cooperative endeavor that was conducted at the Roman L. Hruska U. S. Meat Animal Research Center

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(MARC), Clay Center, Nebraska, as part of a long-term and comprehensive Germplasm Evaluation (GPE) Program.

Materials and Methods

Table 1 shows the mating plan for the first eight cycles of the GPE Program at MARC. Each cycle has been an experiment conducted over a span of about 10 yr. Topcross performance of 34 sire breeds has been evaluated in F_1 calves out of Hereford, Angus, or Composite MARC III (Composite MARC III is ¼ each Angus, Hereford, Pinzgauer, and Red Poll) dams. Hereford and Angus sires have been used in each cycle of the program to provide ties for analysis of data pooled over cycles. Results will be reported only for Hereford- and Angus-sired progeny and for nine tropically adapted breeds including Nellore and Longhorn evaluated in Cycle IV (Cundiff et al., 1998); Brahman, Boran, and Tuli evaluated in Cycle V (Cundiff et al., 2000), and Brangus, Beefmaster, Bonsmara, and Romosinuano included in Cycle VIII of the GPE Program (Wheeler et al., 2005).

Calves were born in the spring and weaned in the fall at about 7 mo of age. Male calves were castrated within 24 hr of birth. Calves were weaned in a dry lot at about 200 d of age. Following weaning, steers were fed a growing mixed diet consisting primarily of corn, corn silage, and protein supplement, containing about 1.2 to 1.3 Mcal metabolizable energy per lb dry matter and 12% crude protein, and a finishing diet from about 700 lb to slaughter containing about 1.4 Mcal ME per lb dry matter and 13% crude protein. Steers were implanted with Synovex S (20 mg progesterone and 20 Mg estrodial benzoate) in December and again in late February or early March each year. Postweaning average daily gain and final weights will be presented for steers slaughtered in three to four groups spanning a 35 to 56 d and averaging about 444 d at slaughter.

Following weaning, females were fed a mixed corn silage/haylage based diet containing about 1.1 to 1.2 Mcal ME/lb dry matter and 10-11% crude protein until they were moved to grass in early to mid-May of each year. Females were checked visually twice daily for estrus to determine age at puberty. In Cycle VIII, about half of the Brangus-, Beefmaster-, Bonsmara-, and Romosinuano-sired F_1 cross females produced were transferred to Louisiana State University for a cooperative evaluation of reproduction and maternal performance in temperate (Nebraska) and subtropical environments (Louisiana). Only data obtained at MARC are included in this report. Females produced in Cycles IV and V of the program were exposed to Red Poll bulls as yearlings to produce their first calves as 2 yr olds. Females produced in Cycles VI, VII, and VIII were exposed to composite MARC III (¼ each Angus, Hereford, Pinzgauer, and Red Poll) bulls to produce their first calves as 2 yr olds. Again, calves were born in the spring and weaned at about 200 d of age. Reproduction and maternal performance will be reported for females sired by Hereford, Angus, and tropically adapted sire breeds calving as 2 yr olds in Cycles IV, V, and VIII of the program. Data will be shown only for females produced in Cycles IV and V for reproduction and maternal performance at 3 through 7 yr of age, because data are not yet available for females at 3 yr of age or older in Cycle VIII of the Program.

Data Analysis. Data for all traits analyzed were pooled over Cycles IV, V, VI, VII, and VIII of the GPE Program (Table 1). Although 27 sire breeds evaluated in Cycles IV through VIII of the GPE Program were included in all analyses, results will be reported in this paper only for Hereford, Angus, and nine tropically adapted sire breeds (i.e., Brahman, Brangus, Longhorn, Nellore, Boran, Tuli, Beefmaster, Bonsmara, and Romosinuano). Preweaning data for gestation length, calving difficulty score (1 = no difficulty, 2 = little difficulty by hand, 3 = little difficulty with a calf jack, 4 = slight difficulty with a calf jack, 5 = moderate difficulty with a calf jack, 6 = major difficulty with a calf jack, 7 = caesarean birth, and 8 = abnormal presentation), unassisted calvings (1 = calving difficulty score $\leq$ 2; or 0 = calving difficulty scores $\geq$ 3); birth weight, survival from birth to weaning (1 live calf weaned, or 0 calf died before weaning) were analyzed by least squares procedures using a model that included fixed effects for year of birth (14 yr), sex of calf (male and female), age of dam (4 yr, 5 to 9 yr, $\geq$ 10 yr), breed of sire (27 breeds), breed of dam (Hereford, Angus, MARC III), and breed of sire X breed of dam interaction, and random effects for sire within sire breed and for individual animals. Data for postweaning average daily gain (ADG) and slaughter weight of steers were analyzed by least squares procedures using a model that included fixed effects for year of birth (14 yr), age of dam (4 yr, 5 to 9 yr, $\geq$ 10 yr), breed of sire (26 breeds), breed of dam (Hereford, Angus, MARC III), and breed of sire X breed of dam interaction, linear regression coefficients for weaning age and days on feed from weaning to slaughter, and random effects for sire within sire breed and for individual animals. Data for growth and puberty traits of F_1 cross heifers exposed to breeding were analyzed with least squares procedures using a model that included fixed effects for year of birth (14 yr), age of dam (4 yr, 5 to 9 yr, $\geq$ 10 yr), breed of sire (27 breeds), breed of dam (Hereford, Angus, MARC III), and breed of sire X breed of dam interaction, and random effects for sire within sire breed and for individual animals.

Table 1. Sire breeds used in Germplasm Evaluation Program at MARC

Cycle I (1970-72)	Cycle II (1973-74)	Cycle III (1975-76)	Cycle IV (1986-90)	Cycle V (1992-94)	Cycle VI (1997-98)	Cycle VII (1999-2000)	Cycle VIII (2001-2002)
F_1 crosses (Hereford or Angus dams)[a]							
Hereford	Hereford	Hereford	Hereford	Hereford	Hereford	Hereford	Hereford
Angus	Angus	Angus	Angus	Angus	Angus	Angus	Angus
Jersey	Red Poll	Brahman	Longhorn	Tuli	Wagyu	Red Angus	Brangus
S. Devon	Braunvieh	Sahiwal	Salers	Boran	Norwegian Red	Limousin	Beefmaster
Limousin	Gelbvieh	Pinzgauer	Galloway	Belgian Blue	Swedish Red&White	Charolais	Bonsmara
Simmental	Maine Anjou	Tarentaise	Nellore	Brahman	Friesian	Simmental	Romosinuano
Charolais	Chianina		Shorthorn	Piedmontese		Gelbvieh	
			Piedmontese				
			Charolais				
			Gelbvieh				
			Pinzgauer				
3-way crosses out of F_1 dams							
Hereford	Hereford						
Angus	Angus						
Brahman	Brangus						
Devon	Santa Gertrudis						
Holstein							

[a]Composite MARC III cows (¼ each Angus, Hereford, Red Poll, and Pinzgauer) were also included in Cycles V, VI, VII, and VIII.

Table 2. Sire breed least squares means for preweaning traits of F_1 cross calves

Sire breed of calf	No. calves born	Gestation Length Days	Calvings unassist. %	Calv. diff. score	Birth wt. lb.	Surv. to wn. %	205-d wn. wt[a]., lb.
Hereford	1,064	284.4^{h}	97.3^{bc}	1.15^{bcdef}	90.3^{ef}	95.0^{b}	527^{cd}
Angus	1,021	282.5^{i}	97.6^{bc}	1.12^{bcde}	85.4^{d}	95.8^{b}	529^{cd}
Brahman	436	291.4^{bc}	89.4^{e}	1.55^{g}	97.7^{i}	88.1^{c}	542^{b}
Nellore	196	292.9^{b}	94.6^{cd}	1.25^{bdef}	94.1^{fgh}	95.5^{b}	536^{bc}
Boran	456	291.2^{cd}	94.1^{d}	1.31^{f}	90.8^{efg}	93.9^{b}	505^{e}
Brangus	214	285.8^{gh}	97.5^{bc}	1.13^{bcdef}	89.1^{e}	94.0^{b}	534^{bcd}
Beefmaster	222	287.4^{f}	96.1^{cd}	1.17^{bcdef}	94.1^{fh}	93.5^{b}	546^{b}
Bonsmara	207	287.5^{f}	98.3^{bc}	1.03^{bcd}	88.9^{e}	91.9^{bc}	519^{c}
Tuli	492	289.5^{e}	95.7^{cd}	1.27^{ef}	80.8^{c}	93.8^{b}	492^{f}
Romosinuano	207	289.7^{de}	99.7^{b}	0.99^{b}	83.2^{c}	95.8^{b}	493^{ef}
Longhorn	200	286.7^{fg}	100.0^{b}	1.00^{bc}	73.5^{b}	95.4^{b}	466^{g}

[a]Heterosis was significant for 205- d wn wt (H^i = 20.32 lb), and Hereford and Angus sire breed means were adjusted by adding 0.4167 (H^i) to adjust to the level of heterosis expected in F_1 crosses to provide for unbiased comparisons to F_1 crosses by all other sire breeds.

[bcdefghi]Means in the same column that do not share a common superscript differ ($P<.05$).

Since matings to Hereford and Angus sire breeds included some straightbred and partial backcross matings as well as F_1 reciprocal crosses, if effects of Hereford X Angus heterosis (Hereford X Angus and Angus X Hereford versus straightbred Hereford and Angus) were significant ($P < 0.05$), estimates of sire breed effects for Hereford and Angus sire breeds were adjusted to the level of heterosis expected in F_1 crosses to provide for unbiased comparisons to F_1 crosses by all other sire breeds. The same adjustment was made for Red Angus-sired crosses as Angus-sired crosses. Differences between sire breed means were tested by computing the least significant difference (LSD, $P < 0.05$) for each pair wise comparison using the sire within breed mean square to estimate error variance. *P*-values are nominal and are not corrected for number of comparisons.

Results and Discussion

Preweaning traits.

Least squares means for preweaning traits of F_1 cross calves by Hereford, Angus, and tropically adapted sire breeds are shown in Table 2. Sire breed means reflect direct breed effects (D^i) on progeny raised by Angus, Hereford. or Composite MARC III dams. Thus, they represent half of the difference expressed in direct effects ($1/2\ D^i$) among pure breeds. Means for each trait shown in the same column that do not share a common superscript differ significantly ($P < 0.05$).

Gestation length. Calves by the *Bos indicus* sire breeds (rankings will be presented parenthetically as 1st, 2nd, ….11th) including Nellore (1st), Brahman (2nd), and Boran (3rd) had significantly longer gestation lengths than those by all other sire breeds, except that Boran did not differ from Romosinuano. Romosinuano-(4th) and Tuli-(5th) sired progeny had significantly shorter gestation length than Nellore and Brahman, but longer gestation lengths than all other breeds. *Bos taurus* British breeds (Hereford 10th and Angus 11th) had significantly shorter gestation lengths than all other breeds, except that Hereford did not differ significantly from Brangus. The rankings and means for gestation length of Bonsmara (6th), Beefmaster (7th), and Brangus (9th) were consistent with proportion British breed influence with the Angus influence in Brangus reducing gestation length relatively more than the Hereford influence in Beefmaster and Bonsmara. Longhorn-sired progeny ranked 8th in gestation length and differed significantly from all breeds except for Bonsmara, Beefmaster, and Brangus. Tropically adapted breeds, especially calves by *Bos indicus* sire breeds, had longer gestation length than temperately adapted *Bos taurus* breeds.

Calving ease. Breed group means for percentage unassisted calvings and for calving difficulty score are shown in Table 2. Longhorn- (1st) and Romosinuano-(2nd) sired progeny did not differ significantly in either measure of calving ease (unassisted calvings or calving difficulty score) and required significantly less assistance than Beefmaster (7th), and required less assistance and had lower calving difficulty scores than Tuli- (8th), Nellore- (9th), Boran- (10th) and Brahman-(11th) sired progeny. Bonsmara (3rd) differed significantly from Boran and Brahman in both unassisted calvings and calving difficulty score, but not from any other sire breed. Bonsmara-sired progeny differed significantly from Tuli-sired progeny for calving difficulty score but not for unassisted calvings. Angus (4th), Brangus (5th), Hereford (6th), Beefmaster (7th), Tuli (8th in unassisted calvings or 9 th in calving difficulty score), and Nellore (9th in unassisted calvings or 8 th in calving difficulty score) did not differ significantly from each other in either measure of calving ease, but did differ significantly from Boran and Brahman. Boran-sired progeny had significantly more unassisted births and lower calving difficulty scores than Brahman-sired progeny.

Birth weight. Longhorn (1st) sired progeny were significantly lighter at birth than those by any other sire breed. Tuli- (2nd) and Romosinuano- (3rd) sired progeny did not differ significantly in birth weight and were significantly lighter than all other sire breeds except Longhorns. Angus-(4th) sired progeny were significantly lighter at birth than Bonsmara (5th) and Brangus (6th), which were in turn significantly lighter than Nellore- (9th), Beefmaster-(9th-10th) and Brahman- (11th) sired progeny. Hereford- (7th), Boran- (8th), and Nellore- (9th-10th) sired progeny did not differ significantly in birth weight but were lighter than Brahman-sired progeny. Boran-sired progeny were significantly lighter at birth than Beefmaster- and Brahman-sired progeny. Among *Bos indicus* breeds, the Boran-sired progeny were relatively light compared to Brahman- and Nellore- sired progeny. *Bos indicus*- sired F_1 cross progeny by Brahman and Nellore sires were heavier at birth than those by Angus sires. The mean for birth weights for Brangus and Beefmaster were consistent with the relative contribution of Angus, Hereford, and Brahman germplasm in their foundation.

Survival to weaning. Only Brahman-sired progeny differed significantly from all other breeds except Bonsmara in survival from birth to weaning. The breed rankings for survival from birth to weaning are consistent with an earlier report of data from Cycle III of the GPE Program by Josey et al. (1993), indicating that mortality increased significantly as the proportion *Bos indicus* inheritance increased relative to *Bos taurus* inheritance (Table 3), especially as

Table 3. Means for breed groups with different ratios of *Bos indicus* to *Bos Taurus* inheritance and average daily temperature classes on date born (Josey et al., 1993)

Temp.	*Bos indicus:Bos taurus* ratio[a]				
Class (F°)	0:100	25:75	50:50	75:25	Mean
			Number of calves		
52 or more	118	33	57	42	250
46 to < 52	71	26	42	17	156
41 TO < 46	75	11	28	26	140
36 TO < 41	73	29	44	25	171
30 TO < 36	89	26	50	21	186
less than 30	53	14	28	12	107
Total	479	139	249	143	1010
			Mortality, birth to weaning, %		
more than 52	2	0	4	1	2
46 to < 52	2	5	0	4	2
41 to < 46	5	0	4	36	11
36 to < 41	2	4	4	41	13
30 to < 36	1	2	22	37	16
less than 30	3	8	12	9	8
Mean	3	3	8	21	
			Heat chamber required [b], %		
more than 52	0	0	0	0	0
46 to < 52	0	0	10	17	7
41 to < 46	4	0	2	27	8
36 to < 41	14	17	30	32	23
30 to < 36	16	34	54	27	33
less than 30	29	17	66	86	50
Mean	11	11	27	31	
			Mortality or heat chamber [b], %		
more than 52	2	0	4	1	2
46 to < 52	2	5	10	20	9
41 to < 46	9	0	6	54	17
36 to < 41	16	21	34	52	30
30 to < 36	17	36	64	60	44
less than 30	32	25	76	86	55
Mean	13	14	32	46	

[a]Reciprocal backcross and F_2 matings among *Bos indicus* (Braham, Sahiwal,) and *Bos Taurus* (Hereford, Angus, and Pinzgauer) breeds provided calves for this study.

[b]When signs of cold stress such as increased shivering, glazed eyes, huddling and decreased activity were observed, calves were placed in a heat chamber for 30 min to 3 hr. The chamber was rectangular in shape, enclosed on three sides, open in the front and elevated about 30 inches above the ground. Hot air was forced upward into the chamber through an expanded metal floor by a forced air propane space heater placed in front of the chamber at a distance manually regulated to maintain ambient temperature within the chamber at about 100-200 F°. It was assumed that calves would have died as a result of cold stress had they not been revived in the heat chamber.

average temperature on the day of birth decreased to temperatures below 41°F. Reciprocal backcross and F_2 matings provided calves for this study with 0:100; 25:75, 50:50, and 75:25 ratios of *Bos indicus* (Brahman or Sahiwal) to *Bos taurus* (Hereford, Angus, or Pinzgauer) inheritance. Results (Josey et al., 1993) indicated that calves with 50% or more *Bos indicus* inheritance were not as well adapted as calves with 25% *Bos indicus* inheritance to spring calving conditions in Nebraska which could be classified as cold (mean daily temperature 41°F or less) or cold and wet (46°F or less combined with 0.1 inch or more precipitation).

205-d weaning weight. The 205-d weaning weight for Beefmaster (1st) and Brahman (2nd) sired progeny were significantly heavier than all other breeds, except Nellore (3rd) and Brangus (4th). Nellore- and Brangus-sired progeny were significantly heavier than Boran- (8th), Romosinuano- (9th), Tuli- (10th), and Longhorn- (11th) sired progeny at weaning. Angus- (5th), Hereford- (6th), and Bonsmara- (7th) sired progeny did not differ significantly from each other in

205-d weaning weight, but were significantly heavier than Boran-, Romosinuano-, Tuli-, and Longhorn-sired progeny. Boran-, Romosinuano-, and Tuli-sired progeny were significantly heavier than Longhorn-sired progeny at 205 d.

Postweaning growth of steers

Postweaning average daily gain. Least squares means for postweaning average daily gain of F_1 cross steers are shown in Table 4. Beefmaster- (1^{st}) and Angus- (2^{nd}) sired progeny did not differ significantly in postweaning average daily gain. Angus differed significantly from all other breeds and Beefmaster differed significantly from all other sire breeds except Hereford (4^{th}) and Nellore (6^{th}). Brangus- (3^{rd}) sired progeny did not differ from Hereford-sired progeny, but progeny by both of these sire breeds had higher postweaning average daily gains than those by sire breeds ranking 5^{th} through 11^{th}. Bonsmara- (5^{th}) and Nellore- (6^{th}) sired progeny had significantly heavier average daily gains than Tuli- (9^{th}), Longhorn- (10^{th}), and Boran- (11^{th}) sired progeny. Nellore-, Romosinuano- (7^{th}), and Brahman- (8^{th}) sired progeny did not differ significantly in average daily gain, but did have higher postweaning average daily gains than Tuli- (9^{th}), Longhorn- (10^{th}), and Boran- (11^{th}) sired progeny, which did not differ significantly.

Slaughter weight. Least squares means for slaughter weight of steers adjusted to the average age at slaughter (444 d) are shown in Table 4. Beefmaster- (1^{st}) and Angus- (2^{nd}) sired progeny did not differ significantly for slaughter weight, but were heavier than those by all other sire breeds, except that Brangus (3^{rd}) did not differ from Angus. Brangus did not differ significantly from Hereford- (4^{th}) sired progeny for slaughter weight, but did differ significantly from sire breeds ranking 5^{th} through 11^{th}. Nellore- (5^{th}), Bonsmara- (6^{th}), and Brahman- (7^{th}) sired progeny did not differ significantly for slaughter weight. Nellore- and Bonsmara- (6^{th}) sired progeny were significantly heavier than Romosinuano- (8^{th}) sired progeny, and Nellore-, Bonsmara-, Romosinuano-, and Brahman-sired progeny were significantly heavier at slaughter than Boran- (9^{th}), Tuli- (10^{th}), and Longhorn- (11^{th}) sired progeny, which did not differ significantly.

Table 4. Sire breed least squares means for postweaning average daily gain (ADG, 258 d) and final slaughter weight (444 d) of F_1 cross steers)

Sire breed	N	Post Wn. ADG[a] lb.	Slaughter wt[a], lb
Hereford	448	3.04^{bd}	1279^{d}
Angus	467	3.13^{bc}	1311^{bc}
Brahman	119	2.64^{f}	1201^{ef}
Nellore	101	2.77^{ef}	1229^{e}
Boran	151	2.49^{g}	1126^{g}
Brangus	107	3.01^{d}	1289^{cd}
Beefmaster	103	3.11^{b}	1328^{b}
Bonsmara	104	2.81^{e}	1218^{e}
Tuli	162	2.54^{g}	1120^{g}
Romosinuano	102	2.71^{f}	1180^{f}
Longhorn	104	2.50^{g}	1089^{g}

[a]Heterosis (H^i) was significant for postweaning average daily gain (H^i = .137 lb per day)and slaughter wt (H^i = 50.1 lb). Hereford and Angus sire breed means were adjusted by adding .4167 (H^i) to provide for unbiased comparisons to F_1 crosses by all other sire breeds.

[bcdefg]Means in the same column that do not share a common superscript differ ($P<.05$).

The 205-d weaning weights (Table 2) reflecting growth rates primarily during summer months were greater for Brahman- and Nellore-sired progeny than for Angus- and Hereford-sired progeny, which were in turn greater than in Tuli-, Longhorn-, or Romosinuano-sired progeny. However, postweaning average daily gains and slaughter weights (444 d) for steers affected primarily by growth rate during winter months were heavier for progeny of Angus- and Hereford-sired steers than for steers by *Bos indicus* (Nellore, Boran, and Brahman) sire breeds, which were in turn heavier than those for progeny of Romosinuano, Tuli, or Longhorn sires. Beefmaster (influenced by Brahman, Hereford- and Shorthorn breeds) and Brangus (3/8 Brahman, 5/8 Angus) gained relatively well in both seasons. These results are consistent with breed effects evaluated earlier by Souza et al. (1993), indicating that Brahmans had significantly greater average daily gains during summer months than Hereford or Angus, but that Hereford and Angus had significantly greater average daily gains than Brahman in winter months (Figure 1).

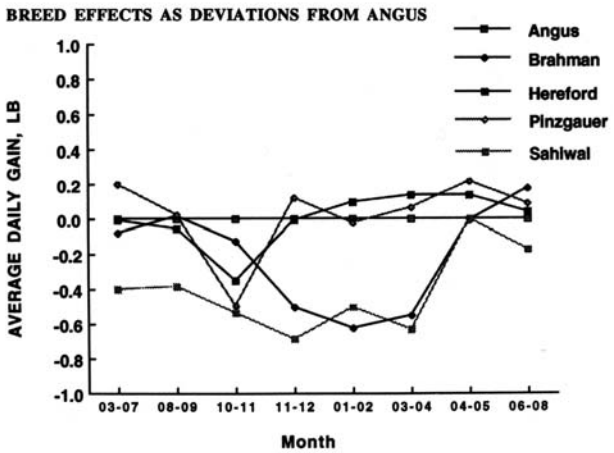


Figure 1. Breed effects as deviations from Angus during different seasons of the year for average daily gain.

Postweaning growth and puberty traits for heifers

Least squares means for growth and puberty traits of heifers are shown in Table 5. Observations were relatively few for Brangus-, Beefmaster-, Bonsmara-, and Romosinuano-sired females because half of the females in each breed group were transferred from MARC to Louisiana for a cooperative evaluation of genotype-environment interaction.

400-d weight. Beefmaster- (1st) and Brangus- (3rd) sired heifers did not differ significantly from Angus- (2nd) and Hereford- (4th) sired heifers for 400-d wt; they were significantly heavier than heifers by all other sire breeds. Angus-sired heifers did differ significantly from Hereford-sired heifers for 400-d wt. Bonsmara- (5th), Nellore- (6th), and Brahman- (7th) sired heifers, which did not differ significantly and were intermediate for 400-d weight, were significantly heavier than Boran- (8th), Romosinuano- (9th), Tuli- (10th), and Longhorn- (11th) sired heifers, which did not differ significantly for 400-d wt.

550-d weight. Beefmaster- (1st), Brangus- (2nd), Hereford- (3rd), Brahman- (4th), Bonsmara- (5th), Angus- (6th), and Nellore- (7th) sired heifers did not differ significantly in 550-d wt, except that Beefmaster were significantly heavier than Nellore and Angus, and heifers by all seven of these sire breeds were significantly heavier than those by Romosinuano (8th), Boran (9th), Tuli (10th), and Longhorn (11th) sires (Table 5). Boran-sired heifers were significantly heavier than Tuli- and Longhorn-sired heifers at 550 d of age. Romosinuano-sired heifers did not differ significantly from Boran- and Tuli-sired heifers, but were significantly heavier than Longhorn-sired heifers.

Again, for heifers as noted for steers, weights influenced primarily by gains made during winter months (i.e., 400-day wt) were heavier for progeny of *Bos taurus* sire breeds (Angus and Hereford) than for those of *Bos indicus* breeds (Nellore, Brahman, or Boran); the opposite was true for weights taken at the end of a summer (i.e., 205-d wt, or 550-d wt), which were much heavier for progeny of *Bos indicus* breeds. Again, breeds influenced about equally by *Bos indicus* and *Bos taurus* breeds (e.g., Beefmaster, Brangus, Bonsmara) performed relatively well and ranked relatively high at the end of either summer (205-d wt, and 550-d wt) or winter seasons (400-d wt).

Hip height. Least squares means for 18-mo hip height of heifers are shown in Table 5. Nellore- (1st) sired heifers were significantly taller than those by all other sire breeds except Brahman (2nd). Brahman-sired heifers did not differ significantly from Brangus- (3rd), Beefmaster- (4th), Hereford- (5th) Bonsmara- (6th), and Angus- (7th) sired heifers in height, but were significantly taller than Romosinuano (8th), Boran (9th), Longhorn (10th), and Tuli (11th). Brangus-, Beefmaster-, and Hereford-sired heifers did not differ significantly in height. Brangus- and Beefmaster-sired heifers were significantly taller than Bonsmara-, Angus-, Romosinuano-, Boran-, Longhorn-, and Tuli-sired heifers. Hereford-sired heifers did not differ significantly from Bonsmara- and Angus-sired heifers in height, but were significantly taller than Romosinuano-, Boran-, Longhorn-, and Tuli-sired heifers. Bonsmara-sired heifers were significantly taller than Tuli-sired heifers, but did not differ significantly from Angus-, Romosinuano-, Boran-, or Longhorn-sired heifers. Angus-sired heifers did not differ significantly from Romosinuano-sired heifers in height, but were taller than Boran-, Longhorn-, and Tuli-sired heifers. Romosinuano-, Boran-, Longhorn-, and Tuli-sired heifers did not differ significantly in height.

Puberty expressed (%). Females were checked visually for estrus behavior beginning in early February in Cycles IV and V, and in early January in Cycles VI, VII, and VIII. Least squares means for the percentage of heifers expressing their first estrus before estrus observations were discontinued, and heifers were moved from the dry-lot to grass pastures in early or mid-May of each year are shown in Table 5. Angus- (1st) sired heifers expressed a higher percentage estrus than those by all other sire breeds except Tuli (2nd). Tuli, Hereford (3rd), Boran (4th), Beefmaster (5th), Brangus (6th), Bonsmara (7th), and Romosinuano (8th) did not differ significantly in percentage expressing estrus. Tuli and Hereford differed significantly from Brahman (9th), Longhorn (10th), and Nellore (11th) in percentage expressing estrus. Boran differed significantly from Brahman in percentage expressing estrus. Nellore-sired heifers differed significantly from those by all other sire breeds in percentage expressing estrus.

Age at puberty. Least squares means shown in Table 5 for age at puberty were adjusted to remove bias due to differences in percentage expressing estrus when observation of estrus was discontinued in May. The means were adjusted to the age at puberty expected if 100% of the heifers had expressed estrus by adding $i(s)$ to the unadjusted means, where i is the expected negative deviation in standard deviation units (s) from the true mean for the "selected" sample of observed ages at puberty and s is estimated for a non truncated distribution from the observed s' as s'/s where $s^2 = 1 - i^2 + iZ$. Z is the deviation in s units from the true mean at the point of truncation of a normal distribution (Dickerson and Laster, 1975).

Angus (1st) and Hereford (2nd) sired heifers reached puberty at significantly younger ages than all

Table 5. Breed group means for growth and puberty traits for F_1 cross heifers

Sire breed of female	No	400-d wt.[a] lb.	550-d wt.[a] lb.	18 mo ht. cm	Puberty expressed %	Age at puberty[a] d	Preg. rate %
Hereford	486	810^{b}	924^{bcde}	127.7^{cde}	88.4^{bc}	351^{c}	89.8^{bcde}
Angus	461	825^{bc}	916^{ce}	126.8^{cdfg}	95.6^{b}	341^{b}	85.2^{cde}
Brahman	211	764^{d}	922^{bcd}	131.7^{bc}	77.4^{de}	415^{g}	82.8^{ce}
Nellore	205	771^{d}	909^{cde}	132.3^{b}	52.1^{f}	396^{f}	92.1^{bc}
Boran	244	716^{e}	846^{fg}	125.8^{fh}	85.7^{ce}	388^{f}	90.6^{bcd}
Brangus	47	815^{b}	928^{bc}	129.7^{cd}	82.4^{cde}	365^{cd}	95.0^{bc}
Beefmaster	51	828^{b}	951^{b}	129.4^{cd}	84.1^{cde}	369^{de}	99.3^{b}
Bonsmara	50	782^{d}	919^{bcde}	127.1^{cef}	82.0^{cde}	380^{def}	87.9^{bcde}
Tuli	53	707^{e}	828^{fh}	125.4^{h}	90.2^{bc}	365^{d}	86.5^{cde}
Romosinuano	50	715^{e}	848^{f}	126.5^{fgh}	81.7^{cde}	385^{ef}	92.7^{bc}
Longhorn	82	687^{e}	800^{i}	125.5^{fh}	77.0^{e}	357^{c}	93.6^{bc}

[a]Heterosis (H^i) was significant for 400-d wt (38 lb), 18 month weight (35 lb), and age at puberty adjusted to a 100% estrus expression (-12.4 days). Hereford and Angus sire breed means were adjusted by adding .4167 (H^i) to provide for unbiased comparisons to F1 crosses by all other sire breeds.

[bcdefghi]Means in the same column that do not share a common superscript differ ($P<.05$).

other more tropically adapted breeds except Longhorn (3rd) and Brangus (4th). Longhorn-sired heifers expressed their first estrus at significantly younger ages than all other breeds except Brangus. Brangus, Tuli (4th-5th), Beefmaster (6th), and Bonsmara (7th) did not differ significantly for age at puberty. Beefmaster-sired heifers were significantly younger than Boran- (9th) and Nellore- (10th) sired heifers, but Beefmaster-, Bonsmara-, Romosinuano- (8th), and Boran-sired heifers did not differ significantly for age at puberty. Heifers by all sire breeds reached puberty at a significantly younger age than those by Brahman (11th) sires. Thus, age at puberty was significantly younger for *Bos taurus* (Angus, Hereford, Longhorn) breeds than for *Bos indicus* breeds (Boran, Nellore, and Brahman); mean ages at puberty for other tropically adapted breeds (Tuli, Romosinuano) were more intermediate between that for *Bos indicus* and *Bos taurus* breeds, or, in the case of composite populations (Brangus, Beefmaster, and Bonsmara), consistent with the contribution of *Bos indicus* and *Bos taurus* germplasm in their foundation.

Pregnancy rate for yearling heifers. Least squares means for pregnancy rate for yearling heifers are in Table 5. In general, differences among sire breeds were not significant for pregnancy rate, except that Beefmaster- (1st) sired females had significantly higher pregnancy rates than Tuli- (9th), Angus- (10th), or Brahman- (11th) sired females, and Boran- (6th) sired heifers had significantly higher pregnancy rates than Brahman-sired heifers. Although Angus-sired females reached puberty at a relatively young age, their pregnancy rate was relatively low, reducing the association usually observed between age at puberty and conception rate of yearling heifers (Martin et al., 1992).

Reproduction and Maternal Performance of F_1 cross females.

For females produced in Cycle VIII (Brangus, Beefmaster, Bonsmara, and Romosinuano), the data are complete through 2 yr of age only. Thus, the analysis of pooled data for reproduction and maternal performance for F_1 cross females by 11 sire breeds was possible only for females calving at 2 yr (Table 6). Data for the F_1 females by the other sire breeds calving at 3 through 7 yr of age are shown in Table 7. Means for Hereford, Angus, Brahman, Boran, and Tuli were estimated from an analysis of data obtained in Cycle V of the GPE Program (Cundiff et al., 2000). Means for Nellore- and Longhorn-sired females shown in Table 7 were estimated by adding their deviation from the mean for Hereford- and Angus-sired crosses (i.e., Hereford and Angus sires sampled and used by AI for the first time in Cycle IV) estimated in an analysis of Cycle IV data, to the mean for Hereford- and Angus-sired crosses estimated in the analysis of Cycle V data.

Calf crop born and weaned for 2 yr olds.. Sire breed least squares means for percentage calf crop born and weaned for F_1 cross females exposed to Red Poll or MARC III bulls to produce their first calves at 2 yr of age are shown in Table 6. Sire breed least squares means for the same traits for F_1 cross females calving at 3 through 7 yr of age are shown in Table 7. In females calving at 2 yr of age, calf crop born did not differ significantly for Beefmaster- (1st), Longhorn- (2nd), Brangus- (3rd), Nellore- (4th), Hereford- (5th), Boran- (6th), Romosinuano- (7th), and

Bonsmara- (8th) sired females. Calf crop born was significantly greater for Beefmaster-sired females than for Tuli- (9th), Angus- (10th), and Brahman- (11th) sired females. Longhorn-, Brangus-, and Boran-sired females calving at 2 yr of age differed significantly for crop born from Brahman-sired females but not from those by any other sire breed. Calf crop born for 2 yr olds was significantly greater for Nellore- and Hereford-sired females than for Angus- and Brahman-sired females. Romosinuano-, Bonsmara-, Tuli-, Angus-, and Brahman-sired females did not differ significantly for calf crop born at 2 yr of age. As expected, results for calf crop born for 2 yr olds were similar to those for conception rate as yearlings (Table 5). The relatively low conception rate and calf crop born for Brahman-sired females was associated with their relatively older age at puberty.

Results for calf crop weaned were similar to those for calf crop born for females calving as 2 yr olds; although rankings were slightly different and there were fewer significant differences among sire breeds. Beefmaster- (1st) sired females differed significantly from Angus- (8th), Bonsmara- (10th), and Brahman- (11th) sired females for calf crop weaned as 2 yr olds. Brangus (2nd), Boran (3rd), Romosinuano (4th), Longhorn (5th), Hereford (6th), Tuli (7th), Angus (8th), Nellore (9th), and Bonsmara (10th) did not differ significantly for calf crop weaned as 2 yr olds. Brangus, Boran, Romosinuano, Longhorn, Hereford, and Tuli sire females did differ significantly from Brahman-sired females for calf crop weaned as 2 yr olds. Angus-, Nellore-, Bonsmara-, and Brahman-sired females did not differ significantly for calf crop weaned as 2 yr olds.

Calf crop born and weaned at 3 through 7 yr of age. Sire breed differences for calf crop born for F_1 females calving at 3 through 7 yr of age did not differ significantly among sire breeds, with one exception: Nellore-sired females had a higher percentage of calves born than Tuli-sired females (Table 7). Sire breed differences for calf crop weaned for F_1 females calving at 3 through 7 yr of age did not differ significantly among sire breeds.

Calvings ease for 2 yr olds. Sire breed least squares means for F_1 cross females calving at 2 yrs of age are shown in Table 6 for percentage of unassisted calvings and for calving difficulty score. Again, these females were producing calves sired by Red Poll or MARC III bulls selected for their calving ease. Percentage of unassisted calvings was determined from calving difficulty score. (Unassisted calving was coded as 1 for little or no difficulty, i.e., calving difficulty score 1 = no difficulty and 2 = little difficulty by hand; or 0 for difficult calvings, i.e., calving difficulty scores 3 = little difficulty with a calf jack, 4 = slight difficulty with a calf jack, 5 = moderate difficulty with a calf jack, 6 = major difficulty with a calf jack, 7 = caesarean birth, and 8 = abnormal presentation).

Percentage unassisted calvings for F_1 females calving as 2-yr-olds were significantly greater for those by Nellore (1st) sires than for all those by all other breeds except for those Romosinuano (3rd) which had a relatively large standard error and small number of observations. Longhorn (2nd), Romosinuano (3rd), Brahman (4th), Brangus (5th) and Beefmaster (6th) did not differ in percentage unassisted calvings. Longhorn sired females did not differ significantly from Tuli (7th) sired females in unassisted calvings but Longhorn sired females did require significantly less assistance than Boran (8th), Angus (9th), Hereford (10th) and Bonsmara (11th) sired females. Romosinuano and Bonsmara sired females differed significantly in unassisted calvings. Although not supported by superscripts on Table 6 (due to smaller standard errors for intra cycle contrasts than between cycle contrasts), Brahman sired females required significantly less assistance at calving than Tuli, Boran, Angus, Hereford (all of which were included in cycle V), and Bonsmara sired females. Brangus and Beefmaster did not differ significantly from Angus and Hereford sired females in unassisted calvings, but did require less assistance than Bonsmara sired females. Tuli, Boran, Angus, Hereford, and Bonsmara sired females did not differ significantly in unassisted calvings. Significance of difference patterns for calving difficulty score were essentially the same as for percentage unassisted calvings.

Calving ease at 3 through 7 yr of age. Sire breed differences for percentage unassisted calvings for F_1 females at 3 through 7 yr of age did not differ significantly among sire breeds (Table 7). At these ages, means for percentage unassisted calvings were high ($\geq$ 95%) for all sire breeds. Although a significant difference for calving difficulty was detected ($P < 0.05$) between Brahman (the lowest ranking sire breed) and Hereford (the highest ranking sire breed), this difference was relatively small, and no other contrast among the seven sire breeds was significant for calving difficulty score for females calving at 3 through 7 yr of age.

Birth weight for progeny of 2 yr olds. Sire breed least squares means for birth weight of calves produced by F_1 dams calving at 2 yr of age are shown in Table 6. Progeny birth weights did not differ significantly for F_1 females by Longhorn (1st ranking from lightest to heaviest), Boran (2nd), Nellore (3rd), Romosinuano (4th), Tuli (5th), Bonsmara (9th), and Bonsmara (9th), and Brangus (10th) sires. Longhorn sired females produced progeny with significantly

Table 6. Sire breed least squares means for reproduction and maternal performance of F_1 cross females producing their first calves at 2 years of age

Sire breed of calf	No. calves born	Calf crop Born %	Calf crop weaned %	Calvings unassist. %	Calv. diff. score	Birth wt. lb.	205-d wn. wt. per Calf lb.	205-d wn. wt. per Cow exposed lb.
Hereford	404	85.7^{bcd}	76.5^{bc}	69.4^{df}	2.00^{cdf}	78.3^{g}	428^{e}	322^{bc}
Angus	366	78.0^{ce}	73.1^{cd}	69.7^{df}	2.03^{df}	76.4^{fg}	451^{d}	325^{bc}
Brahman	163	74.3^{e}	64.5^{d}	83.6^{cde}	1.56^{bcde}	74.6^{bcef}	473^{b}	308^{c}
Nellore	72	90.0^{bcd}	72.9^{bcd}	101.5^{b}	1.01^{b}	72.4^{bcd}	471^{bc}	347^{bc}
Boran	177	85.5^{bcd}	83.1^{bc}	70.2^{df}	1.94^{cdf}	72.3^{bc}	447^{bd}	371^{b}
Brangus	40	90.4^{bc}	87.4^{bc}	79.5^{cde}	1.79^{cdef}	77.7^{bfg}	451^{bcd}	399^{b}
Beefmaster	49	95.8^{b}	88.5^{b}	78.3^{cde}	1.89^{cdef}	76.4^{cdefg}	457^{bcd}	409^{b}
Bonsmara	39	82.7^{bcde}	71.4^{cd}	55.6^{f}	2.43^{f}	76.7^{bdefg}	428^{de}	310^{bc}
Tuli	205	81.3^{cde}	74.5^{bc}	71.6^{cdf}	2.06^{cdf}	73.8^{bcdef}	417^{e}	311^{bc}
Romsinuano	42	84.1^{bcde}	81.6^{bc}	83.8^{bcd}	1.58^{bcd}	72.6^{bcde}	388^{f}	321^{bc}
Longhorn	76	93.8^{bc}	80.4^{bc}	86.2^{c}	1.53^{c}	71.3^{b}	413^{e}	332^{bc}

[a]Maternal heterosis (H^m) was significant for 205-d wn wt (17.4 lb). Hereford and Angus sire breed means were adjusted by adding .4167 (H^m) to provide for unbiased comparisons to F_1 crosses by all other sire breeds.

[bcdefghi]Means in the same column that do not share a common superscript differ (*P*<.05).

Table 7. Sire breed least squares means for reproduction and maternal performance of F_1 cross females calving at 3 through 7 years of age

Sire breed of female	Number cows exposed	Number calves born	Calf crop Born %	Calf crop weaned %	Unassisted calving %	Calving diff. sc	Birth wt. lb.	205-d wt, lb. per calf	205-d wt, lb. per cow exposed
Hereford	470	439	93.8^{a}	88.7^{a}	95.2^{a}	1.25^{b}	93.0^{a}	483^{c}	430^{abc}
Angus	376	354	93.6^{a}	86.3^{a}	96.4^{a}	1.18^{ab}	90.5^{a}	503^{b}	434^{abc}
Brahman	621	575	92.8^{a}	84.3^{a}	98.8^{a}	1.04^{a}	82.1^{c}	527^{a}	444^{abc}
Boran	655	604	93.1^{a}	86.2^{a}	96.9^{a}	1.12^{ab}	81.6^{c}	498^{b}	429^{abc}
Tuli	722	650	90.1^{b}	84.1^{a}	96.8^{a}	1.17^{ab}	84.4^{bc}	481^{c}	405^{c}
Longhorn	333	312	96.4^{a}	89.4^{a}	98.5^{a}	1.04^{ab}	85.9^{b}	455^{d}	411^{bc}
Nellore	319	303	97.5^{a}	91.4^{a}	99.7^{a}	1.08^{ab}	81.9^{c}	513^{ab}	467^{a}

[abcd]Means in the same column that do not share a common superscript differ (*P* < .05).

lighter birth weights than females by Angus (4^{th} – 5^{th}), Beefmaster (4^{th} – 5^{th}), and Hereford (11^{th}) sires. Boran-sired females produced significantly lighter calves at birth than Angus-, Bonsmara-, Brangus-, and Hereford-sired females. Nellore-sired females had lighter calves at birth than Brahman-, Angus-, Bonsmara-, Brangus-, and Hereford-sired females. Calves produced by Romosinauno-sired females were lighter at birth than those by Angus, Brangus, and Hereford sires. Birth weights for calves produced by Tuli- and Brahman-sired females did not differ from those produced by Beefmaster-, Angus-, Bonsmara-, and Brangus-sired females, but were significantly lighter than those produced by Hereford sires. Progeny birth weights did not differ significantly for F_1 females by Angus, Beefmaster, Bonsmara, Brangus, and Hereford sires.

Rankings for sire breed means of F_1 calves (Table 2) reflecting direct effects of breed (1/2 D_i, for the i^{th} breed) on fetal growth and development as expressed in birth weight were very different than those for F_1 female sire breed means (Table 6) reflecting maternal breed and reduced direct effects (1/2 M_i + 1/4 D_i) of breed. The F_1 cross calves by *Bos indicus* (Nellore - 1^{st}, Brahman - 2^{nd}, and Boran - 3rd) sire breeds were the heaviest at birth among all sire breeds. Heavier birth weights expressed in F_1 calves by *Bos indicus* sire breeds were also associated with greater calving difficulty (Table 2). On the other hand, calves produced by *Bos indicus*-sired F_1 cross females (by Red Poll or MARC III sires) were relatively much lighter at birth (Boran – 10^{th}, Nellore – 9^{th}, and Brahman- 6^{th}). Lighter maternal birth weights were also associated with greater calving ease (Table 6) for F_1 females by *Bos indicus* sire breeds. In general, calving difficulty was not a problem in females sired by tropically adapted breeds, and especially in females sired by *Bos indicus* or *Bos indicus*-influenced breeds. Biological mechanisms responsible for these very striking differences between direct and maternal effects of *Bos indicus* and *Bos taurus* breeds are discussed in more depth in reports by Gill et al. (2005) and Ferrell (2005) in these proceedings.

Birth weight for progeny for females calving at 3 through 7 yr of age. Sire breed least squares means for birth weight of calves produced by F_1 dams by seven sire breeds calving at 3 through 7 yr of age are shown in Table 7. Results for progeny birth weights at these ages are very similar to those discussed above for 2-yr-old dams. Hereford- (1^{st}) and Angus- (2^{nd}) sired dams birthed significantly heavier calves than Longhorn- (3^{rd}) and Tuli- (4^{th}) sired dams. Longhorn-sired dams birthed significantly heavier calves than Brahman- (5^{th}), Nellore- (6^{th}), and Boran- (7^{th}) sired dams. Again, the strong maternal ability for *Bos indicus* breeds to reduce fetal growth and development was very evident.

205-d weaning weight for females calving at 2 yr of age. Weaning weights of three-way cross progeny raised by 2-yr-old F_1 cross dams, reflecting maternal breed and direct effects (1/2 M_i + 1/4 D_i) of breed, are shown in Table 6. Brahman- (1^{st}), Nellore- (2^{nd}), Beefmaster- (3^{rd}), and Brangus- (4^{th-} 5^{th}) sired dams did not differ significantly for maternal weaning weight. Although, the mean difference between Brahman- and Boran- (6^{th}) sired dams was greater than that between Brahman- and Angus-sired dams, the difference between Brahman and Boran was not significant; that between Brahman and Angus was significant because fewer observations were available for Boran- than for Angus-sired dams. Nellore-sired dams weaned significantly heavier calves than Angus- or Boran-sired dams. Both Brahman- and Nellore-sired dams weaned significantly heavier calves than Bonsmara- (7^{th}– 8^{th}), Hereford- (7^{th}– 8^{th}), Tuli- (9^{th}), Longhorn- (10^{th}), or Romosinuano- (11^{th}) sired dams. Beefmaster-, Brangus-, Angus-, Boran-, and Bonsmara-sired dams did not differ for 205-d weight, but these crossbred cows did wean significantly heavier calves than Hereford, Tuli, or Longhorn crossbred cows. Calf 205-d weight for Hereford-, Tuli-, and Longhorn-sired cows did not differ significantly, but they did wean significantly heavier calves than Romosinuano-sired dams.

205-d weaning weight for females calving at 3 yr of age or older. Weaning weights of three-way cross progeny raised by F_1 cross dams calving at 3 through 7 yr of age are shown in Table 7. Brahman (1^{st}) sired dams weaned significantly heavier calves than Angus- (3^{rd}), Boran- (4^{th}), Hereford- (5^{th}), Tuli- (6^{th}), and Longhorn- (7^{th}) sired dams for maternal weaning weight. Brahman- and Nellore- (2^{nd}) sired dams did not differ significantly. Nellore- (2^{nd}), Angus- (3^{rd}), and Boran- (4^{th}) sired dams did not differ significantly for 205-d weight of their calves, but they weaned significantly heavier calves than Hereford-, Tuli-, and Longhorn- sired dams. Hereford- and Tuli-sired dams did not differ significantly, but did wean significantly heavier calves than Longhorn-sired dams.

205-d weaning weight per cow exposed. Sire breed least squares means for 205-d weaning weight per cow exposed to breeding for F_1 cross females producing their first calves at 2 yr of age are shown in Table 6 and those for producing calves at 3 through 7 yrs of age are shown in Table 7. Weaning weight per cow exposed combines variation in percentage calf crop weaned with variation in maternal weaning weight to reflect variation in output per cow in the herd at breeding time. Since this trait is strongly influenced by calf crop percentage weaned, and since only the widest breed differences for calf crop weaned

were significantly different, differences among breed groups for weaning weight per cow exposed were significantly different only for the most widely different breed group means as well. For 2 yr olds, Beefmaster (1st), Brangus (2nd), Boran (3rd), Nellore (4th), Longhorn (5th), Angus (6th), Hereford (7th), Romosinuano (8th), Tuli (9th), and Bonsmara (10th) did not differ significantly for weaning weight per cow exposed. Only Brahman-sired females differed significantly from those by any other sire breeds (Beefmaster, Brangus, and Boran). The reduced 205-d weaning weight per cow exposed for Brahman crosses (11th) was due to lower calf crop percentage weaned (11th) associated with their older age at puberty (11th; Table 5), and not their maternal weaning weight (1st). Thus, at 3 to 7 yr of age, when reproduction rate was no longer influenced by older age at puberty, and differences in calf crop percentage were not significantly different among sire breeds, Brahman (2nd) ranked higher among sire breeds in 205–d weaning weight per cow exposed. At 3 to 7 yr of age, Nellore- (1st), Brahman-, Angus- (3rd), Hereford- (4th) Boran- (5th) sired females did not differ significantly for this estimate of output per cow in the breeding herd. The only significant differences found involved only the highest-ranking Nellore and Brahman versus the lowest-ranking Longhorn- (6th) and Tuli- (7th) sired females. Nellore differed significantly from both Longhorn and Tuli, while Brahman differed significantly from Tuli.

Implications

No one breed excels in all traits of importance to beef production. Thus, crossing of two or more breeds can be used to optimize performance levels. To limit costs of production and improve efficiency of production a strong influence of tropically adapted germplasm is needed in U.S. subtropical regions. In the hotter and more humid climates of the Gulf Coast, about 50:50 ratios of *Bos indicus* to *Bos taurus* inheritance may be optimal. A little further north (e.g., Southeastern Oklahoma, central Arkansas, Tennessee, and parts of North Carolina), 25:75 ratios of *Bos indicus*: *Bos taurus* inheritance may be optimal in cowherds. In temperate climates (e.g., Nebraska), crosses with 50% or more *Bos indicus* inheritance suffer increased mortality when calves are born in colder seasons and reduced average daily gains in feedlots during winter.

Use of F_1 Brahman cross cows, Nellore, or Boran F_1 cross cows or rotational crossing of composite breeds such as Beefmaster, Brangus, Bonsmara, or Santa Gertrudis, are especially appropriate in subtropical environments. In developing composite populations with an overall level of 50% tropical adaptation, it may be appropriate to substitute a portion (e.g., 25%) of non *Bos indicus* germplasm for *Bos indicus* germplasm from such breeds as the Tuli or Romosinuano to maintain tropical adaptation and improve meat tenderness, provided they are crossed with other breeds that optimize size and growth rate. However, experiments in progress need to be completed to determine optimum contributions of *Bos indicus*, British *Bos taurus*, Continental *Bos taurus*, and tropically adapted *Bos taurus* breeds from Africa or from Central or South America for beef production in U. S. subtropical environments.

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Feed Utilization and Performance of Crossbred Tropically Adapted Cattle

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ABSTRACT: Four studies were conducted to evaluate tropically adapted breeds for feed utilization and energy use during growth. In Study 1, 10 *Bos indicus*-sired (5 Boran, Bo; 5 Brahman, Br) and 10 MARC III steers were used to assess cattle age and breed influence on digestion of a high grain diet. Duodenal flows of total N, microbial N, nonmicrobial N, total amino acids, and total tract N digestibility were not different ($P > 0.05$) due to age or breed. In Study 2, ¼ (21), ½ (7), and ¾ (9) Br were compared to MARC III (14) steers fed bromegrass hay or corn silage diets during a 119-d period. Brahman crosses ate less (14.6 vs. 16.3 lb/d) and grew slower (1.37 vs. 1.59 lb/d) than MARC III ($P < 0.05$), but ME/gain was similar (16.0 vs. 14.1 Mcal/lb; $P = 0.40$). When steers were subsequently fed a high-corn diet, daily DM intake (16.8 vs. 18.7) and ADG (2.60 vs. 2.91 lb/d) were lower ($P < 0.05$) for Br steers. Br and MARC III had similar ME/gain during finishing (9.16 vs. 9.16 Mcal/lb; $P = 0.98$) and for the entire study (9.80 vs. 9.71; $P = 0.79$). Influences of Angus (A), Bo, Br, Hereford (H), and Tuli (T) sires on body composition and energy use during finishing was evaluated in Study 3. Feed intake was least for Bo- and T-, intermediate for Br- and H-, and greatest for A-sired steers. Rates of weight, fat, and energy gains were similar for A-, H-, and Br-sired steers, but less ($P < 0.01$) for Bo and T when fed ad libitum. Liver weights differed ($P < 0.01$) among sire breeds (14.0, 10.0, 11.2, 13.4, and 10.7 lb for ad libitum fed A, Bo, Br, H, and T, respectively) and increased in response to increased daily feed intake in H (0.65), A (0.55), Bo (0.47), Br (0.38), and T (0.40). Maintenance and efficiency of energy use for gain differed ($P < 0.05$) among sire breeds. In Study 4, fasting heat production (FHP) at 30 wk of age was highest for MARC III heifers and decreased as Br increased (0, ¼, ½, ¾). FHP decreased with aging, but the rate of decrease followed the same ranking, resulting in similar values at 86 wk. A number of differences between tropically and temperately adapted cattle were observed, but efficiency of feed use was similar.

Key Words: Digestibility, Fasting Heat Production, Feed Efficiency, Maintenance

Introduction

Steer genotype can have large influences on feed intake, feed utilization, growth rate, and body composition during the growing-finishing period. However, a high proportion of this kind of information has resulted from comparisons of relatively well-fed animals of *Bos taurus* breeds in temperate environments. Less attention has been devoted to feed intake and performance of *Bos indicus*, *Bos indicus* crossbred, or other tropically adapted breeds of cattle. Many of the available comparisons of tropically adapted cattle to those developed in more temperate regions have been conducted under nutritionally and/or environmentally stressful conditions. Relatively few evaluations of feed intake and performance of growing-finishing animals of tropically adapted breeds in temperate environments are available.

Several authors have suggested that *Bos indicus* cattle use low-quality forage diets more efficiently than *Bos taurus* cattle. Those reports are primarily based on performance of cattle provided low-quality forage diets. Other available reports suggest that tropically adapted cattle, in general, have lower maintenance requirements than breeds developed in more temperate regions. If one assumes similar feed intake, animals with reduced maintenance requirements are expected to perform better in a nutritionally restrictive environment. Thus, improved performance on low-quality forages may result from lower maintenance requirements, rather than improved utilization of low-quality diets *per se*. In contrast, when high-quality forage or forage plus concentrate diets are fed, *Bos taurus* cattle generally consume more feed relative to their maintenance requirements, and gain faster than *Bos indicus* cattle. For example, Beaver et al. (1989) reported that Angus steers consumed more feed and gained faster, but had similar diet digestibility and feed efficiency compared to Brangus steers when fed an 87.5% concentrate diet. The purpose of this report is to review results from studies conducted at the U.S. Meat Animal Research Center (MARC) in which feed intake, diet digestibility, maintenance requirements, rate and efficiency of gain, and body composition have been evaluated in crossbred cattle sired by tropically adapted breeds during growing and/or finishing.

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Materials and Methods

Study 1. Details of the study have been reported previously (Krehbiel et al., 2000). In brief, 5 Boran (Bo) and 5 Brahman (Br) × MARC III (¼ Angus, Hereford, Pinzgauer, Red Poll) steers (initial BW, 664 ± 44 lb), and 10 MARC III steers (710 ± 35 lb) were selected from the Germplasm Evaluation herd at MARC. Steers were adapted to facilities, diets, and handling. Steers were fed a forage-based diet to gain 1.3 to 1.5 lb/d, then, surgically fitted with duodenal cannulas as calves (three Bo×, two Br×, and five MARC III; 290 days of age) or yearlings (two Bo×, three Br×, and five MARC III; 400 days of age), then individually fed a high concentrate diet (86.7% corn; 95% concentrate) for 240 d (calves) or 165 d (yearlings). Daily feed provided and orts were recorded daily throughout the feeding period.

Four times during the feeding period (days 14, 67, 137, and 228 for calves; days 13, 42, 102, and 159 for yearlings) steers were moved to a metabolism barn for 4-d collection periods. Chromic oxide, used as a flow marker, was mixed with dried molasses (7.5:92.5) and 200 g was top-dressed so that each steer received 15 g chromic oxide/d. During the sampling periods, duodenal digesta were collected (approximately 150 g) three times daily (0700, 1400, and 2100 h) for three consecutive days. Fecal grab samples (150 g) were collected once daily for four consecutive days. Duodenal and fecal samples were stored frozen, lyophilized, ground, composited, and analyzed for DM, N, ash, and Cr. In addition, duodenal samples were analyzed for purines and amino acids. At slaughter, ruminal digesta were collected to harvest bacterial cells, which were analyzed for N and purine content. Stomach and post-stomach digestibility were estimated using the marker ration technique with Cr as the reference. Duodenal bacterial N flows were determined by the use of purines as a microbial marker.

For all response variables, the initial model included breed to test for differences between Bo × MARC III and Br × MARC III steers. When the F-test for breed was not significant ($P > 0.05$), steers sired by *Bos indicus* breeds were pooled and compared to MARC III steers. Intake and performance data were analyzed by use of a model that included age, biological type, and the two-way interaction. Data on intake, site, and extent of digestion were analyzed as a split plot.

Study 2. Objectives of this study were to evaluate diet × biological type interactions in terms of feed intake, feed utilization, and performance of steers fed bromegrass hay or corn silage-corn diets, and to evaluate the influence genotype and diet during the growing period on compensatory gain responses during the finishing period. For this study, 51 steers (14 MARC III, 21 ¼ Br × ¾ MARC III, 7 ½ Br × ½ MARC III, and 9 ¾ Br × ¼ MARC III) from the MARC population were randomly allotted to eight pens partially under an open-fronted barn and individually fed *ad libitum* once daily by use of Calan headgates. Steers in four of the pens were fed coarsely chopped bromegrass hay (9.53% CP, 10 Mcal ME/lb), whereas steers in the other four pens were fed a corn silage-based diet (11.91% CP, 1.25 Mcal ME/lb) during a 119-d growing period. At the end of the growing period, all steers were adapted to a high corn diet (11.71% CP, 1.40 Mcal ME/lb) and fed to a target weight of 1,235 lb (finishing period). Steers were weighed at the beginning and at approximately 14-d intervals throughout the study. The amount of feed provided to each steer was recorded daily and orts were recorded at 14-d intervals. Samples of the feeds were taken daily, frozen, composited over each 14-d interval, and subsequently analyzed for dry matter and CP (N × 6.25) content. Metabolizable energy was calculated from tabular values. Carcass cooler data were obtained after harvest at the MARC abattoir.

Regression of weight or feed intake on days fed was developed for each steer within feeding period. Those regressions were then used to calculate initial weight, weight at the end of the growing period, weight at harvest, and feed intake for each steer within feeding period. Daily weight change and feed intake were calculated from the resulting regressions. Data were analyzed by analysis of variance. Biological type (MARC III vs. Br crosses; T), diet (D) during the growing period, and the interaction (T × D) were included in the model.

Study 3. Details of this study have been reported by Ferrell and Jenkins (1998b). Steer calves (n = 96) were obtained from the U.S. Meat Animal Research Center breeding project (Germplasm Evaluation Program, Cycle V). Steers were sired by Angus, Boran, Brahman, Hereford, or Tuli bulls and out of MARC III cows. At weaning, steers were penned in three groups, and, over an eight-week period, were adjusted to a growing diet consisting of 66% corn silage, 22% rolled corn, and 12% supplement. Steers were fed the growing diet ad libitum until average weight was about 660 lb.

Steers were then moved to an individual feeding facility and assigned to initial slaughter, limit-fed, or ad libitum-fed treatment groups by sire breed. Steers were penned by sire breed, pooling Angus- and Hereford-sired steers, and treatment group in groups of eight steers per pen and fed individually by use of Calan-Broadbent headgates. Steers were switched to a

high-concentrate diet (1.42 Mcal ME/lb, 11.19% CP) and adapted to the facilities and diet. Limit-fed steers were fed approximately 140 kcal ME/kg$^{0.75}$ daily, and ad libitum-fed steers were fed once daily to appetite. Steers were weighed at 2-wk intervals and feed allotments for limit-fed steers were adjusted at those times. All steers were killed at the MARC abattoir after approximately 140 d on feed. Feed samples were taken daily, frozen, and composited for each 2-wk period for subsequent DM and CP determinations. Growth stimulants were not used. Procedures followed at slaughter, measurements taken, and methods used to determine offal, carcass, and empty body composition were as described by Ferrell and Jenkins (1998a).

Data calculations and analyses have been described in detail previously (Ferrell and Jenkins, 1998a). General approaches were similar to the comparative slaughter procedures described by Lofgreen and Garrett (1968). Feed intake, carcass traits, organ weights, composition, and gain data were statistically analyzed by use of a model that included sire breed, dietary treatment, and the interaction of sire × treatment.

Study 4. Details of this study have been reported by Freetly et al. (2003). Calves were produced by artificially inseminating F_1 (Brahman × MARC III) and MARC III cows to either Brahman or MARC III bulls. Thirty-one heifers were produced consisting of MARC III (7), ¼ Brahman (13), ½ Brahman (5), and ¾ Brahman (6). Calves were born between March 15 and April 30. Heifers and their dams grazed improved grass pastures before weaning and did not receive additional feed. Heifers were weaned at 152 ± 2 d of age and were allowed ad libitum access to a diet that contained 20% chopped alfalfa hay, 22% corn, 54.3% corn silage, 0.5% limestone, 3% soybean meal, and 0.2% sodium chloride on a dry basis. Heifers remained on this diet for the rest of the study, except when feed was removed to determine heat production.

Five or six heifers were placed in each pen (86 sq yd) partially covered by an open-fronted barn. Heifers were periodically moved to stanchions and trained for sample collection with indirect calorimetry. Calorimetry measurements were first taken when heifers were 30.2 ± 0.3 wk of age and then every 6 wk for a total of six measurements. Feed was withheld for 55 h before calorimetry measurements started. Composite gas samples were collected from 55 through 71.5 h after feed removal. Following calorimetry measurements, heifers had ad libitum access to bromegrass hay for 2 d, then returned to their normal diet over an 8-d period.

Data were analyzed as a split-plot design. Age was treated as a continuous variable. The model was animal (breed type), breed type, age, and breed type × age. Breed differences were tested with animal (breed). Age and breed × age were tested with the residual error.

Following the last measurement during the heifer development portion of the study, heifers were mated to an Angus bull and calorimetry measurements were made 23 wk after being placed with the bull. Pregnant heifers were fed a diet that contained 27% chopped alfalfa hay, 67.3% corn silage, 5.5% soybean meal, and 0.2% sodium chloride to provide 172 kcal ME/kg$^{0.75}$/d. The same protocol for measuring heat production in young heifers was used in bred heifers. Data were analyzed by ANOVA.

Results

Study 1. By design, initial BW (Table 1) for the finishing period was greater ($P < 0.01$) for yearlings (849 lb) than for calves (686 lb), but final BW was similar ($P > 0.05$). Yearling steers ate 28% more feed ($P < 0.01$), gained 16% more rapidly ($P = 0.03$), and were 10% less efficient ($P = 0.03$) than calves. Yearling steers had greater ($P < 0.01$) OM intake, and greater OM digested in the stomach, but lower post-stomach OM disappearance (as a percentage of OM intake) than calves. Apparent total tract OM digestibility of yearlings and calves were similar. Similarly, N intake and N disappearing in the stomach were greater in yearlings than in calves (Table 2). However, N flows (microbial and nonmicrobial) in the duodenum, as well as post-stomach N disappearance, was similar in yearlings and calves. As a result, although daily fecal N excretion was greater in yearlings than in calves, apparent digestibility, expressed as a percentage of N intake, was not different ($P > 0.05$). These results suggest site of digestion may influence efficiency of feed utilization, even though few differences in total tract apparent digestibility were evident. None of these traits were significantly influenced by biological type or the biological type × age interaction. These results do not support the suggestion that *Bos indicus* steers digest and utilize high-grain diets less efficiently than *Bos taurus* steers.

Study 2. Initial weights did not differ among treatment groups, but MARC III steers grew faster ($P < 0.02$) than Brahman crossbred steers. Steers fed the corn silage-based diet grew faster ($P < 0.01$) than steers fed bromegrass hay during the growing period (Table 3). Dry matter intake ($P < 0.04$) and ME intake ($P < 0.05$) of MARC III steers were greater than that of Brahman crossbred steers. Steers fed the

Table 1. Performance of *Bos indicus* × MARC III and MARC III calves and yearlings consuming a high grain diet[a]

	Calves		Yearlings			Probability		
Item	*Bos indicus*	MARC III	*Bos indicus*	MARC III	SEM	Type	Age	T × A
Initial BW, lb	659	710	855	842	19.8	0.35	0.01	0.15
Final BW, lb	1,215	1,299	1,318	1,292	42	0.50	0.26	0.20
Daily gain, lb/d	2.47	2.62	3.02	2.91	0.18	0.87	0.03	0.47
DM intake, lb/d	15.7	17.9	22.0	20.9	0.66	0.62	0.01	0.47
Gain/feed	0.16	0.15	0.14	0.14	0.009	0.42	0.03	0.25
OM intake, lb/d	14.8	16.7	19.3	18.9	0.49	0.43	0.01	0.21
OM digested in the stomach								
Apparent, lb/d	9.8	11.37	13.81	14.28	0.50	0.23	0.01	0.51
% of OM intake	65.8	68.3	70.8	75.1	1.6	0.28	0.07	0.77
Fecal OM, lb/d	1.85	2.22	2.61	2.55	0.16	0.53	0.03	0.37
Post stomach OM disappearance, % of OM intake	21.8	18.4	15.7	11.5	1.5	0.22	0.05	0.89
Apparent total tract OM digestibility, %	87.6	86.7	86.5	86.6	1.7	0.72	0.54	0.59

[a]From Krehbiel et al., 2000.

Table 2. Nitrogen digestion by *Bos indicus* × MARC III and MARC III calves and yearlings consuming a high grain diet[a]

	Calves		Yearlings			Probability		
Item	*Bos indicus*	MARC III	*Bos indicus*	MARC III	SEM	Type	Age	T × A
N intake, g/d	157	176	205	199	4	0.45	0.01	0.20
N disappearing in the stomach								
Apparent, g/d	77	93	109	110	4	0.30	0.01	0.36
% of N intake	49	53	52	54	2	0.24	0.48	0.80
Duodenal N flow								
Total, g/d	80	90	96	90	4	0.69	0.15	0.12
Microbial, g/d	57	70	69	68	3	0.20	0.31	0.13
Nonmicrobial, g/d	23	20	27	22	2	0.44	0.51	0.74
Post stomach OM disappearance								
Apparent, g/d	57	64	66	61	4	0.83	0.46	0.15
% of duodenal flow	71	70	68	68	1	0.84	0.19	0.98
Fecal N excretion, g/d	23	26	30	29	1	0.52	0.01	0.23
Apparent total tract N digestibility, %	85	86	85	86	1	0.55	0.87	0.99

[a]From Krehbiel et al., 2000.

corn silage diet consumed similar amounts of DM ($P = 0.56$), but greater ME ($P < 0.01$) than steers fed bromegrass hay during the growing period. Neither DM/gain nor ME/gain differed ($P = 0.41$) between MARC III and Brahman crossbred steers, but both were reduced ($P < 0.01$) in corn silage as compared to bromegrass-fed steers. No interactions between steer genotype and diet were observed ($P \geq 0.44$), suggesting diet differences resulted in similar responses in the *Bos taurus* and *Bos indicus* crossbred steers. Gross efficiency of utilization of diet DM and ME, regardless of diet, was similar in *Bos taurus* and *Bos indicus* crossbred steers during the 119 d growing period.

During the finishing period, daily DM intake and ADG was greater and days to finish was less for MARC III steers ($P < 0.04$) than for Brahman crossbred steers (Table 4), but feed-to-gain ratios (DM/gain or ME/gain) were similar ($P = 0.98$). Weight at the start of the finishing period was higher ($P < 0.01$), but ADG was lower ($P < 0.01$) for steers fed corn silage as compared to those fed bromegrass hay during the growing period, resulting in similar days to finish (168 vs. 170) for the two groups. Daily DM or ME intake of the high concentrate diet tended to be lower ($P = 0.11$), and feed conversion ratios were greater ($P < 0.01$) for steers that had been fed corn silage as compared to bromegrass hay during the growing period. No interactions between steer genotype and dietary treatment were observed ($P \geq 0.22$).

Neither carcass weight ($P = 0.35$) nor marbling score ($P = 0.42$) differed between MARC III and Brahman crossbred steers at slaughter (Table 5). Quality grade ($P = 0.12$), KPH fat percentage ($P = 0.09$), and longissimus muscle area ($P = 0.11$) tended to be less, but external fat thickness at the 12th rib was greater ($P = 0.04$) and yield grade tended to be greater ($P = 0.07$) for the Brahman cross steers. Carcass weight ($P < 0.01$), fat thickness at the 12th rib ($P =$

Table 3. Weight and performance of MARC III and Brahman crossbred steers when fed brome grass hay or a corn silage-based diet during the growing period

	Genotype		Diet, period 1			Probability		
Trait	MARC III	Brahman×	Hay	Silage	RSD	Type	Diet	T × D
Initial wt, lb	611	600	622	589	96	0.71	0.29	0.95
Ending wt, lb	802	761	717	849	119	0.29	0.01	0.90
ADG, lb/d	1.61	1.37	0.79	2.18	0.04	0.02	0.01	0.90
DM intake, lb/d	16.3	14.6	15.2	15.7	2.65	0.04	0.56	0.77
ME intake, Mcal/d	18.3	16.4	15.1	19.6	3.05	0.05	0.01	0.61
DM/gain, lb/lb	13.1	15.1	21.1	7.26	7.02	0.41	0.01	0.44
ME/gain, Mcal/lb	14.1	16.0	21.0	9.1	7.0	0.40	0.01	0.60

Table 4. Weight and performance of MARC III and Brahman crossbred steers during the finishing period after having been fed brome grass hay or a corn silage-based diet during the growing period

	Genotype		Growing period diet			Probability		
Trait	MARC III	Brahman×	Hay	Silage	RSD	Type	Diet	T × D
Starting wt, lb	802	761	717	849	119	0.29	0.01	0.90
Finish wt, lb	1,243	1,232	1,232	1,243	59	0.56	0.59	0.76
Days to finish	154	184	170	168	46	0.04	0.92	0.92
ADG, lb/d	2.91	2.60	3.15	2.38	0.37	0.01	0.01	0.71
DM intake, lb/d	18.7	16.8	18.5	17.0	2.8	0.04	0.11	0.24
ME intake, Mcal/d	26.1	23.5	25.8	23.8	3.92	0.04	0.11	0.24
DM/gain, lb/lb	6.57	6.56	5.93	7.20	1.02	0.98	0.01	0.22
ME/gain, Mcal/lb	9.16	9.16	8.30	10.07	1.43	0.98	0.01	0.22

Table 5. Carcass characteristics of MARC III and Brahman crossbred steers at harvest after having been fed bromegrass hay or a corn silage-based diet during the growing period

	Genotype		Growing period diet			Probability		
Trait	MARC III	Brahman×	Hay	Silage	RSD	Type	Diet	T × D
Carcass wt, lb	750	761	741	769	16.4	0.35	0.01	0.59
Marbling score[a]	469	442	476	435	105	0.42	0.36	0.51
Quality grade[b]	16.2	15.5	16.1	15.6	1.4	0.12	0.36	0.56
Adjusted fat, in	0.34	0.50	0.35	0.49	0.23	0.04	0.03	0.48
Longissimus, in^2	12.3	11.8	12.1	12.0	1.1	0.11	0.31	0.09
KPH fat, %	3.18	2.67	2.69	3.15	0.93	0.09	0.15	0.81
Yield grade	2.90	3.36	2.86	3.40	0.80	0.07	0.01	0.17

[a]Small = 400, modest = 500, etc.
[b]High select = 15, low choice = 16, etc.

0.03), and yield grade ($P < 0.01$) were greater in carcasses of steers fed corn silage than in those of steers fed brome grass hay during the growing period, but other carcass characteristics did not differ ($P \geq 0.15$). As with the growth and performance traits, dietary treatment × biological type interactions were not observed ($P \geq 0.09$). These observations suggest that the different diets (moderate quality forage, forage grain mixtures, and a high-concentrate diet) were utilized similarly by *Bos taurus* and *Bos indicus* crossbred steers and that compensatory responses during the finishing period of the two biological types of steers were similar.

Study 3. By design, ME intake (kcal/$kg^{0.75}$/d) of limit-fed steers was similar (Table 6) among the five sire breeds. Initial weights were greatest for Angus-sired steers, intermediate for Brahman- and Hereford-sired steers, and less for Boran- and Tuli-sired steers. Daily feed intake was similar, but ADG differed among sire breeds when steers were limit fed. When fed ad libitum, Boran- and Tuli-sired steers ate less feed and grew slower than Angus-, Brahman-, or Hereford-sired steers. Feed/gain, however, did not differ among sire breeds ($P = 0.21$).

Weights of most body organs differed among sire breeds and treatments (Table 7). The sire × treatment interaction was significant for only liver and lung weights. This result suggests that for most tissues, response to altered nutritional status was similar among sire breeds. In contrast, liver and lung weights responded differently among sire breeds to altered feed level. Liver and lung weight of Hereford-sired steers was low at low intake, but increased

Table 6. Initial weight, feed DM intake, and rate of gain of steers of diverse breeds fed limited amounts or ad libitum[a]

Treatment and sire breed	Initial wt, lb	Feed DM intake, lb/d	ME intake kcal/(kg$^{0.75}$/d)	ADG, lb/d	Feed/gain
Limit fed					
Angus	780	7.52	137	0.93	16.49
Boran	657	6.68	134	0.73	9.50
Brahman	690	6.97	137	0.66	11.75
Hereford	685	6.94	138	0.71	10.06
Tuli	666	6.78	141	0.44	23.52
Ad libitum					
Angus	796	18.14	290	2.87	6.65
Boran	637	12.72	233	2.25	5.78
Brahman	708	16.20	270	2.80	5.79
Hereford	717	16.73	280	2.78	6.01
Tuli	677	14.04	251	2.14	6.57
Probability					
Sire breed	0.001	0.002	0.08	0.001	0.21
Treatment	0.55	0.001	0.001	0.001	0.003
S × Trt	0.94	0.02	0.12	0.11	0.32
RSD	0.71	1.85	26.7	0.35	9.53

[a]From Ferrell and Jenkins, 1998b.

Table 7. Influence of treatment and sire breed on weights (lb) of selected organs and tissues of steers[a]

Treatment and sire breed	Liver	Stomach complex	Small intestine	Large intestine	Lung
Limit fed					
Angus	8.29	27.8	11.5	13.0	5.25
Boran	7.21	21.2	9.3	9.5	4.17
Brahman	7.58	20.1	9.9	9.9	4.34
Hereford	7.17	23.4	11.0	10.6	4.23
Tuli	6.86	20.1	9.3	8.8	3.92
Ad libitum					
Angus	13.96	33.1	15.4	18.5	4.85
Boran	10.03	23.4	11.0	12.3	4.41
Brahman	11.15	25.6	11.9	15.2	4.85
Hereford	13.43	31.7	14.3	15.4	5.25
Tuli	10.74	24.7	11.7	15.9	4.23
Probability					
Sire breed	0.001	0.001	0.001	0.001	0.001
Treatment	0.001	0.001	0.001	0.001	0.001
S × Trt	0.006	0.34	0.44	0.065	0.017
RSD	1.15	3.37	1.11	1.94	0.37

[a]From Ferrell and Jenkins, 1998b.

substantially in response to increased intake, suggesting those organs adapted to the nutritional environment. The magnitude of liver weight response to increased feed intake was less ($P < 0.05$) in Boran-, Brahman-, and Tuli-sired steers. The response of Angus-sired steers was intermediate. Similarly, lung weight increased 24% in Hereford-sired steers, 6%, 12%, and 8% in Boran-, Brahman-, and Tuli-sired steers, respectively, but decreased 5% in Angus-sired steers in response to increased feed intake.

Empty body weight, water, fat, protein, ash, and energy were greater ($P < 0.01$) at slaughter in ad libitum-fed than in limit-fed steers (Table 8). Empty body weight, water, fat, ash, and energy differed ($P < 0.01$) among sire breeds, but protein content of the empty body did not differ ($P = 0.18$). The sire × treatment interaction was nonsignificant ($P \geq 0.10$) for all empty body components.

Rate of gain of total empty body weight, fat, and energy (kcal/kg$^{0.75}$/d) were influenced by sire breed, dietary treatment, and the sire × treatment interaction (Table 9). When limit-fed, weight gain of all sire breeds was similar, but when fed ad libitum, Angus-, Brahman-, and Hereford-sired steers gained weight more rapidly than Boran- or Tuli-sired steers. When limit-fed, rates of fat and energy gain of Angus-sired steers were greater than those of Brahman- and Tuli-sired steers, with Hereford- and Boran-sired steers being intermediate. Ad libitum-fed Angus-, Brahman-, and Hereford-sired steers gained fat and energy at similar rates, and at higher rates than Boran- or Tuli-sired steers. Mean heat production, calculated as the difference between calculated ME intake and energy

Table 8. Influence of treatment and sire breed empty body chemical components in steers at slaughter[a]

	Empty body component, lb					
Treatment and sire breed	Weight	Water	Fat	Protein	Ash	Energy Mcal
Limit fed						
Angus	820	467	179	123	52.7	1,069
Boran	723	419	150	113	43.2	924
Brahman	739	441	137	117	46.3	872
Hereford	730	425	143	114	47.8	895
Tuli	686	403	130	110	42.5	826
Ad libitum						
Angus	1,098	553	335	157	53.8	1,827
Boran	913	483	249	138	45.0	1,409
Brahman	1,053	536	317	148	51.6	1,729
Hereford	1,045	536	306	152	52.9	1,687
Tuli	926	478	267	144	47.0	1,499
Probability						
Sire breed	0.001	0.003	0.01	0.18	0.001	0.01
Treatment	0.001	0.001	0.001	0.001	0.002	0.001
S × Trt	0.36	0.78	0.10	0.89	0.65	0.15
RSD	90	44	42	14.6	3.97	203

[a]From Ferrell and Jenkins, 1998b.

Table 9. Influence of treatment and sire breed on gain of empty body components and heat production relative to metabolic body size ($kg^{0.75}$) in steers[a]

	Empty body component gain, lb/d					
Treatment and sire breed	Weight	Water	Fat	Protein	Energy gain, kcal/ $kg^{0.75}$/d	Heat production, kcal/ $kg^{0.75}$/d
Limit fed						
Angus	1.22	0.66	0.37	0.123	23.0	113.9
Boran	1.15	0.73	0.19	0.159	17.0	117.2
Brahman	1.08	0.77	0.08	0.159	10.3	126.7
Hereford	1.03	0.57	0.27	0.128	19.6	118.3
Tuli	0.95	0.61	0.12	0.141	12.3	128.5
Ad libitum						
Angus	3.31	1.45	1.31	0.421	75.0	214.5
Boran	2.59	1.31	0.82	0.359	56.9	176.5
Brahman	3.22	1.38	1.36	0.370	79.0	190.8
Hereford	3.14	1.35	1.29	0.395	76.4	203.3
Tuli	2.61	1.13	1.06	0.374	68.2	182.8
Probability						
Sire breed	0.007	0.012	0.004	0.99	0.06	0.49
Treatment	0.001	0.001	0.001	0.001	0.001	0.001
S × Trt	0.043	0.54	0.007	0.63	0.02	0.20
RSD	0.36	0.23	0.22	0.082	11.1	24.6

[a]From Ferrell and Jenkins, 1998b

gain, was greater for steers fed ad libitum than for steers that were limit-fed, but did not differ with sire breed ($P = 0.49$) or sire × treatment interaction ($P = 0.20$).

Study 4. Fasted body weight increased with age, and the relationship between fasted body weight and age differed among breed types ($P < 0.01$), as did the relationship between heat production scaled for body weight and age ($P < 0.01$; Table 10). Heat production scaled for BW decreased in MARC III, ¼ Brahman, and ½ Brahman as heifers aged, but did not change significantly for ¾ Brahman heifers. Fasted body weight of pregnant heifers tended to differ with breed type ($P = 0.08$). Weights were 1,021 ± 97, 930 ± 68, 946 ± 44, and 946 ± 62 lb for MARC III, ¼ Brahman, ½ Brahman, and ¾ Brahman, respectively. Heat production of pregnant heifers scaled for BW (lb) did not differ among breed types and were 8.98 ± 1.0, 8.75 ± 0.6, 8.89 ± 1.3, and 9.25 ± 2.0, for MARC III, ¼ Brahman, ½ Brahman, and ¾ Brahman, respectively.

Table 10: Relation between body weight (kg) or fasting heat production (kcal/kg) to age (weeks) for heifers differing in proportion Brahman and MARC III[a]

Trait	Intercept ± SE	Slope ± SE	R^2
Body weight, lb			
MARC III	1.59 ± 45.15	14.64± 0.94	0.86
¼ Brahman	20.83 ± 26.65	13.27 ± 0.57	0.88
½ Brahman	54.52 ± 18.21	12.52 ± 0.40	0.97
¾ Brahman	71.80 ± 39.82	12.34 ± 0.88	0.86
Heat production kcal/lb			
MARC III	17.55 ± 0.73	0.121 ± 0.015	0.61
¼ Brahman	16.28 ± 0.50	0.096 ± 0.010	0.52
½ Brahman	15.24 ± 0.68	0.074 ± 0.015	0.47
¾ Brahman	13.33 ± 0.95	0.031 ± 0.021	0.06

[a]From Freetly et al., 2003.

Discussion

In the studies described above, in which individual feed intake was measured, ad libitum-fed crossbred steer calves of tropically adapted genotypes consumed about 12.8% less feed and grew about 11.7% slower than Angus-sired, Hereford-sired, or MARC III composite steers when averaged across studies. Efficiencies of feed conversion did not differ significantly among genotypes. In addition, where evaluation was possible (Study 2), no diet × genotype interactions were evident, suggesting the genotypes responded similarly on the different diets. Kappel et al. (1972) and Young et al. (1978) observed no significant differences in feedlot performance among Brahman-sired and Hereford- or Angus-sired steers. Results of other researchers indicated that when provided moderate to high-quality forage, forage plus concentrate, or high concentrate diets, *Bos indicus* steers consumed less feed (Frisch and Vercoe, 1977; Beaver et al., 1989; Huffman et al., 1990), gained slower (Carroll et al., 1955; Rogerson et al., 1968; Adams et al., 1982), but had similar feed conversion as *Bos taurus* types of cattle. Boyles and Riley (1991), among others, reached similar conclusions. Thus, results are relatively consistent across several studies and indicate lower intake, lower gain, but similar feed efficiency in tropically adapted genotypes as compared to *Bos taurus* genotypes developed in temperate regions when fed moderate to high-quality diets.

Improved digestibility of low-quality forage diets by *Bos indicus* as compared to *Bos taurus* cattle has been suggested (Moore et al., 1975). Those authors, as well as others, have, conversely, suggested that digestion of high-quality or high-grain diets is reduced in *Bos indicus* as compared to *Bos taurus* cattle. Results from our studies suggest that although site of digestion may differ among breeds (Krehbiel et al., 2000), total tract digestibility of a high-grain diet by *Bos indicus* and *Bos taurus* crossbreds was similar. These observations are supported by those of Colditz and Kellaway (1972) and Boyles and Riley (1991).

It has been reported that *Bos indicus* or other tropically adapted types have lower maintenance requirements, allowing them to perform as well or better in a nutritionally restrictive environment than *Bos taurus* cattle (Frisch and Vercoe, 1982; Solis et al., 1988; Hotovy et al., 1991). Visceral organs, especially the liver and digestive tract tissues, have high metabolic rates and are responsive to altered nutrient intake. Differences in weights of those tissues and changes in weight in response to altered nutritional status may help explain differences in maintenance requirements and nutrient utilization. In Study 3, weights of most organs differed among sire breeds and dietary treatments (Table 7). In general, organ weights were lower and were less responsive to ad libitum feeding in Boran-, Brahman-, and Tuli-sired steers than in Angus- and Hereford-sired steers. However, those responses were confounded by the lower ad libitum feed consumption of Boran- and Tuli-sired steers, especially. Further analyses (Ferrell and Jenkins, 1998b) suggested liver weight of Hereford-sired steers was low at low intake, but increased substantially (0.65 lb/lb DMI) in response to increased intake. The magnitude of liver weight response to increased feed intake was less in Boran-, Brahman-, and Tuli-sired steers and intermediate for Angus-sired steers. Similar patterns were observed for stomach complex weights. The pattern of these responses is similar to the response observed when heat production of Hereford and Simmental cows chronically adapted to different levels of intake was compared (Jenkins et al., 1991). These observations are consistent with lower maintenance requirements and better relative performance in nutritionally restrictive environments of the tropically adapted breeds and greater performance of the British types in a nonrestrictive nutritional environment. We speculate that Hereford-sired steers were more

responsive to altered nutrition than steers of the other sire groups.

When evaluated at similar slaughter weights (Study 2), Brahman × steers tended to have lower quality grade and longissimus area, but greater external fat thickness and yield grade than MARC III steers. Similar results were observed when ad libitum-fed Brahman- or Boran-sired steers were compared to Angus- or Hereford-sired steers in Study 3. These observations and consistent results from several other studies, such as that of Young et al. (1978), indicated carcass merit to be lower in *Bos indicus*- than in *Bos taurus*-sired steers. However, Tuli-sired steers had lower carcass weights, fat thickness, yield grade, and quality grade but similar longissimus area as compared to Angus- or Hereford-sired steers. Carcass merit of the various genotypes was discussed in detail by other speakers.

Total heat production (kcal/kg$^{0.75}$/d) was lower for Boran- and Tuli-sired steers, intermediate for Brahman- and Hereford-sired steers, and highest for Angus-sired steers (Table 9). Those differences paralleled ME intake (Table 6, kcal/kg$^{0.75}$/d). To evaluate whether the observed differences in heat production were caused by genotype per se or attributable to differences in intake, heat production was regressed on ME intake (Figure 1). Studies reported by Ferrell and Jenkins (1998a; 1998b) were combined for this analysis to provide a more robust test of the concept. No differences in intercept or slope were attributable to sire breed. Results suggested a single, nonlinear regression was applicable to steers of diverse genotypes and indicated observed differences in heat production among genotypes were linked to ME intake differences.

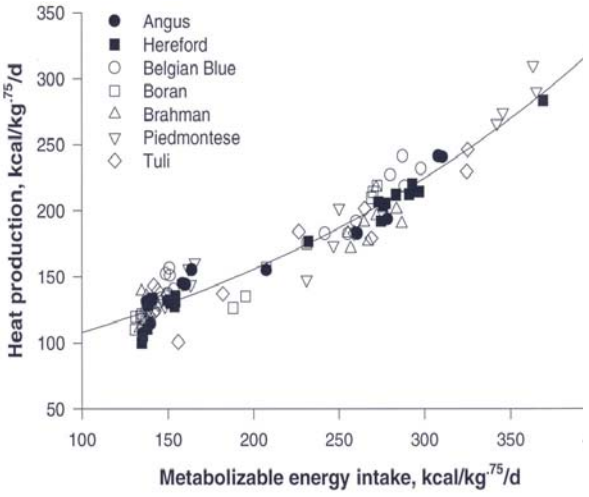


Figure 1. Relationship of heat production (HP) to metabolizable energy intake (MEI). HP = 74.9 e $^{0.00366\ MEI}$, R^2 = 0.99, n = 107; pooled data reported by Ferrell and Jenkins, 1998b.

Maintenance is defined as the ME intake at which heat production is equal to ME intake (or ME intake at which energy gain is zero). Thus, estimates of fasting heat production (74.9 kcal/kg$^{0.75}$/d) and maintenance (113.5 kcal/kg$^{0.75}$/d) appear to be equally applicable to the genotypes evaluated.

These results are consistent with those reported from Study 4 (Freetly et al., 2003). Those data indicated the relative ranking for fasting heat production in young heifers was highest for MARC III and decreased as the proportion of Brahman increased, but the rate of decrease with aging followed the same ranking. These patterns resulted in fasting heat production of the four genotypes being equal at 47 to 49 wk and resulted in a reversal in rank among genotypes in older heifers. By 86 wk of age, no differences in fasting heat production were observed. The study of Ferrell and Jenkins (1998b) was conducted with steers over an age interval of 36 to 56 wk of age, which centers on the period of rank reversal observed by Freetly et al. (2003).

Summary

Four studies were briefly reviewed to evaluate tropically adapted relative to breeds developed in temperate environments for feed utilization and energy requirements during growth. Findings were relatively consistent among studies and indicated crossbred steers sired by tropically adapted breeds (Brahman, Boran, Tuli) tended to consume less feed (13%), grow slower (11%), and have similar feed conversion as steers sired by Angus, Hereford, or MARC III bulls. Although some differences in site of digestion were observed among breeds, total tract digestibility of high-quality diets appears to be similar. Visceral organ weights and response of those organs to altered nutritional status differed among breeds. Those differences appear to be associated with differences in feed intake, total heat production, and perhaps to the animal's capacity to adapt to altered nutritional status. Differences in heat production among genotypes were observed, but they appear to be primarily associated with differences in feed intake. Fasting heat production and maintenance requirements appear to be similar among genotypes when evaluated in a good nutritional environment under temperate environmental conditions.

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Carcass and Meat Traits of Tropically Adapted Breeds Evaluated at the U.S. Meat Animal Research Center[1]

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ABSTRACT: Tropically adapted breeds from the United States, South America, and Africa have been evaluated at the U.S. Meat Animal Research Center. The breeds have included Brahman, Brangus, Beefmaster, Boran, Tuli, Bonsmara, Nellore, Sahiwal, and Romosinuano. Because tropical adaptation is necessary in some areas of the United States and because *Bos indicus* breeds produce less tender meat on average than *Bos taurus* breeds, we have evaluated these breeds in search of germplasm that could be incorporated into U.S. beef production to maintain the advantages of *Bos indicus* without detrimental effects on meat tenderness or other economically important traits. Relative to Hereford- and Angus-sired crosses (HA), progeny of Brahman, Beefmaster, and Brangus sires were similar in carcass weights, had slightly lower fat thickness, lower marbling scores, and similar ribeye areas, except Brangus had slightly larger ribeye areas. Brahman crosses had greater retail product yield, and Beefmaster and Brangus crosses were similar to HA crosses. Brahman and Beefmaster progeny had less tender ribeye than HA crosses and Brangus progeny had a tendency to be slightly less tender. Compared to HA crosses, Sahiwal and Nellore progeny were similar in carcass weights, had lower fat thickness, higher retail product yields, lower marbling scores, and much less tender ribeye. Relative to HA crosses, Tuli and Boran progeny had lighter carcass weights, with similar ribeye areas and retail product yields. Tuli had lower fat thickness but similar marbling scores; Boran had similar fat thickness and lower marbling scores compared to HA crosses. Tuli crosses had similar and Boran crosses had lower ribeye tenderness than HA crosses. Bonsmara and Romosinuano crosses had lighter carcass weights, lower fat thickness, slightly larger ribeye areas, greater retail product yields, lower marbling scores, and similar ribeye tenderness relative to HA crosses. There is as much variation in tenderness within breeds as there is between the least and most tender breeds. There is no interaction between marbling score or postmortem aging time, and species (*Bos taurus* and *Bos indicus*) for tenderness. Elevated 24-h postmortem calpastatin activity is responsible for reduced proteolysis, and thus, reduced tenderness in ribeye from cattle of *Bos indicus* origins, but not all muscles are affected. This project has identified three sources of tropically adapted germplasm (Tuli, Bonsmara, and Romosinuano) that do not compromise ribeye tenderness, but have the disadvantage of slower growth rate.

KEY WORDS: Beef, Breeds, Carcass, Palatability, Quality, Tenderness

Introduction

By the 1970s, the advantages of tropically adapted *Bos indicus* beef breeds for use in crossbreeding programs in subtropical and tropical climates were well established (Carroll et al., 1955; Cole et al., 1963; Crockett et al., 1979). Even in temperate climates, *Bos indicus* × *Bos taurus* cows had outstanding performance (Cundiff et al., 1986a,b); however, by the mid-1980s numerous studies had evidence that *Bos indicus* breeds produced less tender meat than *Bos taurus* breeds (e.g., Ramsey et al., 1963; Koch et al., 1982; McKeith et al., 1985; Crouse et al., 1987). Then a definitive study by Crouse et al. (1989) showed that, as the percentage of *Bos indicus* (either Brahman or Sahiwal) increased, meat tenderness declined (Figure 1). Conclusive evidence that on average *Bos indicus* breeds produced less tender meat convinced Roman L. Hruska, U.S. Meat Animal Research Center (**MARC**) scientist, to search for alternative sources of tropically adapted

[1]Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

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germplasm and to determine the biological basis for the reduced tenderness of meat from *Bos indicus* breeds.

In the eight cycles of the beef Germplasm Evaluation (**GPE**) program at MARC, nine tropically adapted breeds have been evaluated (Brahman, Brangus, Beefmaster, Boran, Tuli, Bonsmara, Nellore, Sahiwal, and Romosinuano). Carcass and longissimus palatability traits of these breeds have been reported by Koch et al. (1982) and Wheeler et al. (1996, 2001, 2005b). The objective of this paper is to review the carcass and meat traits of tropically adapted breeds evaluated at MARC and the biological basis for the reduced tenderness of meat from some of these breeds. Because there are differences in the way some traits were measured in different cycles over time (despite efforts to maintain a standard protocol for as many traits as possible), tropically adapted breeds were compared to Hereford- and Angus-sired crosses (HA) within the cycle in which they were evaluated. Dam breeds used in each cycle were as follows: Cycle III, Hereford and Angus; Cycle IV, Hereford and Angus; Cycle V, Hereford, Angus, and MARC III composite; and Cycle VIII, Angus and MARC III. No purebred Hereford or Angus were used in these comparisons.

Carcass Traits

In cycle III, Brahman-sired steers had heavier carcasses than did HA steers, which had heavier carcasses than Sahiwal-sired steers (Table 1). In cycle IV, Nellore carcasses were similar in weight to HA carcasses. In cycle V, HA carcasses were heaviest, followed by Brahman, with Tuli and Boran carcasses the lightest. In cycle VIII, Beefmaster, Brangus, and HA had the heaviest carcasses and Bonsmara and Romosinuano the lightest carcasses. Dressing percentage tended to be higher for tropically adapted breeds than for HA, but this difference was not always significant. Adjusted fat thickness was lower for all tropically adapted breeds relative to HA, except for Beefmaster in cycle VIII. In cycles III, IV, and V, ribeye areas were similar among HA and tropically adapted breeds. However, in cycle VIII, Brangus and Bonsmara had larger ribeye areas than HA or Beefmaster. All tropically adapted breeds except Brahman and Beefmaster had lower USDA yield grades than HA. All tropically adapted breeds except Tuli had lower USDA marbling scores than did HA.

Retail product yield as a percentage of the carcass was higher for Brahman, Sahiwal, Nellore, Bonsmara, and Romosinuano than for HA (Table 2). Trimmable fat as a percentage of the carcass was lower for Brahman (cycle III but not cycle V), Sahiwal, Nellore, Brangus, Bonsmara, and Romosinuano than for HA. The percentage of the carcass as bone was lower for Tuli and Boran and higher for Brangus and Romosinuano, compared to HA.

Table 1. Comparison of carcass traits among F_1 progeny of tropically-adapted breeds relative to Hereford- and Angus-sired crosses (HA)

Breed	HCWT	DP	AFT	REA	YG	MARB
Cycle III						
H	653^{b}	63.5^{b}	0.63^{a}	10.7	3.8^{a}	Sm50^{a}
Brahman	679^{a}	64.5^{a}	0.55^{b}	10.9	3.7^{a}	Sl80^{b}
Sahiwal	628^{c}	63.9^{ab}	0.55^{b}	10.7	3.5^{b}	Sl90^{b}
Cycle IV						
H	745	62.2^{b}	0.59^{a}	11.3	3.8^{a}	Sm28^{a}
Nellore	739	64.3^{a}	0.47^{b}	11.4	3.5^{b}	Sl90^{b}
Cycle V						
H	769^{a}	59.4^{b}	0.47^{a}	11.6	3.5^{a}	Sm38^{a}
Brahman	732^{b}	60.5^{a}	0.39^{b}	11.3	3.3^{ab}	Sl73^{c}
Tuli	679^{c}	60.2^{a}	0.39^{b}	11.4	3.0^{c}	Sm24^{a}
Boran	683^{c}	60.4^{a}	0.43^{ab}	11.5	3.1^{bc}	Sm03^{b}
Cycle VIII						
H	770^{b}	60.9^{c}	0.48^{a}	12.5^{b}	3.0^{a}	Sm31^{a}
Beefmaster	789^{a}	60.8^{c}	0.48^{a}	12.5^{b}	3.1^{a}	Sl83^{b}
Brangus	774^{ab}	61.6^{a}	0.39^{b}	13.0^{a}	2.7^{b}	Sl97^{b}
Bonsmara	729^{c}	61.5^{ab}	0.36^{bc}	13.1^{a}	2.4^{c}	Sl87^{b}
Romosinuano	702^{d}	61.0^{bc}	0.31^{c}	12.7^{ab}	2.3^{c}	Sl88^{b}

HCWT = Hot carcass weight.
DP = Dressing percentage.
AFT = Adjusted fat thickness.
REA = Ribeye area.
YG = USDA yield grade.
MARB = Marbing score; Sm = Small, Sl = Slight.
^{abcd}Means within a trait and cycle lacking a common superscript differ ($P < 0.05$).

Longissimus Palatability Traits

Ribeye steak tenderness as measured by Warner-Bratzler shear force or trained sensory panel tenderness rating was generally lower for progeny with 25% or more of *Bos indicus* breeding (Tables 3 and 4). In cycle III, Sahiwal was least tender, then Brahman, and HA was most tender based on Warner-Bratzler shear force and tenderness rating. In cycle IV, Nellore was less tender than HA according to both measures of tenderness. In cycle V, Brahman was least tender followed by Boran, then Tuli, and HA had the highest tenderness rating. However, for Warner-Bratzler shear force Brahman was least tender, Boran

Table 2. Comparison of carcass retail product yield traits among F_1 progeny of tropically adapted breeds relative to Hereford- and Angus-sired crosses (HA)

Breed	RPY, %	Fat, %	Bone, %
Cycle III			
H	65.8[b]	22.2[a]	12.0
Brahman	68.9[a]	18.5[b]	12.6
Sahiwal	68.6[a]	19.0[b]	12.4
Cycle IV			
H	60.2[b]	26.4[a]	13.4
Nellore	63.2[a]	23.4[b]	13.5
Cycle V			
H	62.0[b]	23.6[ab]	14.4[a]
Brahman	63.9[a]	21.7[b]	14.4[a]
Tuli	63.4[ab]	22.7[ab]	13.8[b]
Boran	62.6[ab]	23.9[a]	13.5[b]
Cycle VIII			
H	61.0[b]	25.9[a]	14.2[bc]
Beefmaster	61.3[b]	25.5[ab]	14.5[ab]
Brangus	62.1[b]	24.3[bc]	14.6[a]
Bonsmara	63.5[a]	23.8[c]	14.1[c]
Romosinuano	64.4[a]	22.0[d]	14.7[a]

RPY = Retail product yield as percentage of carcass weight; 0.3 inch fat trim endpoint for Cycle III; 0.0 inch fat trim endpoint for Cycles IV, V, and VIII.

Fat = fat trim as a percentage of carcass weight.

Bone as a percentage of carcass weight.

[abcd]Means within a trait and cycle lacking a common superscript differ ($P < 0.05$).

Table 3. Comparison of ribeye palatability traits among F_1 progeny of tropically adapted breeds relative to Hereford- and Angus-sired crosses (HA)

Breed	Tenderness	Juiciness	Beef flavor
Cycle III	day 7	day 7	day 7
HA	7.1[a]	7.2	7.1
Brahman	6.2[b]	6.9	7.0
Sahiwal	5.6[c]	6.9	6.9
Cycle IV	day 7	day 7	day 7
HA	4.7[a]	5.1[a]	4.8
Nellore	4.0[b]	4.8[b]	4.7
Cycle V	day 7	day 7	day 7
HA	5.4[a]	5.3[a]	4.9
Brahman	4.0[d]	4.8[c]	4.8
Tuli	5.0[b]	5.2[a]	4.9
Boran	4.5[c]	5.0[b]	4.8
Cycle VIII	day 14	day 14	day 14
HA	5.8[a]	5.6	4.6
Beefmaster	5.7[b]	5.5	4.6
Brangus	5.7[ab]	5.5	4.5
Bonsmara	5.9[a]	5.5	4.6
Romosinuano	5.8[ab]	5.5	4.5

[abcd]Means within a trait and cycle lacking a common superscript differ ($P < 0.05$).

Table 4. Mean and variation in ribeye Warner-Bratzler shear force among F_1 progeny of tropically adapted breeds relative to Hereford- and Angus-sired crosses (HA)

Breed	WBS, lb	Minimum	Maximum	% > X lb
Cycle III	day 7			% >11 lb
HA	7.5[c]	4.9	10.8	0
Brahman	8.6[b]	4.6	17.0	17
Sahiwal	9.5[a]	5.4	16.7	18
Cycle IV	day 7			% >13 lb
H	12.3[b]	5.5	24.7	30
Nellore	15.9[a]	7.1	24.3	74
Cycle V	day 14			% >13 lb
HA	9.7[d]	5.1	20.3	8
Brahman	13.2[a]	5.3	18.3	34
Tuli	10.1[cd]	6.2	24.9	8
Boran	11.3[bc]	5.7	18.5	26
Cycle VIII	day 14			% >11 lb
HA	7.8[c]	5.5	13.7	3
Beefmaster	9.0[a]	6.0	18.5	12
Brangus	8.6[ab]	5.7	13.4	7
Bonsmara	8.1[bc]	5.5	13.0	6
Romosinuano	8.3[bc]	5.1	13.2	7

[abcd]Means within a trait and cycle lacking a common superscript differ ($P < 0.05$).

Table 5. Effects of proportion of *Bos indicus* (Sahiwal) on tenderness and calpain system traits.

Trait	Hereford Angus	3/8 Sahiwal	5/8 Sahiwal
Warner-Bratzler shear force, lb	10.4[c]	14.1[b]	17.0[a]
Tenderness rating	5.9[a]	5.0[b]	4.4[c]
μ-calpain, 24 h	0.4	0.6	0.5
m-calpain, 24 h	1.1	1.2	1.1
Calpastatin activity, 24 h	1.4[b]	2.0[a]	2.2[a]

Adapted from Whipple et al. (1990).
[abc]Means within a trait lacking a common superscript differ ($P < 0.05$).

Table 6. Effects of *Bos indicus* (Brahman) on tenderness and calpain system traits.

Trait	Hereford Angus	5/8 Brahman
Warner-Bratzler shear force, lb	9.9[c]	11.9[a]
μ-calpain, 24 h	0.5	0.7
m-calpain, 24 h	1.1	1.2
Calpastatin activity, 24 h	1.8[b]	2.5[a]

Adapted from Shackelford et al. (1991).
[abc]Means within a trait lacking a common superscript differ ($P < 0.05$).

was intermediate, and Tuli was similar in tenderness to HA. In cycle VIII, for tenderness rating Beefmaster was less tender than HA. Beefmaster and Brangus had the highest shear force, and Bonsmara and Romosinuano were similar in shear force to HA. Juiciness ratings usually were not different between HA and tropically adapted breeds except for Nellore in cycle IV and Brahman and Boran in cycle V. Because the only time juiciness ratings were lower was when tenderness was lower, it is likely these differences in juiciness reflect the tendency for autocorrelation among sensory traits rather than real differences in juiciness of ribeye steaks. Beef flavor intensity ratings were not different between HA and tropically adapted breeds.

The difference in tenderness between Brahman and HA is apparent by 1 d postmortem (Figure 2). There is no interaction between postmortem aging and species. The rate of tenderness improvement with aging from 1 to 14 d postmortem is about the same. Even after aging 14 d, the tenderness difference still exists. For most meat, tenderization is virtually complete by 14 d postmortem; however, meat that is still tough at 14 d postmortem may continue to improve in tenderness with additional aging time. Furthermore, there is no interaction between marbling score and species (Figure 3). The small effects of marbling score on longissimus tenderness do not differ between *Bos indicus* and *Bos Taurus,* and the lower average tenderness of *Bos indicus* cannot be offset by increased marbling (Wheeler et al., 1994).

The GPE project at MARC has determined that, on average, some breeds of cattle produce more tender meat and some produce less tender meat relative to other breeds (Koch et al., 1976, 1979, 1982; Wheeler et al., 1996, 2001, 2004, 2005a,b). It is well documented that the mean shear force of ribeye and variation in shear force increases as the percentage of *Bos indicus* inheritance increases (Crouse et al., 1989). Furthermore, meat from 25 to 50% or greater *Bos indicus* (Brahman, Nellore, Sahiwal) cattle is usually significantly less tender than meat from cattle with less than 25 to 50% *Bos indicus*. On the other hand, several breeds (Jersey, Pinzgauer, South Devon, Red Poll, and Piedmontese) tend to produce meat that is more tender than meat from other breeds. But, on average, most breeds are fairly similar in meat tenderness; however, there is more variation in tenderness within each breed than among the most different breeds (Table 4; Figure 4). Figure 4A indicates the amount of change that could be expected in shear force by substituting Angus for Brahman purebred cattle (6.45 genetic standard deviations) relative to the within-breed variation (six genetic standard deviations). For F_1 progeny, this same comparison results in 3.23 genetic standard deviations between Angus- and Brahman-sired progeny (Figure 4B), although only 1.56 phenotypic standard deviations are realized among Angus- and Brahman-sired progeny (Figure 4C). Thus, the realized improvement in tenderness from substituting one breed for another will be small (at most 3.4 lb; to change from half-blood Brahman to half-blood Angus). To make additional improvement within a breed requires identifying those sires (and dams) whose progeny produce more tender meat, either through progeny testing or some direct measure on the sire and dam to predict the tenderness of their progeny.

Basis for Tenderness Variation

It is well established that variation in postmortem proteolysis during meat aging is primarily responsible for variation in ribeye tenderness after 14 d or more of aging (Koohmaraie et al., 1996). It also has been established that the calpain enzyme system is responsible for this proteolysis and that the inhibitor of the calpains, calpastatin, is a primary regulator of this process. Variation in calpastatin activity at 24 h postmortem has been shown to explain more of the variation in tenderness than any other single trait (Figure 5). Furthermore, the decreased meat

tenderness in ribeye of *Bos indicus* cattle has been shown to be due to increased calpastatin activity at 24

h postmortem (Tables 5 and 6; Whipple et al., 1990; Shackelford et al., 1991). However, not all muscles from *Bos indicus* cattle are decreased in meat tenderness. We have shown that three factors (postmortem proteolysis, muscle shortening during rigor development, and collagen concentration) can explain a large portion of the variation in tenderness (Wheeler et al., 2000, Rhee et al., 2004). However, the relative importance of each of these three factors varies among muscles. For example, tenderness of muscles from the round that are higher in collagen (connective tissue) is less influenced by the extent of proteolysis than other muscles that are lower in connective tissue. Likewise, muscles that are stretched as they go into rigor will be more tender regardless of proteolysis or collagen concentration. Thus, the tenderness of any given muscle is determined by the interaction of these three factors. This explains why not all muscles from *Bos indicus* cattle are affected to the same extent by reduced proteolysis resulting from increased calpastatin activity. In fact, only longissimus (ribeye), triceps brachii (shoulder clod), supraspinatus (mock tender), biceps femoris (bottom round), and quadraceps femoris (knuckle) are significantly less tender in *Bos indicus* cattle (Figure 6; Shackelford et al., 1995). It is possible that with improvements in tenderness measurement of various muscles, more of them would be different between *Bos taurus* and *Bos indicus*, but clearly the ribeye is most affected by calpastatin differences between *Bos taurus* and *Bos indicus*.

Conclusions

Tropically adapted breeds have various trade-offs in carcass traits relative to HA crosses. However, tropically adapted breeds with *Bos indicus* origins are on average less tender than HA crosses when *Bos indicus* breeding is 25% or greater. The biological basis for this difference in tenderness has been identified as reduced tenderization during postmortem aging due to inhibited calpain activity by elevated activity of calpastatin. One of the major objectives of the GPE project is to identify tropically adapted germplasm that does not have detrimental effects on meat tenderness. Toward this goal, three breeds (Tuli, Bonsmara, and Romosinuano) have been shown to have ribeye tenderness similar to HA crosses. The major disadvantage of these breeds is that they have not been subjected to the degree of selection for growth rate that breeds in the United States have been, thus, they are much smaller. This problem makes it less likely that widespread use of these breeds will occur unless 1) greater economic incentives for improved meat tenderness can offset the cost of reduced size, or

2) crossbreeding plans include use of larger than optimum animals to complement the smaller size of these three breeds and optimize the size of the progeny.

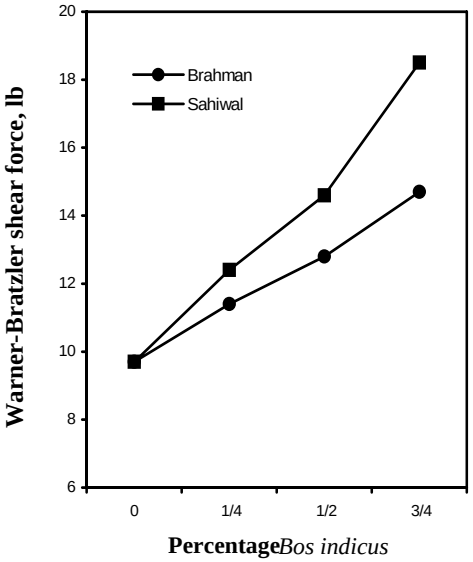


Figure 1. Effect of percentage *Bos indicus* on Warner-Bratzler shear force in Brahman and Sahiwal ribeye steaks after 7 d postmortem aging. Adapted from Crouse et al. (1989).

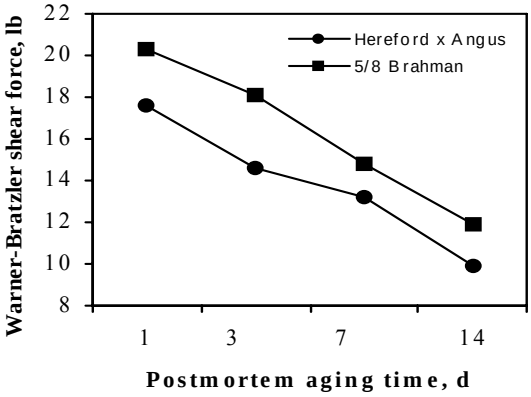


Figure 2. Effect of postmortem aging time on Warner-Bratzler shear force of longissimus from Hereford Angus or 5/8 Brahman crosses. Adapted from Shackelford et al. (1991).

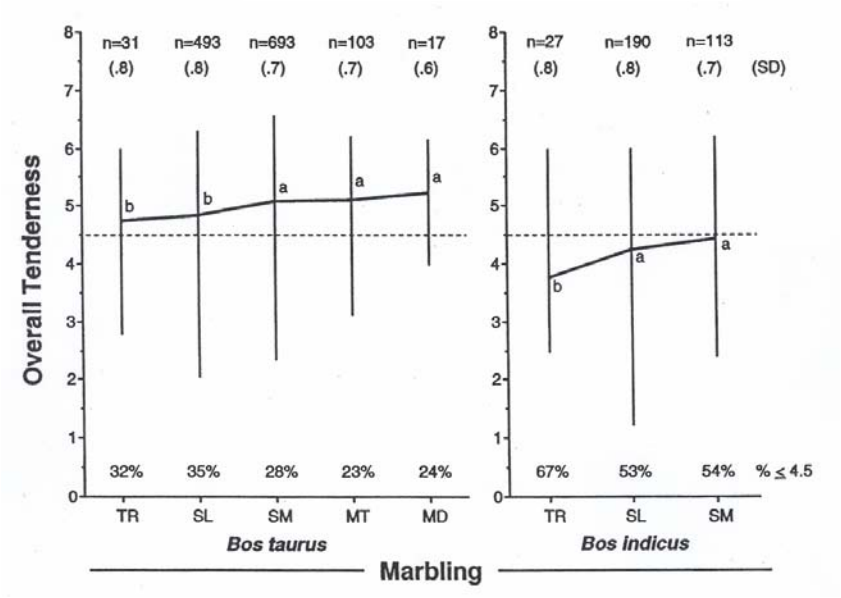


Figure 3. Sensory tenderness rating by species and marbling score for ribeye steaks aged 7 d. The thickest line connects the means for each marbling score. The vertical lines show the range in tenderness rating for each marbling score. The numbers at the top are the number of carcasses with each marbling score. The numbers in parentheses are standard deviations for each marbling score. The percentages at the bottom represent the percentage of carcasses with tenderness rating ≤ 4.5 (slightly tough). Means lacking a common superscript within species differ ($P < 0.05$). Adapted from Wheeler et al. (1994).

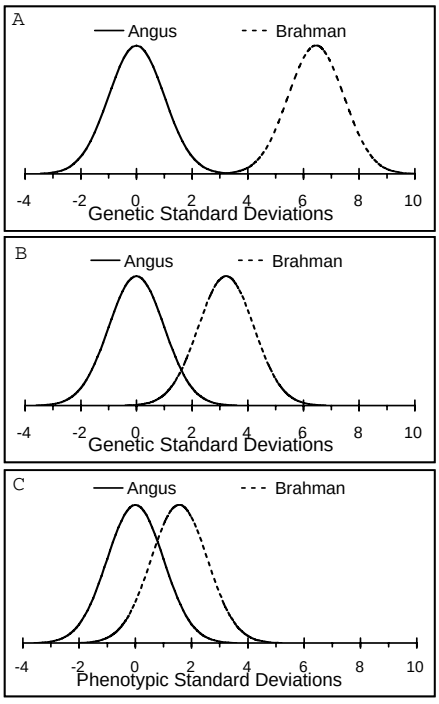


Figure 4. Genetic and phenotypic variation among and within sire breeds for Warner-Bratzler shear force at 14 d postmortem. Curves for Angus and Brahman from cycle V. Angus was set to zero. Differences are expressed in standard deviation units as deviations from Angus. A) Potential genetic variation among and within purebred progeny was obtained by doubling the differences in F_1 progeny. B) Genetic variation among and within sire breeds of F_1 progeny. C) Phenotypic variation among and within sire breeds of F_1 progeny. Adapted from Wheeler et al. (2001).

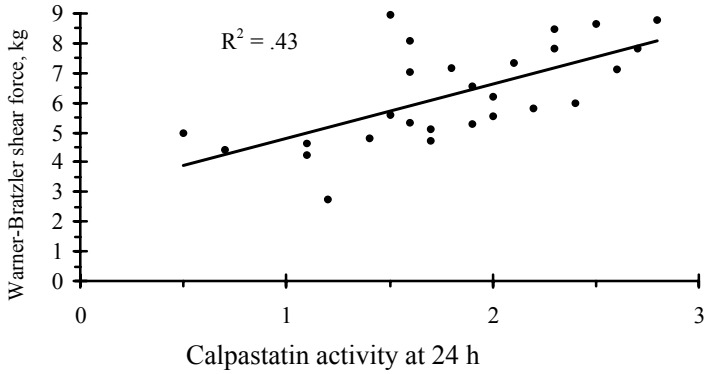


Figure 5. Relationship between calpastatin activity at 24 h postmortem and shear force at 14 d postmortem. Adapted from Whipple et al. (1990).

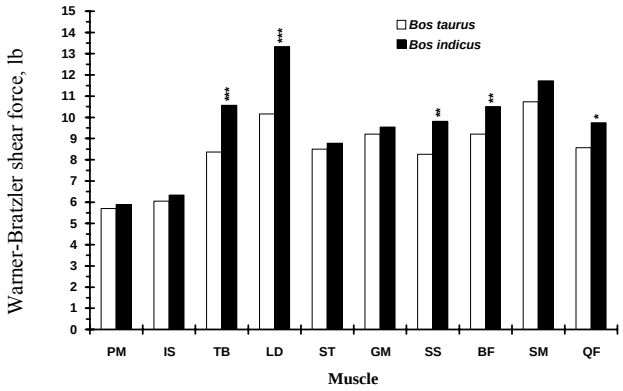


Figure 6. Interaction of species and muscle on Warner-Bratzler shear force of steaks at 14 d postmortem. Muscle names are abbreviated as follows: PM = psoas major; IS = infraspinatus; TB = triceps brachii; LD = longissimus; ST = semitendinosus; GM = gluteus medius; SS = supraspinatus; BF = biceps femoris; SM = semimembranosus; QF = quadriceps femoris. Asterisks indicate significance level for comparison of species within each muscle. **P* < 0.05; ***P* < 0.01; ****P* < 0.001. Adapted from Shackelford et al. (1995).

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Efficiency of Feed Utilization During the Preweaning Period Among Tropically Adapted Cattle

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ABSTRACT: Productivity of mature F_1 cows from tropically adapted sire breeds produced by mating Angus and Hereford, Brahman (Cycle III and V), and Sahiwal (Cycle III), Nellore (Cycle IV), and Boran and Tuli (Cycle V) sires by AI or natural service to Angus and Hereford cows (AH) was measured. Comparisons were relative to Angus/Hereford F_1. Daily milk yields were recorded via weigh-suckle-weigh. Brahman and Sahiwal F_1 cows produced significantly more total lactation yield (TY), weight of calf weaned (WCW), and were more efficient (Eff, weight calf weaned/feed consumed by cow). These breed crosses exhibited 15.2% and 11.8% more TY, 18.8% and 13.1% more WCW, and were 3.8% and 7.2% more Eff relative to AH cows (1,764 lb, 440 lb, 38.5 Eff). In Cycle IV, Nellore TY and WCW were greater ($P < 0.05$). Nellore crosses produced 4.8% more TY, 20% more WCW, and were 14.2% more Eff at DMI for maximum weaning weight than AH (1,732 lb, 298 lb, 28 Eff). Cycle V mean TY for Brahman was greater ($P < 0.05$) than Tuli, but neither differed ($P > 0.10$) from AH or Boran cross cows. Relative to AH (3,709 lb), Brahman, Boran, and Tuli produced 6.9% and 1.9% more and 9.1% less TY, respectively. WCW of Brahman and Boran was greater ($P < 0.05$) than Tuli or AH, which did not differ ($P > 0.10$). Brahman, Boran, and Tuli produced 25.0%, 19.2%, and 4.2% more WCW than AH (372 lb). Brahman and Boran Eff exceeded ($P < 0.05$) Tuli, which was greater ($P < 0.05$) than AH. Relative to Angus/Hereford (72.6), Brahman, Boran, and Tuli F_1s were 45%, 35%, and 15%; respectively, more Eff. F_1 cows from tropically adapted sire breeds mated to non-adapted sires were more effective in converting food resources to weight of calf at weaning during the preweaning period during spring and summer in a temperate climate.

KEY WORDS: Lactation, Preweaning, Weaning Weight

Introduction

The interaction between genetic potential for production and food energy availability contribute to variation in the efficiency of production in beef cattle. A series of multidisciplinary studies conducted at the Meat Animal Research Center in south central Nebraska using mature cows from the Germ Plasm Evaluation program has characterized production efficiency of diverse breeds of cattle in varying food energy environments.

Inability to cycle and conceive contributed to reduced production efficiency at low feed availabilities for breeds with higher genetic potential for growth and milk production; lower genetic potential for these characteristics reduced efficiency when food energy was not limiting (Jenkins and Ferrell, 1994). Research addressing the preweaning period has demonstrated variation among cows representing diverse biological types in converting feed resources to weight at weaning. These differences have been associated with mature size and lactation potential (Jenkins et al., 1986), and these differences are associated with rankings for effectiveness of converting feed to weight at calf at weaning for cows fed at varying rates of daily intake during the preweaning period (Jenkins et al., 1991, Jenkins et al., 2000; Jenkins and Ferrell, 2004). It has previously been demonstrated that breeds and breed crosses vary in feed required for maintaining weight or energy stasis (Jenkins and Ferrell, 1993; Ferrell and Jenkins, 1985; Montano-Bermudez et al., 1990). Green et al. (1991) reported differences among diverse breed crosses for efficiency during a defined segment of the preweaning period when cows received rations sufficient to maintain maternal body weight.

Sires from tropically adapted breeds were included as sire breeds in Cycles III, IV, and V of

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GPE. This report compares the traits that contribute to a ratio of output/input that characterizes the effectiveness of converting feed resources to calf weight for these sire breed of cow groups relative to Angus/Hereford within each of the cycles.

Materials and Methods

Animals. Mature F_1 cows (7-12 yr of age) were sampled from the population of cows produced in Cycle III, IV, and V of the Germ Plasm Evaluation Project. Angus and Hereford dams were mated by AI or natural service to Angus, Hereford, Brahman, Sahiwal, Pinzgauer (Cycle III), Longhorn, Piedmontese, Charolais, Salers, Galloway, Nellore, Shorthorn (Cycle IV), Brahman, Boran, or Tuli sires (Cycle V). Cows from each sire of cow breed group (SBC) within the respective cycles that were determined pregnant by rectal palpation at fall were identified for sampled for use in each study. Numbers of cow/calf pairs within each sire of cow breed group in the efficiency studies were 34-36 for Cycle III; 41 Angus/Hereford, and 20-22 for other sire of cow groups in Cycle IV, and 24-35 within Cycle V. Calves for the study were produced from matings to Charolais (Cycle III and Cycle V) or Simmental (Cycle IV) sires.

All cows assigned to the evaluation were calved on pasture. Cows from Cycle III were calved from late March through mid-May and were transported to the test facility in late May. Average age of calf upon arrival was approximately 49 d. Cows from Cycle IV and Cycle V calved from late February through mid-May. Cow/calf pairs were transported to the test facility when calves were 6-9 d of age. All male calves were castrated at birth. Average age at end of test was 175 d, 170 and 200 d for Cycles III, IV, and V, respectively.

Nutritional Management. Cows from Cycle III cows were group fed in replicated pens within each sire of cow breed group (3 pens/ SBC). Cows were fed a corn silage-ground brome hay diet with protein supplement for 126 d at a rate that was sufficient for lactation with zero cow weight change. Pen feed intake was adjusted every 2 wk to meet this objective. Calves were allowed creep access.

Cows from Cycle IV and Cycle V cows were randomly assigned to pens in open front barns within SBC. Each pen was equipped with four electronic head gates (American Calan, Northwood, NH), and each pen housed four cow/calf pairs. A diet of corn silage/alfalfa haylege (2.44 Mcal/ kg dry matter) was presented at one of three feeding rates, 140, 180, or 240 kcal ME/weight$^{.75}$ for Cycle IV cows. Cows from Cycle V cows received a diet of corn silage with soybean meal supplement (2.60 Mcal/ kg dry matter) at a daily rate of 132, or 189 kcal ME/weight$^{.75}$ or ad libitum. Feeding rate and SBC were confounded with pen to minimize the possible effect of cross-nursing. During the testing period, calves received limited creep feed (4-6 lb/wk) after the oldest calf within a pen reached 110 d of age.

Data collection. Weights, heights, and BCS (1-9) (except Cycle V) of cows were recorded at time of entry into test facilities. Cow BW were recorded weekly for cows from Cycle III and monthly for cows from the other two cycles. Daily feed presentation and weekly feed weigh backs were recorded for studies on cows from Cycles IV and V. Daily pen feed presentations were recorded in Cycle III. Weights of calves at the end of the testing period were collected for each cycle.

To estimate milk production, weigh-suckle-weigh measurements were recorded. Calves were separated from the dams for a 12- (Cycle III) or 18-h (Cycles IV and V) period preceding the measurement. The differences between pre- and post-nursing calf weights were recorded as milk production measurements. Measurements on cows from Cycle III were made at an average of 58, 85, 125, and 160 d post partum and from the other two cycles at approximately 14, 28, 56, 84, 112, 140, 168 (Cycle IV), and 196 d (Cycle V) post partum.

Weigh-suckle-weigh measurements were used to estimate lactation curve parameters for the prediction of time of peak lactation, peak milk yield at time of peak lactation, total milk yield for the lactation (Jenkins and Ferrell, 1992).

Efficiency was defined as calf weight gain during the 126-d test period /Mcal ME consumed by the cow Cycle III, adjusted 170-d weaning weight/Mcal ME consumed during 170-d feeding interval at a rate of 29 Mcal ME/d (Cycle IV), and adjusted weaning weight/Mcal ME consumed over 200 d preweaning period (Cycle V). Analyses of covariance (Steel and Torrie, 1960) were used to partition variation affecting traits of interest in the 3 cycles. In Cycle III and Cycle V, linear contrasts were used to compare tropically adapted vs. Angus/Hereford. Covariates of daily ME intake, linear and quadratic terms, were included in analyses in Cycle IV. Response variables included the lactation traits of peak yield, total yield, and measures of calf growth.

Results

Cow traits. Significant differences were observed for many of the contrasts between F_1 cows from tropically adapted sire breeds relative to Angus/Hereford cow in each of the 3 cycles for cow

attributes. In Cycle III, Brahman cross cows were about 7% heavier ($P < 0.05$) and 6% taller at the hip than the Angus/Hereford cows (1,212 lb and 49.6 in, respectively), which did not differ ($P > 0.10$) from the Sahiwal-sired cows at the start of the testing interval. Cows produced from matings with tropically adapted sire breeds had a similar BCS relative to the Angus/Hereford (Table 1). In Cycle IV, on test weight of Angus/Hereford cows

Table 1. Traits of mature F_1 cows relative to Angus/Hereford F_1 cows (%)

	Breedcross[a]			
Trait	Angus/ Hereford	BraX	SahX	PinX
Cow weight, lb	1212	106	98	101
Cow height, in	49.6	106	106	103
BCS[a]	7.2	102	103	97

[a]BraX = Brahman, SahX = PinX = Pinzgauer.
[b] Body Condition Score nine point scale

(1,297 lb) was 4% and 6% higher than Nellore and Longhorn crossbred cows. Nellore F_1 cows were about 5% taller at the hips than Angus/Hereford (51.8 in) and Longhorn F_1 cows (Table 2). On test weights of Angus/Hereford (1,372 lb) cows were 4%, 13%, and 12% greater than the F_1 cows from tropically adapted breeds of Brahman, Boran, and Tuli in Cycle V (Table 3). Height at the hips of the Angus/Hereford (53.0 in) and BCS (6.0) did not differ from the other breed crosses. Body condition score of the tropically adapted breed crosses tended to be similar to the body condition scores of the Angus/Hereford (6.0) on a 1-9 scale.

Table 2. Traits of mature F_1 cows relative to Angus/Hereford F_1 cows (%)

	Breedcross[a]					
Trait	Angus/ Hereford	NelX	LonX	ShoX	GalX	SalX
Cow weight, lb	1,297	96	94	117	98	110
Cow height, in	51.8	105	101	105	99	103
Mcal ME, 170d	3,400	98	98	110	98	102

[a] NelX = Nellore, LonX = Longhorn, ShoX = Shorthorn, GalX = Galloway, SalX = Salers

Table 3. Traits of mature F_1 cows from tropically adapted sire breeds cows relative to Angus/Hereford F_1 cows

	Breedcross[a]			
Trait	Angus/ Hereford	BraX	BorX	TulX
Cow weight, lb	1,372	96	87	88
Cow height, in	53.0	102	98	98
Condition score[b]	6.0	106	110	102

Output traits. Relative mean yields, both daily at time of peak lactation and for the 126-d lactation period, of Brahman and Sahiwal F_1 cows were higher than the mean yields of the Angus/Hereford F_1 (18.3 lb and 1,764 lb) in Cycle III (Table 4). Calves from Brahman and Sahiwal SBC groups were 8% and 17%, respectively, lighter at birth than calves from Angus/Hereford F_1 cows (91 lb), but these SBC groups' calves gained 19% and 13% more weight during the test period than calves from Angus/Hereford F_1 cows (257 lb).

Table 4. Output-input differences among tropically adapted and Pinzgauer F_1 cows relative to Angus/Hereford F_1 cows (%)

	Breedcross[a]			
Trait	Angus/ Hereford	BraX	SahX	PinX
Lactation, lb				
Peak yield, lb	18.3	108	105	126
Total yield, lb	1,764	118	112	114
Calf weight				
Birth, lb	91	92	83	103
Gain, lb	257	119	113	109
Mcal ME	3,043	115	106	112
Efficiency, lb/Mcal	8.4	104	108	97

[a]BraX = Brahman, SahX = Sahiwal, PinX = Pinzgauer.

In Cycle IV (Table 5), milk production at time of peak yield of the Nellore and Longhorn F_1 cows was 4% and 6% lower than the yield of the Angus/Hereford F_1 cows (17.3 lb), but the yields for the Brahman F_1 cows exceeded the 170-d lactation yield of the Angus/Hereford F_1 cows (1,732 lb) by 5% while the Longhorn F_1 cows produced 2% less milk during the lactation period. As in Cycle III, birthweight of calves from cows produced from matings with tropically adapted breeds were 5-12% lighter than those from Angus/Hereford F_1 cows (92.4 lb), but age-adjusted weaning weights (170 d) were 15% higher for calves from the Nellore F_1 cows than calves from the Angus/Hereford F_1 cows. Adjusted weaning weight of calves from the Longhorn F_1 cows was approximately the same as Angus/Hereford F_1 cows (298 lb).

Output characteristics for cows from Cycle V are reported in Table 6. Angus/Hereford F_1 cows produced a daily yield at time of peak lactation of 22 lb and a 200-d lactation yield of 3,706 lb. Relative to Angus/Hereford F_1 cows, Brahman F_1 cows exhibited 5% more, Boran yield was similar, and Tuli F_1 cows produced 8% less daily yield at peak lactation than Angus/Hereford F_1 cows. Brahman F_1 cows produced 7% more milk for the total lactation than Angus/Hereford F_1 cows, and Boran F_1 cows yield was similar and Tuli F_1 cows yield was 9% less. The mean birthweight of the Angus/Hereford F_1 cows (98 lb) was 11%, 11%, and 6% higher than the birthweight of the Brahman, Boran, and Tuli SBC groups, respectively. Adjusted to 212-d weaning age, the

Table 5. Output-input differences among mature tropically adapted and *Bos taurus* cross F_1 cows relative to Angus/Hereford F_1 cows (%)

	Breedcross					
Trait	Angus/Hereford	NelX	LonX	ShoX	GalX	SalX
Lactation, lb						
Peak yield	17.3	96	94	117	98	110
Total yield, 170d	1,732	105	98	122	96	119
Calf weights, lb						
Birth	92.4	88	95	109	100	102
Adjusted Weaning weight	298	115	101	108	90	106
Efficiency, (lb/McalX100)						
@ 29 Mcal/d intake	6.0	116	102	108	92	107

[a] NelX = Nellore, LonX = Longhorn, ShoX = Shorthorn, GalX = Galloway, SalX = Salers

Table 6. Output-input differences among tropically adapted and non-adapted breed F_1 cows relative to Angus/Hereford F_1 cows (%)

	Breedcross			
Trait	Angus/Hereford	Brahman X	Boran X	Tuli X
Lactation, lb				
Peak yield	22.0	105	101	92
Total yield	3,709	107	102	91
Calf weights, lb				
Birth	98	89	89	94
Adjusted weaning	372	125	119	104
Mcal ME	6,050	86	89	91
Efficiency, (lb/Mcal x100)	6.1	145	135	115

weaning weight of Angus/Hereford F_1 cows (372 lb) was 25%, 19%, and 4% less than the adjusted weaning weights of the F_1 cows from tropically adapted sire breeds cows.

Inputs. Test period ME intakes (Mcal) are reported in Tables 4, 5, and 6 for Cycles III, IV, and V, respectively. Brahman and Sahiwal intake (Mcal ME) was 15% and 6% greater than Angus/Hereford F_1 cows (3043 Mcal ME) in Cycle III, but Angus/Hereford mean intake (6050 Mcal ME)) was 9 to 14% greater than F_1 cows sired by tropically adapted breeds in Cycle V. Nellore and Longhorn F_1 cows consumed approximately 2% less energy during the 170-d test interval in Cycle IV than Angus/Hereford F_1 cows (3485).

Efficiency. This report considers efficiency during the preweaning period and ignores potential differences between tropically adapted and non-adapted breed groups in life cycle efficiency that may be related to breeding performance. The efficiency ratio in the present report reflects the ability of these breed groups to convert cow feed intake into weight of calf at weaning. Cycle III was designed to feed cows such that energy intake was sufficient to meet demands for lactation and maintenance of the cow. In contrast, the design of Cycles IV and V set individual daily rations of the cows based on the cow weights as they entered the test facility. Results across the cycles were consistent, at 100% reproductive success; F_1 cows from tropically adapted sire breeds cows were more efficient than Angus/Hereford F_1 cows.

Relative to Angus/Hereford F_1 cows ((8.4 lb calf/Mcal ME consumed by cow)x 100) Brahman and Sahiwal F_1 cows were 4% and 8% more efficient at converting feed resources to weight at calf at weaning even though their milk production for the test period exceeded Angus/Hereford F_1 cows. By the study design to restrict energy intake to that required to maintain average cow body weight, the ME intake of these groups exceeded the Angus/Hereford F_1 cows by 15% and 6%, respectively. The 19% and 13% increase in preweaning weight gain for Brahman and for Sahiwal SBC groups, respectively, offset the increase in food intake, resulting in a more favorable efficiency ratio.

By allowing feed intake to vary in Cycle IV, the response in production per unit of cow feed consumed could be evaluated over a range of energy availabilities (Table 5). This approach addresses the question of the impact of increased feed availability on preweaning efficiency. Significant differences attributable to SBC were observed for inputs and outputs in this cycle. A non-linear relationship was observed for measure of lactation and adjusted

weaning weight. In general, the rate of increase in productivity, measures of lactation or calf performance, decreased with increasing levels of energy consumed by the cow. Rankings between tropically adapted vs Angus/Hereford F_1 cows for efficiency at different energy intakes were the same. At the daily rate of MEI for maximum weight at which maximum weaning weight would be observed, efficiency for Angus/Hereford F_1 cows ((6 lb calf/Mcal ME consumed by cow) x 100) the Brahman and Longhorn F_1 cows were 16% and 2% more effective at converting energy to weight of calf.

In contrast to Cycle IV, a non-linear relationship was not observed between energy intake and measures of output (Cycle V). Besides differing in SBC, the two studies differed by about 30 d in length and diet, which may have contributed to this result. Significant differences were observed between the F_1 cows from tropically adapted sire breeds and Angus/Hereford F_1 cows ((6.1 lb calf/ Mcal ME) x 100) for efficiency. In this cycle, the Angus/Hereford F_1 cows consumed significantly more ME and yielded fewer pounds of weight of calf at weaning than the tropically adapted SBC. Brahman, Boran, and Tuli F_1 cows were 45%, 35%, and 15% more efficient than Angus/Hereford F_1 cows because they consumed less ME and yielded more pounds of weight of calf at weaning than the Angus/Hereford F_1 cows.

Summary

Included in a list of production resources for cow/calf operations would be attributes of the physical environment and management. The latter makes decisions regarding the allocation of available capital to produce a product whose revenues would exceed investment. Failure to utilize germplasm suitable for the typical attributes of a physical environment of a defined geographical region may negatively affect the return on investment. Utilization of germplasm that is adapted to the environment would decrease capital expenditures to modify the environment and could increase productivity.

Commercial cow-calf producers whose enterprises are located in hot and humid areas with higher levels of internal and external parasite problems would benefit from access to germplasms that are fit within this type of environment. Crossbred cows containing tropically adapted germplasm were characterized for traits contributing to production efficiency during the preweaning period at MARC in south-central Nebraska. Relative to Angus/Hereford females, the efficiency of converting feed resources to weigh gain during the preweaning period or weight weaned was higher in cows produced through matings with breeds suited to the tropical environment. This higher efficiency was evident even when higher cow feed intakes were observed for F_1 cows from tropically adapted sire breeds cows.

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Foraging Behavior of Tropically Adapted Breeds

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ABSTRACT: Cattle production in the southern United States is heavily dependent on tropically adapted animals, particularly those of Brahman breeding. The fact that feeder calves of overt Brahman influence are often discounted by cattle buyers has led some in the industry to look for alternative tropically adapted germplasm. Three breeds have dominated the search for alternatives: the Senepol, the Tuli, and the Bonsmara. Most research with these breeds has concentrated on comparative reproductive performance and carcass characteristics and quality; only a limited amount of research has examined forage intake and grazing behavior. Foraging behavior (bite size, bite rate, and grazing time) has an important influence on forage intake and is heavily influenced by sward structure and environmental conditions. In environments where daytime temperatures are high, non-adapted animals respond by seeking shade and increasing night-time grazing. However, if nighttime temperatures and particularly nighttime heat index values remain high, overall grazing time declines. In studies in east and southwest Texas, Tuli-sired heifers had similar grazing times to Brahman cattle and showed few of the behavioral changes adopted by purebred Angus heifers. *Bos indicus* cattle have smaller digestive tracts and faster passage rates of digesta than *Bos Taurus* cattle, with crossbred animals such as Tuli x Brahman being intermediate. Heat stress induced reduction in grazing time, combined with poor-quality forage, results in depressed intake. Senepol cattle appear to show a similar intermediate response in grazing time. There was no published foraging behavior data for Bonsmara cattle in the United States. However, in a recent study comparing Angus, Brahman x Angus, Bonsmara and Braunvieh steers grazing cool-season forage in east Texas, Brahman steers had the highest intakes, followed by Bonsmara, Braunvieh, and Brahman x Angus, with Angus steers having the lowest intakes (20.2, 18.2, 16.2, 15.3 and 13.4 g DM/kg BW, respectively, SEM 0.598). While foraging behavior studies provide valuable insights into differences in performance among breeds, labor costs will likely preclude much further work of this type.

Key Words: Grazing Time, Intake, *Bos Indicus*

Introduction

The importance of tropically adapted cattle in beef production systems in the southern United States has been recognized since the introduction of the first *Bos indicus* cattle in the late 1800s. *Bos indicus* cattle are well adapted to the temperature and nutritional stresses prevalent in the tropics and subtropics where they evolved, and which are to be found in the southern United States, particularly during the summer months. In the latter part of the 1900s, another group tropically adapted cattle began to be imported into the United States. These included the Sanga cattle from southeast Africa (Schoeman, 1989) as well as the Senepol, a tropically adapted *Bos taurus* breed developed in St Croix, U.S. Virgin Islands. These breeds, which included the Tuli and more recently the Bonsmara, were imported primarily for their carcass characteristics rather than any superior ability to handle environmental stress.

In the late 1960s and 1970s, a great deal of attention was focused on understanding the individual components of grazing systems, in particular concentrating on the plant-animal interface. Much of the forage livestock research in the United States has concentrated on measuring output of a particular grazing system rather than identifying the interactions between the grazed forage and the grazing animal (Forbes, 1988). However, measuring ingestive behavior of grazing cattle provides valid comparative data and should be an integral part of any thorough investigation of the suitability of a breed for a particular environment. Unfortunately, the considerable labor and operating costs associated with the conduct of even medium-scale grazing experiments has meant that such research has always been difficult to accomplish. As a result there has been but a handful of studies conducted over the last twenty years that have examined intake together with some measure of ingestive behavior of tropically adapted cattle.

Reported here are the results of four studies conducted in east and southwest Texas since the 1990s that examined intake and/or ingestive behavior of

crossbred cattle sired by Angus, Brahman, Tuli, or Bonsmara bulls and compared to purebred Angus or Brahman cattle.

Study 1: Angus vs Brahman x Angus cattle

In 1991, twelve non-lactating 3-yr-old Brahman x Angus, and 12 non-lactating 3-yr-old Angus females were used to relate grazing time and shade-seeking behavior to the reported ability of the breed types to adapt to high environmental temperatures. Both groups of animals were obtained from livestock producers in southwest Texas and thus were acclimatized to local conditions. Two groups of six animals of each breed were grazed separately in four, 6 ha, kleingrass pastures (*Panicum coloratum* **L**.) for two trials of 12 d each starting in mid August and mid October. Each pasture was 472 m long and 200 m wide, with a water source available at the east end and a shade at the west end. Each shade was a 7 m by 3 m frame, 2 m high, covered with 80% dairy shade cloth. Before each trial the animals grazed on an adjoining area of kleingrass in a single group for 2 wk. Mean herbage mass was determined by harvesting six areas of 15 m^2 per pasture using a power mower, cutting 2.5 cm from the soil surface, prior to the start and after the end of the trial. Body condition and weight were recorded before and after each trial.

Estimates of digesta flow and fecal output were determined over the first six days of each trial following the concepts of Ellis et al. (1979) and Pond et al. (1988). On the first day all animals were gavaged with 150 g DM of Yb labeled kleingrass. The kleingrass was cut and air dried 1 wk before the start of the trial and ground through a 2-mm screen. The ground material was then sieved through a 250-micron screen to remove very fine particles. Material retained on the screen was then soaked in a solution containing 2.5 g Yb/L deionized water for 48 h, in the ratio of 1 kg DM to 7 L of solution. The Yb solution was then drained off, and the labeled forage rinsed five times before being dried. Gavage was accomplished by wetting the dried labeled forage with water and pouring the resulting slurry through a tube inserted into the rumen via the esophagus. Fecal samples were collected for five days after the day following gavage. Starting at first light on the first day, fecal samples were collected when each animal was observed to defecate. On the second day of fecal collection, samples were collected soon after first light, close to noon, and just before dark. On the third, fourth, and fifth days of fecal collection, feces were collected around midmorning and during late afternoon. A minimum of 15 fecal samples per animal was collected over the duration of the trial. Fecal samples were dried at 100°C and ground through a 1-mm screen. Ytterbium was extracted and determined by atomic absorption spectrophotometry following the procedure of Hart and Polan (1984). Fecal output (FO, g DM/kg LW/d) was determined using a two-compartment gamma 2 model (Pond et al. 1988). Forage intake was not calculated because sufficient numbers of esophageal fistulated animals of both breeds were not available, and because it was felt that hand-plucked material would not detect potential differences in diets selected by the two breeds.

On days eight through 12 of the trial, observations of daylight grazing time (DGT), resting in shade (RSH), resting in sun (RSN), and walking (WLK) were recorded by teams of two observers at 5-minute intervals on all animals during the hours of daylight (06.00 to 20.30 h). Estimates of RSN included time at water, but not walking. During the five days of observations, five animals in each replicate (four in October) were fitted with Kienzle vibracorders to record 24-h grazing time (GT-24). Nighttime grazing time (NGT) was determined from the vibracorder records. With an infrared thermometer, skin surface temperatures of all animals were taken in the midafternoon while the animals were in the shade on three days during each trial. Relative humidity and ambient temperature were recorded hourly by an automatic weather station 400 m from the pastures. Heat index was derived using the formula:

$$HI=AIRT-(0.55-(0.55*(RELH/100)))*(AIRT-14.4)$$

where HI=heat index, AIRT=ambient air temperature, and RELH=relative humidity (Dougherty et al. 1991).

Statistical Analysis. All data were analyzed (PROC GLM; SAS Institute, 1988) with the model:

$$Y_{ijklm}=R_i+T_j+B_k+T*B+R_l(T*B)+D_m+D*T+D*B+D*T*B+X+X*T+X*B+X*T*B+e_{ijklm}$$

where Y= dependent variable, R=ith rep effect, T=jth season effect, B=kth breed effect, D=mth day effect, X=covariate and e=error. R(T*B) was used as the error term to test T and B and T*B. Dependent variables used were 24-h grazing time, NGT, DGT, RSH, RSN, and WLK.

Results and Discussion

Mean values for animal bodyweight, body condition, herbage mass, maximum, minimum and mean ambient temperature, relative humidity, and heat index are given in Table 1. The maximum and minimum temperatures and humidities given in Table 1 are for the five days of observations.

Fecal output and digesta dynamics. In August, two Brangus animals did not receive complete doses of Yb-labeled fiber, while three did not receive full doses in October. Data from these animals were not included in analyses of fecal output. No differences ($P > .10$) in fecal output were detected between the breeds, though a significant ($P > 0.05$) difference was detected in fecal output between trials (11.9 $\pm$ 2.07, and 5.5 $\pm$ 2.11 g OM kg/LW/d, for Trials 1 and 2, respectively). No differences ($P < 0.10$) were detected between breeds or trials for such attributes of digesta flow as gastrointestinal mean residence time or rate of passage. While forage quantity was probably not limiting in either trial, IVDMD as selected by esophageally fistulated cows declined from 648 $\pm$ 5.9 g/kg DM in August to 568 $\pm$ 14.0 g/kg DM in October.

24-h Grazing time. In August, vibracorder records were obtained from only two of the animals of each breed in each replicate because of failure of recorder clocks. In October, records were obtained from four Angus in rep 1, and 2 in rep 2, while records were obtained from two Brangus in rep 1 and 3 in rep 2. 24-h grazing times differed ($P < .0001$) between trials and breeds ($P < .03$), though no significant trial x breed interaction ($P > .10$) was detected (Table 1). Grazing times by the Angus cattle were lowest in August, but increased 175 min/d in October (Table 2). Brangus cattle increased grazing time from August to October by 115 min/d, to give the breeds similar ($P >0$ .10) 24-h grazing times in October. The number of grazing periods in 24 h differed between breeds ($P < 0.0001$) but not between trials ($P > .6$), though the trial x breed interaction was significant ($P < 0.02$) (Table 2). Angus had fewer grazing periods in both trials than Brahman x Angus, but the number of grazing periods for Angus did not differ significantly between trials. Brahman x Angus reduced the number of daily grazing periods from a mean of 9.6 to 8.6 ($P < .04$) from Trial 1 to Trial 2.

Nighttime grazing. There was no difference ($P > 0.10$) in total time spent grazing at night between Angus and Brahman x Angus. There was, however, a significant difference ($P < .001$) between trials, and the trial x breed interaction was significant ($P < 0.004$. Table 2).

Daytime shading and grazing behavior. Skin surface temperature in the shade, grazing time, resting in the shade, resting in the sun, and walking and watering time are given in Table 2. Animals spent 96 min longer ($P < 0.0001$) grazing in October than they did in August. As an average for both trials, Brahman x Angus spent 59 min/d longer ($P < 0.0001$) grazing than Angus. A trial by breed interaction was not detected ($P > .10$) for daytime grazing time.

A trial by breed interaction was detected for time spent resting in the shade ($P < 0.0001$), with Angus spending 78 min longer in the shade than Brahman x Angus in August and 206 min longer in October. The trial by breed interaction was significant ($P < 0.0001$) for time spent resting in the sun. While Angus spent approximately the same time resting in the sun as Brahman x Angus in August, they spent 60 min/d less in the sun in October. The Brahman x Angus frequently laid down away from the shade in October between grazing bouts. As an average of both trials, Brahman x Angus went to shade more often ($P < 0.0001$) than Angus and more frequently ($P < 0.0001$) in August than October (Table 2). Brahman x Angus spent 60 min/d less ($P < 0.0001$) time watering and walking to and from water than Angus in August but 21 min/d more ($P < 0.0001$) in October. Skin surface temperatures of Angus taken in mid-afternoon in the shade were significantly ($P < 0.0001$) lower than those of Brahman x Angus in August, but they were not different ($P > .10$) in October. By staying in the shade almost all the time in August, Angus were presumably able to achieve and maintain lower body temperatures. Brahman x Angus moved in and out of the shade more frequently than Angus and thus maintained higher body temperatures. In October, in the lower ambient temperatures, staying in the shade conferred no advantage to Angus and may have actually contributed to the reduced fecal output. The decline in fecal output may be a reflection of reduced demand by these mature, dry cows. The increase in body condition ($P < 0.004$) between the two trials (Table 2) may have allowed the animals the freedom of becoming more selective in their grazing, sufficient to satisfy maintenance requirements, while reducing actual intake.

Because the animals generally had one major period of resting in shade, around which the other activities revolved, the effects of ambient temperature and humidity on the start and ending times of the resting period were examined. The length of the main period of resting in the shade differed between trials ($P < 0.0001$) and breeds ($P < 0.0001$), and the trial x breed interaction was significant ($P < 0.05$, Table 2). The Angus entered shade earlier ($P < 0.0001$) in the day and left later ($P < 0.0001$) than Brahman x Angus in both trials. Angus also entered shade at lower temperatures and left at higher temperatures than Brahman x Angus. Angus were also much more consistent as to the temperature at which they left the shade. In examining the effects of trial or breed on the time animals left shade, the use of temperature or humidity as a covariate in the models in both cases increased R^2 from 0.68 to 0.96. Heat index, however,

explained less of the variation. In August this was probably because, though on average the two breeds came out of shade at the same heat index, the Brahman x Angus generally left the shade while the heat index was still increasing while the Angus left the shade when the heat index was falling. In October, both breeds left the shade at approximately the same heat index.

In August, high ambient temperature (>32°C) and high relative humidity forced both breeds to spend long periods in the shade, reducing grazing time. Watering time was significantly higher for Angus at this time, in keeping with the results of Winchester and Morris (1956). In October, however, the lower ambient temperature and reduced relative humidity allowed the Brahman x Angus to increase grazing time and time spent resting in the sun (Table 2), though this did result in more frequent trips to water. For Angus, the lower October temperatures allowed the animals to spend less time in the shade. This allowed more time available for grazing, while time spent resting in the sun was reduced to a minimum, reducing their need for water relative to Brahman x Angus. Though the potential for compensatory grazing at night was available, there was little difference between the two breeds in August (Table 2), and, in both breeds, approximately 47% of total grazing was done at night. In October, Angus grazed for 47 min longer than Brahman x Angus during the hours of darkness. While the Angus continued to spend about 47% of the total grazing time grazing at night, Brahman x Angus reduced that amount to 37%. In August the mean low temperature over the course of the trial was above 25°C, the upper limit of thermoneutrality for cattle, and thus the animals had little opportunity to reduce their heat load, even at night. Although ambient temperatures were lower in the second trial, the threshold for allowing grazing unrestricted by heat stress was apparently not reached by either breed.

Study 2: Tuli-, Brahman-, and Angus-sired heifers.

Research into components of ingestive behavior was carried out in the 1990s soon after Tuli cattle were placed at research centers in southwest Texas at Uvalde and east Texas at Overton. The first set of experiments involved a comparison among Tuli-, Brahman-, and Angus-sired heifers (Forbes et al., 1998). In this study, Tuli-, Brahman-, and Angus-sired heifers were grazed at two locations in Texas in the summer of 1995. The first study began in mid-August (August 16) at the Texas Agricultural Experiment Station, Overton, in humid east Texas (32°16'N 94°59'W, average annual rainfall 1168 mm, mean annual temperature 18.8°C). The second began on September 14 at the Texas Agricultural Experiment Station, Uvalde, in semi-arid southwest Texas (29°13'N 99°47'W, average annual rainfall 600 mm, mean annual temperature 21.1°C). Heifers used in east Texas included eight each of purebred Brahman and Angus, and crossbred Angus x Brahman and Tuli x Brahman heifers; those used in southwest Texas included eight each of purebred Brahman and Angus, and crossbred Brahman x Angus and Tuli x Angus. All heifers were between 14 and 16 m of age at the time of the trials and were in the first 60 d of pregnancy. In east Texas, cattle grazed 0.25 ha 'Coastal' bermudagrass (*Cynodon dactylon*) pastures, while in southwest Texas the pastures (6 ha) were of 'Kleingrass 75' (*Panicum coloratum)*. At both locations, animals grazed their respective pastures for 12 d following a 2-wk acclimation period on adjoining pastures similar in forage availability, structure, and composition. During the first 6 d, a forage intake and digesta kinetics trial was conducted. The animals remained on pasture for another 6 d, with behavior observations taking place on the last 4 d. Digesta kinetics were estimated using a pulse-dosed marker technique (Burns et al., 1994). Estimates of passage kinetics were calculated using a two-compartment, gamma 2 residence time model as described by Ellis et al. (1994). The following secondary parameters were calculated (terminology and procedures follow Ellis et al., 1994): fecal output (FO), age-dependent age-independent compartmental residence time (MCRTS), gastrointestinal residence time (RTG), and the initial time delay (J). Ellis et al. (1994) proposed a two-compartment model for rumen contents: a lag compartment (CM1) in which forage fragments undergo age-dependent conditioning required for escape and a second mass action age-independent turnover pool (CM2). Together, these compartments comprised what Ellis et al. (1994) called the two compartment system (CMS). In vitro digestibility of the forage on offer was determined from 20 hand-plucked samples per pasture. Dry matter digestibility of the hand-plucked samples from both locations was determined in a two-stage in vitro procedure (Tilley and Terry, 1963). Intake was estimated from fecal output estimates and in vitro digestibility estimates (Le Du and Penning, 1982). Grazing behavior data were obtained by using vibracorders (Lucas Kienzle Instruments Ltd., Argo Instruments, Winchester, VA) to record 24-h grazing time (GT24) and by visual observation during the hours of daylight. Night grazing time (NGT) and number of grazing periods (NP) were also determined from the vibracorder charts. At both locations, visual observations of grazing behavior lasted from 0700 until dark (2000) on each of the 4 d. Instantaneous observations of all animals were made at 5-min intervals of the following

activities: grazing, resting in the shade, resting in the sun, walking, drinking, and eating mineral. Resting in the sun included both lying down and standing. Because walking, drinking, and eating mineral composed only a small proportion of observations, they were combined. At both locations, weather data (air temperature and humidity) were collected by an automated weather station located within 1 km of the pastures. Heat index was calculated using the formula: Heat index (HI) = AIRT - (.55 - (.55 * (RELH/100))) * (AIRT - 14.4), where AIRT = ambient air temperature (C) and RELH = relative humidity (Dougherty et al., 1991). Fecal output, forage intake, and passage kinetics data were analyzed using the GLM procedure of SAS (1993), with breed as the main effect and replicate within breed as the error term. Where an *F*-test was significant, means were separated using the PDIFF option. Twenty-four-hour grazing times, NGT, NP and, in southwest Texas, water consumption, were analyzed as a split-plot with breed as the main effect, which was tested by the replicate by breed interaction. The subplots of day and the day x breed interaction were tested with the residual error. Where the interaction was not significant ($P > .05$), it was dropped and the data were re-analyzed. Behavior data from daytime observations are reported in terms of minutes of activity per hour, and were analyzed by repeated-measures methods. Examination of the data indicated that the 13 h of observations could be reduced to five main periods: two periods before and two periods after a lengthy period of resting in the middle of the day. These periods were designated as periods 1 (0700 to 0859), 2 (0900 to 1059), 3 (1100 to 1559), 4 (1600 to 1759), and 5 (1800 to 1959). Simple correlations between weather and behavioral variables were conducted using PROC CORR (SAS, 1993).

Results and Discussion

East Texas. Forage mass was not considered to be limiting at any time during the trial in any pasture (mean = 5192 $\pm$ 568.4 kg DM/ha). In vitro DM digestibility of the hand-plucked forage ranged from 38 to 44%, with a mean of 40 $\pm$ .5. Forage quality was lower than normally desirable as a result of allowing biomass to accumulate to ensure sufficient mass for the duration of the trial. One Angus x Brahman heifer regurgitated part of the Yb dose and thus was excluded from data analysis of passage kinetics. There was a difference ($P < 05$) between the initial BW of the different breed types (Table 1). Accordingly, fecal output, forage intake, and compartmental mass data were calculated and analyzed on a BW basis. Mass of the two compartments (CM1 and CM2), MCRTS, fecal output, and forage intake did not differ ($P > 0.05$) among breeds. However, there were differences among breeds (Table 3) in RTG ($P < 0.04$), τ ($P < 0.01$), with the Angus heifers having slower rates of passage and longer residence times than the other breeds. It should be noted that these fecal output and forage intake data, while low, were higher than those reported by Burns et al. (1991) for steers grazing bermudagrass.

For 24-h grazing time, the effect of breed was significant ($P < .05$), with Angus having the shortest and Brahman and Tuli x Brahman heifers the longest overall grazing time (Table 4). The 24-h grazing times for all breeds were somewhat shorter than some other published results (Forbes and Hodgson, 1985: 580 to 625 min/d; Forbes and Coleman, 1993: 576 to 634 min/d; Hendricksen and Minson, 1980: 467 to 668 min/d), though the Angus had similar grazing times to *Bos taurus* breeds grazing bermudagrass in the summer in Arkansas (Erlinger et al., 1990: 380 to 515 min/d). The day effect was also significant ($P < 0.001$), but there was no breed x day interaction. Though the Angus heifers had numerically longer NGT, this difference was not significant. Night grazing time differed among days ($P < 0.001$), with the lowest NGT occurring on d 1 (122 $\pm$ 10.3 min) and the highest on d 3 (189 $\pm$ 10.3 min). This did not, however, appear to be related to either the maximum temperature on the previous day or the minimum reached that night. The lack of a breed x day interaction implies that all breeds responded to differences in ambient temperature and humidity among days in a similar manner. Overall, Angus heifers had fewer ($P < 0$ .04) grazing bouts than the other breeds.

Of the data collected by direct observation, the majority of time was spent in either grazing or resting (including ruminating) under the shades provided. The effect of period and the interactions of period x breed, period x day, and period x breed x day were all significant ($P < .001$) for the four behaviors. Angus heifers consistently limited themselves to two grazing periods, between 0700 and 1100 in the morning and 1700 and 2000 (dark) in the evening. The other breeds generally had at least one substantial grazing period between the morning and evening, but the timing of intermediate grazing periods depended on the day. Grouping the hourly observations into five periods allowed for easier interpretation of the importance of the morning, midday, and evening grazing periods. Figures 1, 2, and 3 show the time (min/h) spent in each of the five periods in each of three activities (grazing, shading, and watering including mineral consumption, respectively) during the hours of daylight (0700 to 1900). The breed x day

interaction was presumably due to the inevitable variations among days in temperature and humidity. Grazing in period 5 was significantly ($P < 0.05$) more intense than in previous periods except for the Angus heifers, whose morning and evening grazing times were similar on most days. This intensity of grazing in the late afternoon and evening is consistent with most of the literature reports of longer evening than morning grazing periods (Kropp et al., 1973; Hinch et al., 1982; Erlinger et al., 1990; Champion et al., 1994). The difference in grazing time seen between the Angus and other breeds was similar to that observed between Hereford and Senepol cows (Hammond and Olson, 1994).

The effects of breed and day were significant ($P < 0.001$), but the breed x day interaction was not ($P > 0.10$) for time spent resting in the sun. Between 0900 and 1800 the Angus heifers spent less than 6 min/h resting in the sun (Figure 2), while the Brahman heifers averaged 20 min/h in the sun over the same period. In the first period there was no difference between breeds, each spending approximately 25 min/h resting in the sun. Watering took only a fraction of the time available to the animals (less than 5 min/h on average). During the daylight hours, the association between the amount of time spent grazing each hour and HI was negative for the Angus heifers (r = -.39; $P < .001$) and positive for the Brahman (r = .10; $P < .03$). The Angus x Brahman and Tuli x Brahman heifers showed no association between HI and amount of time spent grazing per hour (r = .03; $P > .57$, and r = .07; $P > .12$, respectively). This would indicate that the Tuli x Brahman heifers were not inhibited from grazing when HI values were high. The total time spent resting in the shade during the day differed among breeds ($P < 0.004$) and among days ($P < 0.001$) (Figure 2). Obviously, the loss of grazing time caused by the time spent in the shade was not compensated for by nighttime grazing in the Angus heifers. The main differences between breeds were a result of the Angus heifers spending a large proportion of each hour in the shade after 1000. All breeds had positive associations between HI and time spent resting in the shade (Angus: r = .44, $P < .001$; Brahman: r = .20, $P < .001$; Angus x Brahman: r = .21, $P < .001$; Tuli x Brahman: r = .17, $P < .001$).

Southwest Texas. Air temperature and HI were consistently above 25°C throughout the trial (Figure 3), suggesting that the animals experienced some degree of heat stress continuously. Forage mass among pastures ranged from 1010 to 1700 kg DM/ha, with a mean of 1229 $\pm$ 19.8. Differences in herbage mass among pastures were not significant ($P > 0.05$). In vitro DM digestibility of the kleingrass ranged from 40 to 42% with a mean of 41 $\pm$ .5%. The majority of Angus heifers regurgitated the Yb-labeled kleingrass; thus no intake or digesta dynamics data were obtained from them. There were significant differences among the Brahman, Brahman x Angus, and Tuli x Angus heifers (Table 3) in the compartmental mass of CM1 (i.e., the faster turnover compartment; $P < 0.03$), FO ($P < 0.05$), and intake ($P < 0.05$). However, there were no differences ($P > 0.05$) among breeds in the mass of CM2 (i.e., slower turnover compartment), MCRTS, RTG, or J. Brahman heifers had significantly ($P < 0.05$) lower fecal output, intake, and compartmental mass than the Tuli x Angus and Brahman x Angus heifers. These findings, along with the tendency for lower fill and fecal output observed in the Brahman heifers in east Texas, are in agreement with other published results (Colditz and Kellaway, 1972).

Vibracorders were no more reliable in southwest Texas than east Texas, providing reliable data over four consecutive days on four Angus, five Brahman, four Brahman x Angus, and seven Tuli x Angus heifers. Twenty-four-h grazing times, NGT, NP, and water consumption (WC) did not differ ($P > 0.05$) among breeds. Values for GT24, NGT, NP, and WC, when averaged across breeds were 564 $\pm$ 12.6 min/d, 91 $\pm$ 6.7 min/d, 4 $\pm$ 0.2, and 142 $\pm$ 3.8 L/d, respectively. The effect of day and the breed x day interaction was not significant ($P > 0.05$) for all variables. Twenty-four-h grazing times were similar, however, to those reported by Forbes and Coleman (1993) for cattle grazing Old World bluestems in central Oklahoma. Water consumption did not differ among breeds in this study, though *Bos indicus* cattle have been found to have lower water intakes over a range of temperatures than dairy cattle (Colditz and Kellaway, 1972).

Analysis of the daylight grazing behavior indicated significant period effects ($P < 0.001$) and period x breed ($P < 0.001$), period x day ($P < 0.001$), and period x breed x day ($P < 0.001$) interactions for grazing, resting in shade, resting in sun, and watering. Figures 4 and 5 show time spent grazing, resting in shade, and watering, respectively, on a daily basis for the four breed types. The Tuli x Angus heifers spent more time grazing in the second period than the other heifers, indicating either a lower rate of intake during grazing or a willingness to graze when temperatures were rising sharply (Figure 4). The Angus heifers spent more ($P < 0.001$) time resting in the shade than the other heifers, with the Brahman heifers spending the least amount of time. Resting in the shade was, however, confined to periods 2 through 4. No shading activity took place in the early morning or late evening periods, when grazing was at its peak. The Angus and Tuli x Angus heifers never spent more than 10 min/h resting in the sun in any period. The Brahman heifers, on the other hand, spent as many as

20 min/h in periods 2 and 3 resting in the sun. All breeds spent 10 min/h or less resting in the sun in periods 4 and 5. For watering behavior, the effects of breed and day and their interaction were not significant ($P > 0.10$), indicating that the breeds spent the same amount of time at water on the different days. All animals spent longer ($P < 0.5$) at water in periods 4 and 5 than in periods 1 through 3.

All heifers showed consistent negative correlations between time (min/h) spent grazing and heat index (r = -35, -.22, .34, and -.42 for Angus, Brahman, Brahman x Angus, and Tuli x Angus, respectively, $P < .001$) and positive associations between time spent resting in the shade and heat index (r = .31, .15, .21, and .35 for Angus, Brahman, Brahman x Angus, and Tuli x Angus, respectively, $P < .002$). The negative association between time spent grazing per hour and HI indicates that the animals spent more time per hour grazing earlier in the day when the HI was lower. The Brahman heifers spent more time resting in the sun than the others ($P < .001$) during the second and third periods, but not in the hottest part of the day (period 4). The Tuli x Angus heifers spent more time grazing in the morning periods (Figure 5) than in the afternoon, while spending more time ($P < .001$) in the shade in period 4 than all the other breeds, thus reducing activity during the hottest part of the day. However, this reduction in grazing time between 1600 and 1800 did not appear to negatively affect forage intake relative to the other breeds.

Study 3: Angus vs Brahman x Angus and Tuli x Angus cows

This study was conducted during the summer of 1998 by Sprinkle et al. (2000). Angus, Brahman x Angus, and Tuli x Angus cows that were either dry or lactating were grazed on kleingrass pastures at the Texas Agricultural Experiment Station, Uvalde. The study was conducted during July and September when temperature, and thus stress on the animals, was likely to be different. The pastures used and procedures followed were as described in Study 2 above. The cows were allotted to pastures by breed and lactational state. After a 14-d acclimation period, the animals were dosed with Yb-marked kleingrass in gelatin capsules, and digesta kinetics were determined using a pulse-dosed marker technique as used by Forbes et al. (1998) and described above. Grazing behavior was determined in the same manner as in the study conducted in 1998 by Forbes et al. In addition to grazing behavior, bite rate was determined on the last three days of the study by recording a minimum of 14 bites for each animal on two occasions during the first and last 2 h of each day using three observers.

Results and Discussion

Air temperatures exceeded 36°C during the afternoon hours in July and 32°C in September, thus exposing the animals to a severe heat load during the July phase of the study. Forage availability exceeded 2000 kgDM/ha throughout each phase of the study. Diet digestibility exceeded 63% in both July and September. Estimates of digesta dynamics are presented in Table 4. Sprinkle et al. (2000) suggested that the Brahman x Angus cows in their study appeared to have a smaller gastrointestinal tract than the Angus cattle, in agreement with the findings of Schneider and Flatt (1975). Preston and Leng (1975) suggest that *Bos indicus* cattle have faster rates of digesta than *Bos taurus* cattle. Certainly, there was a consistent numerical tendency for the Angus cows to have slower passage rates than the Brahman x Angus and the Tuli x Angus cows in both early and late summer. The larger fasting heat production of the Angus cows may have contributed to their larger heat load that accumulated during the day. Grazing behavior data are presented in Table 5. During early summer, non-lactating Brahman x Angus cows spent more time in the sun than all other cattle ($P < 0.001$), despite being in good body condition, implying that their greater fat stores did not affect their heat adaptation. In late summer, both lactating and non-lactating Tuli x Angus cattle spent more time in the sun than the other breeds, suggesting that the Tuli x Angus cattle were as well adapted to heat as the Brahman x Angus cows. Lactating cattle, in an effort presumably to maintain intake, grazed more during the day in September when air temperatures were more moderate than July.

Study 4: Angus, Bonsmara, Brahman, Bonsmara x Angus, and Braunvieh steers

Ten animals of each breed (Angus ANG, Bonsmara BON, Brahman BRA, Bonsmara x Angus BA, and Braunvieh BRV) steers were randomly allotted to each of five bermudagrass pastures overseeded with rye and ryegrass in December 2002. Animals were weighed and body condition scores (BCS) recorded at the start of the trial and at 28-d intervals for 121 d. On April 19, five animals of each breed were dosed with a controlled-release alkane capsule for the determination of intake and digestibility. Starting on April 29, fecal samples were collected from each dosed animal on five consecutive days. Forage samples were collected daily during the intake trial for alkane determination, and forage mass and sward composition were determined at the start and end of the intake trial. Forage and fecal samples were frozen and lyophilized prior to extraction of alkanes and determination by gas chromatography.

Fecal output, forage intake, and digestibility were calculated using the procedures developed by Dove and Mayes (1990).

Results and Discussion

Initial body weight (BW) and BCS were 255 ± 7.3 kg and 5.3, 183 ± 6.9 kg and 4.5, 197 ± 6.9 kg and 4.3, 256 ± 7.7 kg and 5.1, and 213 ± 6.9 kg and 5.1, respectively, for ANG, BON, BRA, BA, and BRV. Forage mass declined during the intake trial from 2507 ± 104.1 to 2171 ± 110.1 kg/ha, but it was not felt to have affected intake negatively. Results for forage intake, diet digestibility, pasture average daily gain, and feedlot average daily gain are given in Table 6. Animals had higher ADG in the feedlot than on forage, but there was no correlation (r = 0.117, *P* = 0.445) between ADG on forage and ADG in the feedlot. These data suggest that BON steers, though smaller at the onset of the study, were able to grow efficiently and that steers that perform well on forage can also perform satisfactorily in the feedlot.

CONCLUSIONS FROM ALL FOUR STUDIES

Bos indicus breeds have been reported to have smaller digestive tracts and faster passage rates of digesta, Schneider and Flatt, 1975, Preston and Leng, 1987), than *Bos taurus* breeds. While the data from Sprinkle et al. (2000) support these reports, the data of Forbes et al. (1998) do not completely agree. The finding that Angus had the longest RTG and, behaviorally, showed the most heat stress, is consistent with our knowledge of the effects of heat stress on passage rate (Lippke, 1975; Collier and Beede, 1985). At no time during the studies using "Coastal' bermudagrass or kleingrass did the HI drop below 25°C, which indicates that the animals, and particularly the Angus heifers, were under significant heat stress as evidenced by the time spent resting under shade, and they were unable to dissipate heat at nighttime. The combination of reduced grazing time, apparent heat stress, and the relatively low digestibility of the bermudagrass forage could account for the relatively low intakes observed in all groups grazing bermudagrass in east Texas. That differences in intake were not generally significant may be either a reflection of our inability to adequately monitor changes in fill and passage kinetics on a daily basis, or a lack of fundamental differences between the breed types.

Tuli-sired heifers from either Brahman or Angus dams appeared to be well adapted to the warm-season perennial grasses and temperatures prevalent during the summer months in east and southwest Texas. Forage intake of Tuli-sired heifers was similar to forage intake of crossbred heifers of similar age and physiological state in both east and southwest Texas and exceeded intakes of purebred Brahman heifers in southwest Texas. Tuli-sired heifers did not appear to be any more negatively affected by high afternoon temperature and heat index than Brahman crossbred heifers, which are recognized as being well adapted to the region. Similarly, Tuli-sired cows showed only relatively minor differences in digesta dynamics, forage intake, and grazing behavior when compared to Brahman x Angus cows in southwest Texas.

The grazing behavior of either purebred or crossbred Bonsmara cattle has not yet been investigated. Based on the single study cited above, it would appear that Bonsmara x Angus cattle have potential to be used along with or in place of more traditional heat-adapted crossbred cattle.

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Evaluation of Boran, Tuli, Gelbvieh, and Brahman F_1 Crosses in Oklahoma

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ABSTRACT: Genetic adaptation to tropical conditions is an important component of cow/calf breeding systems used in the Southern Great Plains region. The objective of this experiment was to evaluate F_1 calves sired by new tropically adapted beef breeds (Boran and Tuli) and compare them to commonly used breeds (Brahman and Gelbvieh) and the productivity of the F_1 females resulting from these crosses under typical Oklahoma beef management practices. Angus and Angus x Hereford cows were bred by AI to Boran, Tuli, Brahman, or Gelbvieh bulls in the spring (1991 through 1994) to produce F_1 calves (N=173). Tuli-sired calves were lighter ($P < 0.01$) at birth (77.9 lb) than Boran- (87.9 lb), Gelbvieh- (87.2 lb), and Brahman-sired (91.1 lb) calves. Brahman-sired calves were heavier ($P < 0.01$; 492 lb) at weaning (205 d) than Boran- (447 lb), Tuli- (432 lb), and Gelbvieh-sired (462 lb) calves. Preweaning ADG was also greater ($P < 0.01$) for the Brahman-sired calves as compared to the other three sire breeds (1.95 lb vs 1.76 lb). Performance of the F_1 females was observed for six calving cycles. A total of 276 observations were made. Calves from Boran-, Tuli-, and Brahman-sired cows were lighter ($P < 0.01$) at birth than calves from Gelbvieh-sired cows (81.0 lb vs 90.0 lb). Calves from Brahman- and Boran-sired cows had similar BW and were heavier ($P < 0.01$) at weaning than calves from Tuli- and Gelbvieh-sired cows (508 lb vs 462 lb). Average BW of cows sired by Brahman bulls was greater ($P < 0.01$) than the BW of cows sired by Boran and Tuli bulls (1245 lb vs 1102 lb). Boran-sired cows weaned more calf as a percentage of BW than cows sired by Brahman, Tuli and Gelbvieh bulls (45% vs 42%). Tuli-sired cows were smaller, but produced as much calf per 100 lb of BW as Brahman-sired cows. Boran-sired cows were moderate in BW and produced more calf per 100 kg of BW than any of the sire breeds evaluated.

Key Words: Tropically Adapted Breeds, Beef Cows, Weaning Weight, Diet Digestibility, Luteal Activity

Introduction

Alternative sources of tropical adaptation in beef cattle have not been fully characterized under different environments used to produce U.S. beef. Unique traits for beef cattle production may interact with environmental conditions, so beef breeds must be evaluated under different environmental conditions (Thrift et al., 2000). Boran and Tuli are two tropically adapted breeds that are under evaluation in the United States. Both the Boran and Tuli breeds have been shown to be more heat tolerant than Hereford, but not as heat tolerant as Brahman (Gaughan et al., 1999). Boran use the same mechanisms as Brahman to dissipate heat, but Tuli adapt to hot conditions in a different way (Gaughan et al., 1999). These two breeds may differ physiologically and metabolically based on the original genetic source and the country of origin. Boran is a pure Zebu breed (*Bos indicus*) that evolved in southern Ethiopia; Tuli are not an indicus type but are a Sanga type of cattle developed in Zimbabwe. Tuli F_1 calves have been evaluated in Florida (Chase et al., 2000), and both Tuli and Boran F1 calves have been evaluated in Nebraska (Cundiff et al., 1999) and Texas (Herring et al., 1996). The objectives of the present study were to determine the effect of tropically adapted sire breeds on pre-weaning and post-weaning performance of F_1 calves and the subsequent performance of F_1 females under typical Oklahoma beef management practices.

Materials and Methods

This study was part of a multi-location research project initiated in 1991. Semen from a common source was subdivided for AI of cow herds in Nebraska, Oklahoma, Texas, Georgia and Florida. Breed of dam varied across location, and not all sire breeds were used at each location. Reports of results from each location can be found in this publication. This study was conducted at the Grazinglands Research Laboratory (35º 32' N latitude, 98º 02' W longitude) located 6 miles west of El Reno, OK. The area is classified as Tallgrass or True Prairie with an

elevation of 1,200 ft. The annual precipitation is 32.1 in ± 3.1 with 37% of the yearly precipitation falling in the spring and 24% in the fall. The native tallgrasses are Big Bluestem (*Andropogon geradii*) and Little Bluestem (*Andropogon scoparius*). The major forage resources used to maintain the two cow herds (base herd and F_1 crosses) used during this study were warm-season grasses (native tallgrass prairie and bermudagrass) with protein supplementation during the winter as needed to maintain body condition. The management goal was for cows to have a body condition score between 4 and 6 at calving in the spring. Warm-season grass hay was also provided when available standing forage was limited. The procedures used were approved by the laboratory's Animal Use and Care Committee.

Evaluation of F_1 Crosses. Angus and Angus x Hereford cows were bred by AI (1991 through 1994) using semen from Boran (n = 8), Brahman (n = 12), Gelbvieh (n = 6), and Tuli (n = 9) bulls. Brahman and Gelbvieh semen was purchased from U.S. sources, and Boran and Tuli semen was imported from Australia. Each year cows were blocked by age and breed then randomly assigned within block to a sire breed. Cows were AI for two cycles then exposed to a clean-up bull for 1 month. Semen from four to five bulls per sire breed was used each year. Calves were born in the following spring, weighed, and tagged shortly after birth. Male calves were castrated at birth. Calves were weaned in the fall at approximately 7 months of age. Body weights were recorded as full weights, and weaning weights were adjusted to a constant 205 d of age. Cows were weighed each fall at weaning and hip height was recorded. Data were analyzed using a mixed model. Fixed affects were breed of sire, sex of calf, year of birth, breed of sire x sex of calf. Sire within breed of sire was considered random. Means are reported as least squares means.

Sixteen F_1 steer calves born in 1992 and 16 calves born in 1993 were randomly selected from the calves available for metabolism trials to determine the impact of genotype on digestibility and N metabolism of low and high quality forage diets. Steers were maintained on annual cool-season grasses from weaning in the fall until initiation of the metabolism trials in the March. In 1993, Boran- (n = 4), Brahman- (n = 6), and Tuli- (n = 6) sired steers were used. Because the number of males produced at El Reno was limited, three of the Brahman and three of the Tuli steers were born at the Texas A&M Research and Extension Center, Uvalde, TX, and shipped to El Reno in fall after weaning. In 1994, Boran (n = 4), Brahman (n = 4), Gelbvieh (n = 4), and Tuli (n = 4) steers were used and all 16 calves were born at El Reno, OK. Steer were placed in a pen and group fed alfalfa pellets (high quality diet) for 7 d prior to being placed in metabolism stalls designed for the separation and collection of feces and urine. The amount of alfalfa pellets fed during the trial was limited to 2% of BW on an as-fed basis. A 10-d adjustment period to the stalls was followed by a 7-d total fecal and urine collection period. Steers were then removed from the stalls, placed in a pen and given ad libitum access to mature tallgrass prairie hay (low quality diet) for 21 d before being returned to the same metabolism stall. A second 10-d adjustment and 7-d collection period was conducted. Steers had ad libitum access to ground tallgrass prairie hay during both periods. Feed, refusals, fecal samples were analyzed for NDF and ADF concentration (Goering and Van Soest, 1970). Urine, feed, refusal, fecal samples were analyzed for N content by the kjeldahl method. Dry matter was determined by drying samples in a forced air oven at 60º C. Data were analyzed within each year and diet as with a one-way ANOVA with sire breed as the only component of interest.

Evaluation of F_1 cows. Females generated from the mating Boran, Brahman, Gelbvieh and Tuli bulls with Angus and Angus x Hereford cows as described above were placed on winter wheat pasture for growth and development before the first breeding season. All heifers were bred to calve as 2-yr olds. Heifers were exposed to Red Poll bulls for 60 d. The heifers were managed as a single herd separate from the base herd. Subsequent calves were sired by Simmental, Charolias or Brangus bulls. Only one terminal sire breed was used within a year. Management of the F_1 cows was typical of the cow/calf industry for Oklahoma. Cows were rotated between pastures of tallgrass native grass and bermudagrass. During the winter, cows had access to warm-season grass hay and were fed a protein supplement to maintain body condition of 4 to 6. After calving in February to April, cows were fed to maintain BW. A total of 276 records over six calving cycles were made. Date was analyzed with a mixed model. Fixed affects were sire-breed of dam, sex of calf, year of birth, sire-breed of dam x sex of calf. Sire within sire-breed of dam was considered random. Means are reported as least square means.

The influence of genotype and body condition score (BCS) at calving on the interval from calving to luteal activity (first ovulation) in cows 3 to 7 yr of age were determined during the 1996 through 1999 postpartum periods. Body condition scores (1 = emaciated and 9 = obese) were recorded at calving in February through April (Wettemann et al., 2002). Cows were fed to maintain BW after calving. Blood plasma was obtained every 7 d between 40 and 100 d postpartum and progesterone concentration was quantified to determine luteal activity. Once the

progesterone concentration exceeded 1 ng/ml on two consecutive samples, the cow was classified as in estrus. A total of 210 postpartum records were used. Body condition score and BW following a 15-h fast were recorded at 28-d intervals from calving until 100 d postpartum.

Results and Discussion

F_1 calves. Male calves were heavier ($P < 0.01$) than female calves at birth (89.5 lb vs 80.5 lb) and at weaning (473.4 lb vs 449.2 lb). Male calves also had greater ($P < 0.05$) ADG from birth to weaning than female calves (1.87 lb vs 1.80 lb). Calves were weaned at an average age of 230 d ± 8 and age of calf was not different ($P > 0.10$) among the four genotypes. Weaning weights reported in Table 1 are adjusted to a constant 205 d of age. Calves sired by Tuli bulls had lower ($P < 0.01$) birth weights and 205-d weaning weights than calves sired by Brahman bulls (Table 1). In general, very few cows required assistance in calving; however, there was a tendency ($P = 0.16$) for Brahman-sired calves to require more assistance than calves sired by bulls from the other breeds. This may be caused by higher birth weights in Brahman-sired calves. Chase et al. (2000) observed that Brahman-sired calves had more calving difficulty and had lower calf survival rates.

The ADG from birth to weaning was similar among Boran-, Gelbvieh- and Tuli-sired calves and was less ($P < 0.01$) than the ADG for Brahman-sired calves. Brahman-sired calves were heavier at birth and grew at a faster rate than calves sired by Boran or Tuli bulls.

These results are similar to previous reports by Herring et al. (1996), Cundiff et al. (1999), Chase et al. (2000), Baker et al. (2001b), and Holloway et al. (2002). In all five of these reports, Brahman-sired calves were heavier at birth and weaning than Boran- and Tuli-sired calves and had greater pre-weaning ADG. Boran- and Tuli-sired calves had similar birth and weaning weights. It appears that the amount of heterosis for birth weight, pre-weaning ADG, and weaning weight is greater for Brahman-sired calves than for Boran- or Tuli-sired calves when Angus and Angus x Hereford cows are used. When Brahman cows were used as the base herd, Tuli-sired calves had greater weaning weights and higher ADG than purebred Brahman calves (Browning et al., 1995).

F_1 cow production. Least squares means for pre-weaning calf performance from F_1 females are presented in Table 2. Calves from Gelbvieh-sired cows were heavier ($P < 0.01$) at birth than calves from the other three genotypes. Boran- and Brahman-sired cows produced heavier ($P < 0.01$) calves at weaning as compared to calves from Gelbvieh- and Tuli-sired cows. Calf ADG followed the same pattern as weaning weight. Brahman-sired cows had greater ($P < .01$) average BW when weighed in the fall as compared to the other three genotypes (Table 2). Tuli-sired cows had the lowest BW of the four genotypes in the fall. Although Brahman-sired cows were bigger than Gelbvieh- and Tuli-sired cows, all three genotypes weaned similar amounts (41.9 lb of calf/100 lb) amounts of calf averaged over the course of the study. Boran-sired cows were the most efficient of the four genotypes studied. Boran-sired cows weaned 44.6 lb of calf/100 lb of cow BW calculated from the data in Table 2. These data are based on average cow BW and do not take into consideration calving percentage.

Average hip height of F_1 cows followed the same pattern as fall BW (Table 2). Linear regression of BW on age showed that Brahman- and Gelbvieh-sired cows grew at similar rates (64 lb/yr), and Boran- and Tuli-sired cows grew at similar but lower rate (48 lb/yr). Estimated yearly growth rates of F_1 cows were similar to those reported by Warrington et al. (2004). They reported annual BW gains of 68 lb for Brahman-sired cows and 59 lb/yr for Tuli-sired cows. In our study, Boran-sired cows were more moderate in size than Brahman-sired cows, but calf weaning weights were similar. Therefore cow efficiency was greater for Boran-sired cows than for Brahman-sired cows. Tuli-sired cows were smaller than Brahman-sired cows, but weaned as much calf/100 lb of cow BW. With lower BW, we would anticipate that Tuli-sired cows would have lower maintenance cost than Brahman-sired cows.

Brahman-sired males and females are usually taller and heavier than Boran- and Tuli-sired males and females (Freetly and Cundiff, 1997; Chase et al., 2001;Warrington et al., 2004). The differences noted in this study between Brahman-sired F_1 cows and Boran- and Tuli-sired F_1 cows were similar to the reports of research conducted on semiarid rangeland in Texas (Cunningham et al., 2004; Warrington et al., 2004). Under semiarid conditions, Brahman F_1 cows were bigger than F_1 Boran or Tuli cows, but they were not as productive. Cunningham et al. (2004) reported that Boran-sired F_1 cows weaned 37 lb of calf/100 lb of exposed cow as compared to 32 lb and 34 lb for Brahman- and Tuli-sired F_1 cows. They also reported that Boran-sired F_1 cows were smaller than the Brahman-sired F_1 cows (1,129 lb vs 1,320 lb), but weaned calves with equal BW (422 lb). As observed in our study, Tuli-sired F_1 cows weighed less than Brahman-sired F_1 cows and weaned a smaller calf, but the kg of calf weaned/100 kg of cow BW was similar. Warrington et al. (2004) concluded that Tuli x Angus cows were more productive and efficient than

Table 1. Least squares means for preweaning performance of F_1 calves sired by Boran, Brahman, Gelbvieh and Tuli bulls by Angus and Angus x Hereford cows (1992 through 1995)

	Sire breed				
Item	Boran	Brahman	Gelbvieh	Tuli	SE
Number of records	44	41	37	51	
Birth wt, lb	87.9[a]	91.1[a]	87.2[a]	77.9[b]	2.0
205-d weaning wt, lb	447.7[b]	492.1[a]	461.5[b]	432.1[b]	10.2
ADG, lb	1.76[b]	1.95[a]	1.82[b]	1.73[b]	0.09

[ab]Means in the same row with different superscripts differ $P < 0.01$.

Table 2. Least squares means for birth weight and weaning traits of calves from F_1 dams and BW and hip height of F_1 cows averaged across all age groups.

	Sire breed				
Item	Boran	Brahman	Gelbvieh	Tuli	SE
Number of records	72	79	50	75	
Birth wt, lb	82.4[b]	79.8[b]	90.0[a]	80.7[b]	2.0
205-d weaning wt, lb	500.3[a]	518.3[a]	460.9[b]	465.6[b]	9.3
ADG, lb	2.04[a]	2.14[a]	1.81[b]	1.88[b]	0.04
Cow BW, lb[c]	1,121[b]	1,247[a]	1,117[b]	1,088[c]	21.1
Cow hip ht, in[c]	52.3[c]	54.8[a]	53.3[b]	52.2[c]	0.3

[ab]Means in the same row with different superscripts differ $P < 0.01$.
[c]Body weight and hip height recorded in the fall at weaning.

Table 3. Influence of breed of sire on body condition score (BCS) and days to first luteal activity (LA) in F_1 cows.

	Sire breed[a]				
Item	Boran	Brahman	Gelbvieh	Tuli	SE
Number of observations	49	47	31	50	
BCS[b]	4.81	4.70	4.33	4.74	0.1
LA , d[c]	81.9[x]	78.3[x]	73.8[y]	81.5[x]	2.9

[a] Sire of dam.
[b] Body condition scores taken at calving each year.
[c] First luteal activity in d postpartium.
[xy] Means in the same row with different superscripts differ $P < 0.10$.

Brahman x Angus cows under typical semiarid rangeland management. They also concluded that Tuli x Angus heifers had a higher pregnancy rate than Brahman x Angus heifers and that Tuli x Angus cows were reproductively more efficient than Brahman x Angus cows. Tuli-sired calves deposit more fat internally than Brahman-sired calves, which can be used as a buffer during periods of low energy nutrient intake (Baker et. al., 2001a ; Beaver et al., 1989).

Luteal activity. Body conditioning score (BCS) taken at calving varied from year to year ($P < 0.01$) and ranged from 4.43 (1996) to 5.12 (1999). Gelbvieh-sired cows had a lower ($P < 0.06$) BCS at calving (4.3 ± 0.1) than Boran-, Brahman-, and Tuli-sired cows (4.7 ± 0.1). In general, days to luteal activity was negatively (r = -0.11; P = 0.14) correlated to BCS. First luteal activity occurred at similar times in Boran-, Brahman-, and Tuli-sired cows, which tended to be slightly longer than for Gelbvieh-sired cows (Table 3). In general, the F_1 cows in this study were in good body condition. Using the weight and hip height determined in the fall of each year, we calculated an average weight to height ratio of 3.85. NRC (1984) reported that a cow with a weight: height of 4.0 could be considered in good body condition.

Previous research has shown that cows in BCS of 4 to 6 at calving have a greater pregnancy rate than cows that are thinner or fatter (Selk et al., 1988). As BCS increases from 4 to 6, the number of cows in estrus at 20, 40, or 60 d postpartum increases (Spitzer et al., 1995). At 80 d postpartum, we observed an average of 36% of the cows in estrus. By 100 d postpartum, 88% were in estrus. These values are lower than those reported by Spitzer et al. (1995). In their study conducted across three states, 74% of the cows with a BCS of 4 were in estrous by 60 d postpartum, and the percentage increased to 90% if BCS was 5. We conclude that the interval from calving to first luteal activity in Boran-, Brahman-, and Tuli-sired cows is similar when cows calve in thin to moderate body condition.

Digestion of low and high quality diets. The alfalfa pellets used for the high quality diet were produced in Oklahoma (Luther Mill and Farm Supply,

Table 4 . Dry matter intake (DMI) and digestibility of tall-grass prairie hay (low quality diet) by steers sired by Boran, Brahman, Gelbvieh, and Tuli bulls

	Sire breed					
Item	Boran	Brahman	Gelbvieh	Tuli	Mean	SE
DMI, lb/d;						
Year 1[a]	10.29	12.36	--	12.42	11.83	0.13
Year 2[b]	10.53	11.72	11.21	11.59	11.26	0.48
DMI, % BW;						
Year 1	1.70	1.87	--	2.00	1.87	.09
Year 2	1.63	1.71	1.67	1.70	1.68	.05
DM digestibility, %;						
Year 1	42.07	40.28	--	40.08	40.69	1.94
Year 2	42.33	43.45	43.54	44.23	43.39	1.04
N digestibility, %;						
Year 1	36.07	26.52	--	29.66	30.11	2.37
Year 2	19.38	21.16	14.82	20.04	18.85	4.60
N consumed lb/d;						
Year 1	0.0998	0.1132	--	0.1152	0.1104	0.0051
Year 2	0.0870	0.0967	0.0925	0.0958	0.0930	0.0040

[a]Trial conducted in 1993 = Year 1.
[b]Trial conducted in 1994 = Year 2.

Table 5. Dry matter intake (DMI) and digestibility of alfalfa pellets (high quality diet) by steers sired by Boran, Brahman, Gelbvieh, and Tuli bulls

	Sire breed					
Item	Boran	Brahman	Gelbvieh	Tuli	Mean	SE
DMI, lb/d;						
Year 1[a]	10.37	11.28	--	10.73	10.84	0.33
Year 2[b]	10.53	12.05	11.72	11.48	11.45	0.68
DM digestibility., %;						
Year 1	56.66	56.06	--	56.31	56.30	0.95
Year 2	54.22	55.72	57.02	55.27	55.56	2.0
N digestibility, %;						
Year 1	67.32	66.21	--	67.43	66.95	0.66
Year 2	63.96	66.05	65.83	65.92	65.44	1.70
N consumed lb/d;						
Year 1	0.3198	0.3480	--	0.3311	0.3346	0.0106
Year 2	0.3341	0.3830	0.3727	0.3648	0.3644	0.0218

[a]Trial conducted in 1993 = Year 1.
[b]Trial conducted in 1994 = Year 2.

Luher, OK) and contained 3.14% N, 49.05% NDF, and 31.74% ADF on a DM basis. The tall-grass prairie hay used for the low quality diet was harvested at the laboratory and contained 0.83% N, 79.55% NDF, and 53.11% ADF on a DM basis. Genotype did not significantly ($P > 0.10$) affect the amount of DM or N consumed or digestibility of the DM, NDF, ADF, or N components of the diet (Tables 4 and 5). Steers used in 1994 were heavier than the steers used in 1993 (649 lb vs 612 lb), but BW was not different ($P > 0.10$) among genotypes within year. Daily DMI was similar between the high quality and low quality diets (11.13 lb vs 11.53 lb), but the DM in the high quality was more digestible than the DM in the low quality diet (55.93% vs 42.04%). The amount of DM consumed by steers fed alfalfa pellets was limited to 1.87% of BW, so no differences in DMI occur in the high quality diet trials. Because the high quality diet had a higher concentration of N, the steers were able to consume more N (0.3180 lb vs 0.1013 lb) than when the low quality diet was fed. Nitrogen retention was not affected by genotype. Steers were able to retain an average of 0.0485 lb of N/d on the high quality diet and 0.0044 lb of N/d on the low quality diet.

Bos indicus cattle evolved under different forage and environmental conditions than *Bos taurus*, so it is anticipated that differences would exist in digestive kinetics and nutrient utilization (Moore et al., 1975; Beaver et al., 1989). Brahman may utilize low quality diets more efficiently than *Bos taurus* because they produce more saliva and have a different microbial population that can digest fiber more efficiently (Moore et al., 1975). We did not observe any differences in DMI or digestibility of high or low quality diets by steers sired by Boran, Brahman, or Tuli bulls. It has been shown that in response to increased DMI, Tuli calves will increase liver size at a more rapid rate than Boran or Brahman (Ferrell and

Jenkins, 1998). Increased liver size will increase maintenance cost, leaving less energy for growth. Brahman-sired calves do not store fat and protein at different rates than Tuli- or Boran-sired calves (Ferrell and Jenkins, 1998; Baker et al., 2001a). Differences in ADG among the breeds used in this study may be due more to nutrient utilization and the partitioning of energy to fat and protein than to DMI or DM digestion.

Conclusion

From these data we concluded that Tuli-sired calves are lighter at birth and grow slower then Brahman-sired calves. Tuli-sired F_1 females are lighter than Brahman-sired F_1 females, but both breed types wean similar amounts of calf per lb of BW. Boran-sired F_1 females are lighter than Brahman-sired F_1 females, but Boran-sired F_1 females wean more calf per lb of BW than any of the F_1 cows breed type used in this experiment.

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Genotype x Environment Interactions in Brahman, Angus, and Reciprocal Cross Cows and their Calves

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ABSTRACT: Stability of direct and maternal breed effects and individual and maternal heterosis across forage type was evaluated in a diallel of Brahman and Angus using preweaning data from 486 purebred and reciprocal-cross calves, milk yield and quality data from 139 purebred and reciprocal-cross cows, and reproductive and preweaning data on 190 purebred and reciprocal cross cows and their 434 Hereford-sired calves. Cows and calves were managed on either common bermudagrass or endophyte-infected tall fescue from 1985 through 1994; a combination of the two forages was included from 1995 through 1997. Calves were spring-born and not creep-fed. Milk yield was estimated by machine milking, and milk quality was evaluated in a commercial laboratory. Direct heterosis for birth weight, 205-d weight, weaning hip height, and weaning weight:height ratio (WT/HT) was important ($P < 0.01$) and consistent across forage type. Maternal effects for weaning hip height favored Angus on bermudagrass ($P < 0.05$) but not tall fescue. Direct effects for weaning hip height were larger in calves on bermudagrass than tall fescue. Direct heterosis for milk yield was evident on bermudagrass, tall fescue, and a combination of the forages ($P < 0.01$). Direct breed effects for milk fat were similar across forages in favor of Brahman ($P < 0.01$). Direct heterosis for calving rate was larger on tall fescue than bermudagrass or the forage combination ($P < 0.05$), whereas maternal effects were larger on bermudagrass than on the forage combination ($P < 0.10$). Maternal heterosis for birth weight was negative on bermudagrass ($P < 0.11$) but positive on tall fescue and the forage combination ($P < 0.10$). Maternal heterosis for 205-d weight, calf weaning hip height, and calf weaning weight:height ratio was generally greater on tall fescue than bermudagrass ($P < 0.10$). Heterosis for weaning weight per cow exposed was substantial on all forages ($P < 0.01$) and was greater on tall fescue ($P < 0.01$) than bermudagrass or the forage combination These data indicate direct heterosis for preweaning traits was relatively stable across the two forage types, but maternal and direct breed effects may vary with forage type. These data also evidenced more advantage to Brahman-cross cows over purebreds on tall fescue than bermudagrass.

Key Words: Beef Cattle, Environment, Forage, Genotypes, Heterosis

Introduction

The design of efficient beef cattle/forage systems requires that components of such systems be properly matched. The concept of matching animal genetic resources with production environment, considered by Wright (1939) and Lush (1951), as well as increasing productivity in cow-calf production have been of interest for many years. Among the many ways to increase productivity, improvement of the genetic composition of the cowherd is highly desirable, through both selection of superior breeding stock and through utilization of crosses of different breeds.

Crossbreeding in beef cattle is a time-tested management tool available to producers for increasing the efficiency of production. Advantages of crossbred animals include the ability to combine the merits of different breeds (direct breed effects), to use the superiority of different breed for maternal effects, and to use the effects resulting from hybrid calves and cows (direct and maternal heterosis). The maximum advantage is attained by crossing a superior sire breed with crossbred females of two other breeds having the optimal combinations of maternal and direct breed effects for traits of economic importance. The advantage of this three-breed cross over comparable two-breed crosses is primarily due to the expression of heterosis in the dam that is expressed in the offspring (maternal heterosis) plus interactions of this maternal heterosis with other genetic effects.

A complicating issue in crossbreeding is the potential for the genetic effects important in crossbreeding to differ across forage environments. The forage used in the production system is a very important component of efficiency of production. The forage base provides the primary nutrition of the cowherd and influences all aspects of production until the calf is weaned. Two forage environments common to the Mid-South include endophyte-infected tall fescue (E+) and common bermudagrass (BG).

There are about 35 million acres of E+ tall fescue in the United States, with the predominance occurring in the Mid-South. It is a cool-season forage that is easily established and has good persistence under grazing. Endophyte-infected tall fescue produces large amounts of forage that have acceptable levels of energy and crude protein prior to maturation in the late spring. It has obvious disadvantages for spring-calving cows in the South because of low forage growth in the summer and because the forage produces toxins that lower reproductive rates and calf growth. Although many alternatives have been tried, efforts to manage the toxicity of this forage have been only moderately successful or of marginal economic feasibility. Common bermudagrass is prevalent in the southern United States, with about 30 million acres established. It is a warm-season forage that has good levels of forage production in the summer and is persistent under heavy grazing. Bermudagrass has good levels of energy and crude protein in the early summer but lower levels toward the end of the growing season. It can be difficult to establish since most varieties must be sprigged and require proper soil moisture after sprigging and BG may not tolerate heavy, acidic, poorly drained soils common to the Mid-South.

Given the prevalence of both of these forages in the South and Mid-South, along with the potential for genetic effects to interact with forage environment, research was initiated to evaluate the productivity of Brahman-cross cattle both as calves and as cows on these two forages as contrasted with purebreds of the parent breeds. Thus, the objectives of these studies were: 1) to evaluate direct and maternal heterosis and maternal and grandmaternal breed effects in Angus, Brahman, and reciprocal cross cows and their two- and three-breed cross calves managed on either BG or E+, 2) to evaluate the breed groups of cows relative to tolerance of E+ tall fescue compared to BG, 3) to estimate individual heterosis, maternal breed effects, and direct breed effects for milk yield and quality and evaluate the interactions of these effects with forage environment

Materials and Methods

Phase I

Approximately 160 purebred Angus and Brahman cows born in the spring of 1985 were purchased at between 6 months and 1 year of age from several sources in Arkansas, Oklahoma, Texas, and Louisiana. These calves were stratified by breed and source to one of four 40-acre E+ pastures (100% infected) or one of four 40-acre BG pastures and managed on these forages through their first four calf crops. The soil type of these pastures was a Leadvale silt loam (fine-silty, siliceous, thermic, Typic Fragiudults).

These heifer calves were bred at two years of age to calve first as three-year olds to Angus and Brahman sires to produce purebred Angus (A x A), Brahman (B x B), Angus x Brahman (A x B), and Brahman x Angus (B x A) calves (sire breed listed first). Heifers were not bred to calve as 2 year olds because of the late maturity of Brahman. Five Angus and five Brahman sires were used in the study and rotated between forages so that sire effects were not confounded with forage environment. Calves were spring born in 1988 through 1991, weighed and tagged at birth, and bull calves were castrated. Calves were not creep-fed; they were weaned at an average age of 204 d. After weaning, calves were backgrounded on the forage they were weaned on and supplemented to gain approximately 0.75 lb per day through the winter. Milk production was measured in the purebred Brahman and Angus cows by method of milking machine in 1989, 1990, and 1991. Approximately 10 cows of each breed on both forages (approximately 40 cows) were milked each year, starting after calving season and continuing every 28 d until weaning. Data are reported as 24-h estimates averaged over the monthly estimates.

Heifer calves from the first phase of this research were retained to evaluate their performance as cows on the same forage systems. A total of 229 heifers were produced and raised on either BG or E+. Heifers were assigned to one of five 40-acre BG pastures or one of five 40-acre E+ pastures. Each pasture was stocked with approximately 24 heifers, with approximately equal numbers of A x A, B x B, A x B, and B x A. Pastures were fertilized with a total of 138 lb/acre of N in two applications; early May and mid-July for BG and early March and early October for E+. Phosphorus and K were applied as suggested by soil tests.

Data were analyzed by methods of least squares. The statistical analyses for preweaning, postweaning, and reproductive data (calving and weaning percentage) from progeny in the first phase accounted for year, sire breed, sire in sire breed, dam breed, forage, sex of calf, and appropriate two- and three-factor interactions among the fixed effects. Year and sire in sire breed were considered random and other effects fixed.

Phase II Bermudagrass, Fescue, or Rotational

Approximately 190 A x A, B x B, and reciprocal-cross cows (A x B and B x A) born in 1988 through 1991 and 434 two-and three-breed cross calves (Hereford-sired from A x A, A x B, B x A, and B x B

dams) were used to evaluate the effect of forage management system on reproductive and preweaning performance. Cows were managed on 40-acre pastures (0.5 head/acre) of either BG or endophyte-infected tall fescue E+ with all breed types represented in each pasture. After weaning in the fall of 1994, approximately 10 cows from each breed group in each forage were randomly assigned to a new forage management treatment, i.e., E+ in the fall and spring (November-May) and BG in the summer (June-October). Consequently, there were three 40-acre pastures of BG, three 40-acre pastures of E+, and two pairs of 40-acre BG and E+ pastures used in the rotational system (ROT). Stocking rates were approximately 0.5 hd/ acre for BG and E+ and an average of approximately 0.5 hd/acre on ROT (1.0 hd/acre on BG in summer and 1.0 hd/acre on E+ in fall and spring). Pastures were managed similar to Phase I management practices. Eight Polled Hereford bulls were used during the 1994 through 1996 breeding seasons. Thirteen different bulls were used throughout this portion of the study. Bulls were semen checked each year prior to the breeding season, and each breeding pasture was exposed to a minimum of two bulls. All bulls were used in all forage environments to preclude confounding sire effects with forage effects. Heifers were pregnancy checked in the fall each year during brucellosis certification procedures.

Calves were born from late February through May in 1995 through 1997. Calves were weighed at birth and tagged. Bull calves were castrated at birth by banding. Calves were weaned at an average age of 205 days when full weights and hip heights were taken. Creep-feeding was not practiced. A description of production and management of the purebred and crossbred cows used in this study is given by Brown et al. (1993a).

The ratio of weaning weight:weaning height (**WT/HT**) was calculated to estimate weaning condition. This ratio has been used as a predictor of body composition in mature cows (Klosterman et al., 1968; Lemenager and Martin, 1982; Nelsen et al., 1985), is less subjective than visual estimates of condition score (Lemenager and Martin, 1982), and is useful in describing the condition of cows that may vary widely in type and size (Klosterman et al., 1968).

Data were analyzed by methods of mixed model least squares. The statistical analyses for calving percentage accounted for effects of year, sire breed of cow, sire of cow in sire breed, dam breed of cow, forage, age of dam, and appropriate two-and three-factor interactions among the fixed effects where year and sire in sire breed were considered random and other effects fixed. The statistical analyses for preweaning traits of progeny accounted for effects of year, sire of calf, sire breed of cow, dam breed of cow, forage, age of dam, sex of calf, and appropriate interactions among fixed effects where year and sire of calf was random and other effects fixed. Individual and maternal heterosis, maternal and grandmaternal breed effects, and interactions of these effects with forage effects were computed from linear contrasts of the least-squares means and tested using *t* statistics.

Phase II Milk Production

Milk yield and quality were estimated in 1995 through 1997 in 93 A x A, B x B, and reciprocal-cross (A x B and B x A) cows born in 1988 through 1991. These cows were born, raised, and bred to calve as 3 year olds on either BG or E+. Animal and pasture management were consistent with that of a previous phase of this experiment as described by Brown et al. (1993a). Cows were selected from a population of 200 cows to get approximately equal numbers of ages and breed types in each forage. These criteria (including having a calf) dictated that cows be resampled each year.

Milk yield was estimated each year using a single-cow portable machine. Milk yield was estimated in all years at an average 60, 89, 116, 145, 172, and 200 d postpartum. Dates of estimates were late April to late September. Cows and calves were separated at approximately 1700 h the evening before milking and held for approximately 14 h overnight with hay and water provided. There was no milk-out prior to separation. Ten minutes before milking, cows were administered 1.5 mL of acepromazine; in addition, 1.0 mL of oxytocin (20 USP units/mL) was administered immediately before milking to induce milk let-down. After a cow was milked out, milk was weighed and triplicate samples were taken for estimates of milk fat, milk protein, and somatic cell count. Milk fat, milk protein, and somatic cell counts were estimated by a commercial laboratory using a Milkoscan System 4000® (Foss North America, Eden Prairie, MN; AOAC, 1990). Daily milk yield was estimated as twice the net weight of milk adjusted linearly to a 24-h basis ([milk weight/14]*24). Repeated measures analyses were done using least squares mixed models procedures. The initial linear model included year, sire breed, sire nested in sire breed, dam breed, forage, age, the pooled interaction of sire nested in sire breed with fixed effects, month of lactation, and all possible interactions among fixed effects and a residual of the interactions of sire within sire breed with month effects. Sire in sire breed, the pooled interaction of sire nested in sire breed with fixed effects, and the residual were considered random and other effects in the model were fixed. Heterosis, maternal breed effects, and direct breed effects were

estimated as linear constrasts of least square means and tested using "t" statistics. Error terms for heterosis, direct breed effects, and maternal breed effects were constructed from combinations of appropriate random effects by the mixed model procedure.

Results and Discussion

Phase I

Angus and Brahman Cows

Reproduction. Calving percentages and calving intervals for A x A and B x B cows from the first phase are given in Table 1 for each forage, averaged over four years. There was little evidence of breed differences in calving rate but some evidence that calving rate was lower on E+ for Angus ($P < 0.10$). These results are consistent with results of Piper et al. (1991) comparing endophyte-infected with endophyte-free fescue. Calving interval was longer for Brahman on BG ($P < 0.10$), consistent with their longer gestation, but not on E+, suggesting that Brahman received some nutritional benefit from the tall fescue in the spring.

Table 1. Calving percentage and calving interval of Angus and Brahman cows grazing common bermudagrass or endophyte-infected tall fescue, Phase I

Forage	Angus		Brahman	
	Calving %	Calving interval (d)	Calving %	Calving interval (d)
Bermuda	82.1 3.2	309 2	80.1 3.2	317 2
Fescue	73.5 3.6	311 2	73.5 3.4	310 2
BG vs E+	†	ns	ns	†

†$P < 0.10$

Milk Production. Least squares means for 24 h of milk production estimates for Angus and Brahman cows on BG and E+ are given in Table 2. Angus cows grazing E+ produced less ($P < 0.10$) milk than Angus on BG; however, milk production was not reduced by pasture in Brahman cows, suggesting E+ tolerance in the Brahman female. Average daily milk production estimates in Brahman in this study were similar to those reported by Niedhardt et al. (1979) for purebred Brahman cows in Venezula but were higher than estimates reported by Ngere et al. (1973) and Sacco et al. (1987) and lower than estimates by Criss (1986). Milk yields in the Angus in this study were reasonably similar to previous estimated for British cross cows (Cundiff et al., 1974; and Holloway et al., 1985). Values for the Angus in this study were lower than those reported by Kress et al. (1990) for Hereford and Angus x Hereford cross cows and lower than those reported by Criss (1986) for Angus cows. These data suggested that Brahman cows may be able to compensate for adverse effects of E+ forage in their milk production. Mechanisms for this were likely in forage consumption, rate of passage, heat dissipation, or a combination of these.

Table 2. Twenty-four hour milk production of Angus and Brahman cows grazing common bermudagrass or endophyte-infected tall fescue (lb), Phase I

Class	Angus	Brahman
Bermuda	14.07 0.60	12.81 0.62
Fescue	10.45 0.64	11.64 0.62
BG vs E+	†	ns

†$P < 0.10$

Angus, Brahman, and Reciprocal-cross Calves.

Least squares means, direct heterosis, maternal breed effects, and direct breed effects for Phase I calf preweaning traits are given in Table 3 through Table 6. Generally, sire breed, dam breed, sire breed x dam breed, and sex effects were important for all traits studied (data not shown). Forage effects were significant for preweaning ADG, 205-d weight, and weaning WT/HT, and forage effects interacted with both sire breed and dam breed ($P < 0.10$) for weaning hip height. Sire breed x dam breed effects for birth weight were not the same in both sexes ($P < 0.05$). Dam breed effects were different for heifer calves compared with steer calves in birth weight ($P < 0.01$) and weaning hip height ($P < 0.10$), and sire breed effects for birth weight were not the same in both sexes ($P < 0.01$).

Birth Weight. Averaged over sire and dam breed, there was little evidence of forage differences in birth weight in either sex in spite of the higher nutritional level of tall fescue during portions of the last trimester of pregnancy (Table 3). Averaged over forage, bulls exceeded heifers in birth weight by 7.28 lb ($P < 0.01$).

There was also little evidence of a forage x sex interaction for heterosis, maternal effects, or direct effects for birth weight, and these effects were consistent across forages when averaged over sex of calf. There was evidence that heterosis, maternal effects, and direct effects were not consistent across sex of calf ($P < 0.05$).

Heterosis for birth weight was larger in bull calves (10.4 lb, $P < 0.01$) than in heifers (5.9 lb, $P < 0.01$). These results are similar to work reported by Ellis et al. (1965) in Brahman and Hereford crosses of both sexes but contrast with work reported by Turner and McDonald (1969), who found heterosis in Brahman and Angus crosses to be numerically less in bulls. Heterosis averaged over sex in this study was comparable with other estimates in the literature

Table 3. Least squares means, heterosis, maternal, and direct breed effects and associated SE for birth weight (lb), Phase I

Class	A x A[a]	A x B	B x A	B x B	Direct heterosis	Maternal breed effects[b]	Direct Breed effects[c]
	76.3 1.1	69.5 1.3	92.8 1.3	69.9 1.1	8.2 1.1**	-23.4 1.8**	16.8 2.6**
Bermuda	77.2 1.3	68.8 1.5	91.9 1.8	67.7 1.5	7.9 1.5	-23.1 2.4	13.7 3.1
Fescue	75.4 1.5	70.3 1.8	93.7 2.0	71.9 1.5	8.4 1.8	-23.4 2.6	19.8 3.5
Heifers	74.1 1.3	68.4 1.5	84.7 1.8	67.0 1.5	5.9 1.5^{y}	-16.3 2.4^{x}	9.3 3.1^{x}
Steers	78.5 1.5	70.8 1.8	101.0 1.8	72.8 1.5	10.4 1.5^{x}	-30.2 2.4^{y}	24.7 3.5^{x}
Heifers							
Bermuda	74.5 1.8	69.0 2.0	83.8 2.4	66.1 2.2	6.2 2.0	-14.8 3.1^{x}	6.2 4.4^{x}
Fescue	73.6 1.8	67.7 2.4	85.3 2.6	67.9 2.2	5.7 2.4	-17.9 3.5^{x}	11.9 4.9^{xy}
Steers							
Bermuda	79.6 1.8	68.4 2.2	100.1 2.4	69.2 1.8	9.7 2.0	-31.5 3.3^{y}	19.7 4.4^{yz}
Fescue	77.2 2.2	73.2 2.6	102.1 2.6	76.1 2.2	10.8 2.4	-28.9 3.5^{y}	27.8 4.9^{z}

[a]A = Angus, B = Brahman, sire breed listed first.
[b]Heterosis = (A x B + B x A)/2 – (A x A + B x B)/2; Maternal breed effects = A x B – B x A;
Direct breed effects = 2* ((B x A + B x B)/2) – (A x B + A x A)/2).
[x,y,z]Class/subclass means within a column with different superscripts differ ($P < 0.05$).
[**]$P < 0.01$.

(Cartwright et al., 1964; Reynolds et al., 1980; Roberson et al., 1986; Comerford et al., 1987).

Maternal contrasts for birth weight were larger in bull calves (-30.2, $P < 0.01$) than in heifers (-16.3, $P < 0.01$), where negative values indicate lower birth weights in the Brahman dams. This interaction agrees with work by Ellis et al. (1965) in both sign and magnitude. It is also consistent with results of Ferrell (1991), who concluded that the lower birth weights in Brahman cows are a result of lower umbilical blood flow. It would seem reasonable that greater umbilical blood flow in Angus would allow expression of both sex differences and heterozygosity in birth weight, whereas this might be inhibited in Brahman. Average maternal contrasts in this study were similar to estimates reported by Roberson et al. (1986) and Comerford et al. (1987) but were larger in magnitude than those reported by Reynolds et al. (1980).

Direct breed contrasts for birth weight were also larger for bull calves (24.7, $P < 0.01$) than for heifers (9.3, $P < 0.01$), where positive values indicate higher birth weights from the Brahman sires. This also agrees with work by Ellis et al. (1965) and Turner and McDonald (1969), who reported larger direct effects in bull calves than heifers. When averaged over sex of calf, estimates from the current study were slightly larger but of the same sign as estimates in the literature (Reynolds et al., 1980; Roberson et al., 1986; Comerford et al., 1987).

The larger heterosis in male calves, larger direct effect in male calves, and apparent inability of the Angus dam to suppress the birth weight of the male calves suggest that technology to alter sex ratios may be beneficial when producing Brahman-sired calves from cows of British breeds to produce a higher proportion of heifer calves. This would have a dual economic benefit; heifer calves from this cross have a higher economic value than steers, and the lighter heifer birth weights result in lower levels of calving difficulty and associated subsequent reproductive problems in dams. The lack of forage effects on birth weight in this study suggests a reasonable stability of heterosis, maternal effects, and direct breed effects across these two forage environments.

205-Day Weight. Averaged over sire breed and dam breed, forage effects for 205-d weight were similar for each sex (Table 4). Steers exceeded heifers by 25.14 lb ($P < 0.01$). Forage differences averaged over sire and dam breed and sex of calf were 38.81 lb ($P < 0.01$) in favor of common bermudagrasss. Endophyte-infected tall fescue has been implicated in poorer preweaning performance in other studies (Burns et al., 1973; Smith et al., 1975; Hill et al., 1979; Holloway et al., 1979; Ellis et al., 1983; Ashley et al., 1987; Gay et al., 1987; Tucker et al., 1989).

Estimates of heterosis for 205-d weight were consistent across forage environment and sex of calf and averaged 61.7 lb ($P < 0.01$). Direct effects were smaller and averaged 26.9 lb ($P < 0.14$) on bermudagrass and 6.2 lb ($P > 0.75$) on tall fescue, both in favor of Brahman. Maternal effects averaged –25.3 lb ($P < 0.06$) on bermudagrass and –11.47 lb ($P > 0.42$) on tall fescue, both in favor of Angus. Estimates of heterosis from this research were comparable to higher estimates in the literature (Cartwright et al., 1964; Koger et al., 1975; Peacock et al., 1978; Roberson et al., 1986), but were somewhat higher than values reported by Damon et al. (1961) and Turner and McDonald (1969). The estimates of maternal contrasts in this study were closest to those reported by Peacock et al. (1978), but other estimates from the literature favored the Brahman dam and were larger (Koger et al., 1975; Roberson et al., 1986).

Table 4. Least squares means, heterosis, maternal, and direct breed effects and associated SE for 205-day weight (lb), Phase I

Class	A x A[a]	A x B	B x A	B x B	Heterosis	Maternal breed effects[b]	Direct breed effects[c]
	411.7 5.9	463.3 6.8	481.8 7.1	409.9 6.4	61.7 5.9**	-18.5 9.7†	16.3 14.1
Bermuda	427.1 7.3	481.6 8.8	506.9 9.3	428.9 8.4	66.1 7.9	-25.3 12.8	26.9 17.6
Fescue	396.2 8.6	445.0 9.3	456.4 10.6	390.9 9.3	57.3 9.0	-11.4 14.1	6.2 19.4
Heifers	405.9 7.3	445.6 8.4	467.9 9.9	396.7 9.0	55.3 8.4	-22.0 13.0	12.8 18.1
Steers	417.4 8.4	480.9 9.7	495.5 9.9	422.9 8.4	67.9 8.6	-14.8 13.7	20.3 19.0
Heifers							
Bermuda	424.9 9.7	461.7 11.2	490.2 12.8	419.2 12.3	54.0 11.0	-28.2 17.0	22.5 23.8
Fescue	387.0 10.1	428.6 12.6	445.6 15.0	374.2 13.2	56.9 12.8	-16.1 19.4	3.1 25.6
Steers							
Bermuda	429.5 9.9	501.2 12.1	523.7 13.0	438.3 9.8	73.0 11.2	-22.5 17.9	31.3 23.4
Fescue	405.3 12.6	460.6 13.7	467.5 14.6	407.5 12.3	57.5 13.0	-6.8 20.1	8.8 27.3

[a]A = Angus, B = Brahman, sire breed listed first.
[b]Heterosis = (A x B + B x A)/2 – (A x A + B x B)/2; Maternal breed effects = A x B – B x A;
Direct breed effects = 2* ((B x A + B x B)/2) – (A x B + A x A)/2).
†$P < 0.10$, **$P < 0.01$

Estimates of direct effects from this study were smaller than those reported by Turner and McDonald (1969) but of the same sign and were similar to those reported by Koger et al. (1975) on native Florida pasture and by Peacock et al. (1978). Roberson et al. (1986) reported a small direct effect in favor of the Hereford sire.

The maternal effects estimated in this study may differ from estimates in the literature because of potential interactions of these effects with location of study (i.e., Texas and Florida, where Brahman may be better adapted compared with west-central Arkansas). Burns et al. (1979) and Pahnish et al. (1985) reported significant line x location interactions for weaning weight in beef cattle. There was a nonsignificant trend for maternal effects estimated in this study to be larger on bermudagrass, and this was consistent with dam breed differences in milk production observed in these cattle on the two forages (Brown and Tharel, 1991). Koger et al. (1975) reported maternal contrasts for 205-d weight for Brahman and Shorthorn largest on Florida native pastures, intermediate on combinations of native and improved pastures, and lowest on improved pastures, where all contrasts were in favor of the Brahman dam. The environment in Arkansas seems to be more favorable to dams of British breeds, but the advantage in Angus dams compared with Brahman in this study was less in the poorer nutritional environment (tall fescue). Thus, these data agree with the findings of Koger et al. (1975) in showing a compensation by the Brahman dam in a poorer nutritional environment. It does not seem, however, that the forage environments evaluated in this study resulted in a differential response in heterosis.

Weaning Hip Height. Averaged over sire and dam breed, sex of calf differences in weaning hip height were consistent across forages and averaged 43.6 in for heifers and 44.6 in for steers ($P < 0.01$) (Table 5). Forage differences were small and unimportant.

There was little indication of forage x sex interaction of forage x sex interactions with heterosis, maternal effects, or direct effects for weaning hip height nor was there evidence of interactions of these effects with sex of calf. Heterosis, averaged over forage and sex of calf averaged 1.7 in ($P < 0.01$). There was evidence of interactions of maternal effects ($P < 0.05$) and direct effects ($P < 0.07$) with forage environment. Maternal contrasts on bermudagrass were –1.1 in ($P < 0.05$) and on tall fescue were 0.7 in ($P > 0.22$). Direct effects on bermudagrass averaged 3.7 in ($P < 0.01$) and 1.9 in ($P < 0.05$) on tall fescue indicating larger hip heights in Brahman.

In weaning hip height, calves from Angus dams seemed to receive a maternal advantage on bermudagrass, but not on tall fescue. Conversely, calves from Brahman sires received a direct breed advantage on both forages but it was larger on BG. These two effects tended to offset each other, making purebred differences very similar between the two forages.

Weaning Weight:Height Ratio. Averaged over sire and dam breed, calves on bermudagrass had higher ($P < 0.01$) WT/HT than did calves on tall fescue (10.4 vs. 9.52 lb/in, respectively) and steers were significantly higher than heifers (10.13 vs. 9.81 lb/in, $P < 0.01$) (Table 6).

Table 5. Least squares means, heterosis, maternal, and direct breed effects and associated SE for weaning hip height (in), Phase I

Class	A x A[a]	A x B	B x A	B x B	Direct Heterosis	Maternal breed effects[b]	Direct breed effects[c]
	41.9 0.2	44.8 0.3	45.0 0.3	44.6 0.2	1.7 0.2**	-0.2 0.4	2.8 1.0**
Bermuda	42.0 0.3	44.3 0.4	45.3 0.4	44.7 0.3	1.5 0.3	-1.1 0.5^{z}	3.7 0.7^{x}
Fescue	41.9 0.4	45.4 0.4	44.7 0.4	44.5 0.4	1.9 0.4	0.7 0.6^{y}	1.9 0.8^{w}
Heifers	41.7 0.3	44.0 0.4	44.7 0.4	44.0 0.4	1.5 0.3	-0.7 0.5	3.0 0.7
Steers	42.2 0.3	45.6 0.4	45.3 0.4	45.2 0.3	1.8 0.4	0.4 0.6	3.1 0.8
Heifers							
Bermuda	41.9 0.4	43.6 0.4	44.8 0.5	44.1 0.5	1.1 0.4	-1.2 0.7^{z}	3.5 0.9
Fescue	41.5 0.4	44.4 0.5	44.6 0.6	43.8 0.5	1.9 0.5	-0.2 0.8^{yz}	2.5 1.0
Steers							
Bermuda	42.1 0.4	45.0 0.5	45.9 0.5	45.2 0.4	1.7 0.4	-0.9 0.7^{z}	4.0 0.9^{x}
Fescue	42.2 0.5	46.3 0.6	44.7 0.6	45.2 0.5	1.8 0.5	1.6 0.8^{y}	1.3 1.1^{w}

[a]A = Angus, B = Brahman, sire breed listed first.
[b]Heterosis = (A x B + B x A)/2 – (A x A + B x B)/2; Maternal breed effects = A x B – B x A;
Direct breed effects = 2* ((B x A + B x B)/2) – (A x B + A x A)/2).
[w,x]Class/subclass means within a column with differeing superscripts differ ($P < 0.07$).
[y,z]Class/subclass means within a column with differing superscripts differ ($P < 0.05$).
[**]$P < .01$.

Table 6. Least squares means, heterosis, maternal, and direct breed effects and associated SE for weaning weight/height (lb/in), Phase I.

Class	A x A[a]	A x B	B x A	B x B	Direct heterosis	Maternal breed effects[b]	Direct breed effects[c]
	9.78 0.11	10.34 0.11	10.67 0.11	9.16 0.11	1.01 0.11**	-0.34 0.17†	-0.34 0.34
Bermuda	10.11 0.17	10.84 0.17	11.12 0.17	9.56 0.17	1.12 0.17	-0.28 0.28	-0.34 0.34
Fescue	9.39 0.17	9.78 0.17	10.17 0.22	8.77 0.17	0.89 0.17	-0.39 0.28	-0.22 0.34
Heifers	9.67 0.17	10.11 0.17	10.45 0.17	9.00 0.17	0.95 0.17	-0.34 0.28	-0.34 0.34
Steers	9.83 0.17	10.51 0.17	10.84 0.22	9.33 0.17	1.12 0.17	-0.34 0.28	-0.22 0.34
Heifers							
Bermuda	10.11 0.17	10.56 0.22	10.90 0.22	9.44 0.22	0.95 0.22	-0.34 0.34	-0.34 0.45
Fescue	9.39 0.22	9.67 0.28	9.95 0.28	8.49 0.28	0.89 0.28	-0.28 0.39	-0.45 0.56
Steers							
Bermuda	10.17 0.22	11.12 0.22	11.29 0.28	9.61 0.22	1.34 0.22	-0.17 0.34	-0.34 0.45
Fescue	9.56 0.22	9.89 0.28	10.45 0.28	9.00 0.22	0.89 0.28	-0.50 0.39	0.00 0.56

[a]A = Angus, B = Brahman, sire breed listed first.
[b]Heterosis = (A x B + B x A)/2 – (A x A + B x B)/2; Maternal breed effects = A x B – B x A;
Direct breed effects = 2* ((B x A + B x B)/2) – (A x B + A x A)/2).
[†]$P < 0.10$, **$P < 0.01$

Table 7. Performance from weaning to 365-d of Angus, Brahman, and reciprocal cross calves on common bermudagrass or endophyte-infected tall fescue (lb), Phase I

Trait	Class	A x A	A x B	B x A	B x B	Heterosis	Maternal breed effects	Direct breed effects
ADG	Bermuda	0.73 0.02	0.68 0.04	0.77 0.04	0.40 0.04	0.18 0.02**	-0.09 0.08	-0.26 0.11*
	Fescue	0.86 0.04	0.93 0.04	1.04 0.04	0.57 0.04	0.26 0.04**	-0.09 0.08	-0.20 0.13
	B vs F	*	**	**	**	*	ns	ns
365-d wt	Bermuda	575 8.58	611 10.78	665 10.56	521 9.68	90 9.02**	-54 3.76*	0
	Fescue	563 10.12	621 10.34	649 11.88	505 11.0	101 10.34**	-29 24.64	-30 33.6
	B vs F	ns	ns	ns	ns	ns	ns	ns

*$P < 0.05$
**$P < 0.01$
[b]Heterosis = (A x B + B x A)/2 – (A x A + B x B)/2; Maternal breed effects = A x B – B x A;
Direct breed effects = 2* ((B x A + B x B)/2) – (A x B + A x A)/2).

There was little indication of interactions of heterosis, maternal effects, or direct effects with either forage environment or sex of calf. Heterosis for WT/HT averaged 1.01 lb/in ($P < 0.01$), maternal effects averaged -.34 lb/in ($P < 0.09$) in favor of the Angus dam and direct effects were not significant but

in favor of the Angus sire. Weaning weight and WT/HT are strongly correlated (r = 0.92, $P < 0.01$) so that relative magnitudes of average heterosis, maternal, and direct effects for WT/HT tended to be more closely associated with weaning weight than weaning hip height. However, the similar interactions of forage effects in both 205-d weight and weaning hip height resulted in similar estimates of maternal and direct effects for WT/HT in both forages. Koger et al. (1975) and Peacock et al. (1978) reported significant heterosis for weaning condition score. Their estimates of maternal effects for weaning condition score favored the Brahman dam except for Koger et al. (1975) on improved pastures where the Shorthorn dam was favored. Estimates of direct effects in these studies favored the sires of British breeds and the advantages reported by Koger et al. (1975) increased with the better nutritional environments.

Postweaning Traits. Least squares means, direct heterosis, maternal breed effects and direct breed effects for postweaning ADG and 365-d weight are given in Table 7. Calves on E+ gained more per day compared to calves on BG ($P < 0.01$), primarily because calves on E+ had access to growing forage in the fall and spring whereas calves on BG did not. Individual heterosis for postweaning ADG was higher on E+ compared to BG ($P < 0.05$), supporting the theory that heterosis is higher under better nutritional environments. This is consistent with the hypothesis of Barlow (1981), who suggested that heterosis for growth is larger in better environments and with the finding of Long et al., (1979), who reported higher levels of heterosis in crosses of Angus and Brahman in better nutritional regimes. There was very little evidence of forage differences in 365-d weights, suggesting that the calves weaned on E+ were able to compensate for lower gains during the preweaning period.

Phase II Bermudagrass, Fescue or Fescue-Bermuda Combination

Angus, Brahman, and Reciprocal-cross Cows

Calving Percentage. Calving percentage per cow exposed (CPE) is presented in Table 8 for each breed group grazing BG, tall fescue E+, or the combination of forages (ROT) . Angus on BG and ROT were 36.6 and 38.3% higher than Angus on E+ ($P < 0.01$), respectively. The only other forage effect within breed was in A x B where cows on BG were 15% higher than cows on ROT ($P < .10$). Heterosis in CPE was important (29.6%, $P < 0.01$) on E+ and similar but not significant on BG and ROT (9.5 and 2.6%). Brown et al. (1997) reported a 13.3% advantage for Angus on BG compared to Angus on E+ with heterosis in B x A crosses numerically larger on E+ compared to BG. Olson et al. (1993) reported heterosis estimates of 7.6% in crosses of Brahman with Angus for pregnancy rate and 8.0% in crosses of Brahman with Charolais, similar to estimates of Koger et al. (1975) in Brahman x Shorthorn crosses for weaning rate. Winder et al. (1992) reported heterosis of 12.0% for weaning rate in Hereford x Brangus crosses. Neville et al. (1984) did not find significant heterosis for calving rate in crosses of Angus, Hereford, and Santa Getrudis. Long (1980), in a summary of crossbreeding results, reported heterosis in calving rate of 6.5% to 9.6% in British x Brahman crosses and 2.4% to 6.7% in British crosses. There was evidence of interaction of maternal breed effects for CPE (as a trait of the cow) with forage in this research with maternal effects in favor of Brahman dams on BG and maternal effects in favor of Angus dams on ROT.

Milk Yield. Least square means, heterosis, maternal breed effects and direct breed effects for average milk yield are given in Table 9. Milk yield of cows on E+ was lower than cows on BG and ROT for A x A ($P < 0.01$), A x B ($P < 0.10$), B x A ($P < 0.01$), B x B ($P < 0.10$), and averaged over breed group ($P < 0.01$). Milk yield of A x A on ROT was lower ($P < 0.01$) than A x A on BG, but milk yield was similar on BG and ROT for Ax B, B x A, and B x B. Rotating cows from E+ to BG was effective (compared to E+) for all breed groups ($P < 0.10$), but appeared to be most effective for A x A and B x A based on the E+ vs ROT in each breed. Heterosis for milk yield was similar for each forage treatment and averaged 5.3 lb ($P < 0.01$) across forages. However, a trend existed for heterosis to be smallest on BG, intermediate on E+, and largest on ROT. Maternal effects for milk yield were not evident on any forage. Direct effects were similar for each forage treatment and averaged 4.9 lb in favor of the B x B ($P < 0.11$) across forages with a numerical trend for direct effects to be less on BG, intermediate on E+, and largest on ROT. Brown et al. (1996) reported higher levels of heterosis for milk yield on BG compared to E+ and direct effects in favor of B x B. Criss (1986) reported an estimate of 4.3 lb for heterosis for 12-h milk yield in crosses of Brahman and Angus. Cundiff et al. (1974) reported .5 lb for heterosis in 12-h milk yields of British cows and Notter et al. (1978) reported 0.9 lb for heterosis in 12-h milk yield of Angus-Hereford reciprocal crosses. Notter et al. (1978) reported small maternal effects for milk yield in favor of Hereford dams (1.3 lb). Criss (1986) reported higher levels of milk yield in Brahman compared to Angus in Mississippi.

Table 8. Least squares means, heterosis, maternal effects, and SE for calving rate (%) for cows from bermudagrass, tall fescue, and rotational forage environments, Phase II

Preweaning Environment	Breed Group[a] A x A	A x B	B x A	B x B	Mean	Direct heterosis	Maternal breed effects
Bermudagrass	93.0 6.5[b]	100.0 6.0[f]	86.8 6.0	75.2 5.6[hi]	88.8 3.1	9.5 5.9[d]	13.6 8.5[f]
Tall Fescue	56.4 7.2[c]	93.2 7.1[fg]	87.1 6.5	64.7 5.4[h]	75.3 3.3	29.6 6.5[**e]	6.1 9.6[fg]
Rotation	94.7 5.5[b]	85.0 5.2[g]	92.4 5.7	77.6 6.1[i]	87.4 2.9	2.6 5.5[d]	-7.4 7.7[g]
Mean	81.4 3.9	92.9 3.7	88.8 3.6	72.5 3.4		13.9 3.5[**]	4.1 5.2

[a]A = Angus and B = Brahman; breed of sire listed first.
[b,c]Means in the same column with differing superscripts differ ($P < 0.01$).
[d,e]Means in the same column with differing superscripts differ ($P < 0.05$).
[f,g]Means in the same column with differing superscripts differ ($P < 0.10$).
[h,I]Means in the same column with differing superscripts differ ($P = 0.11$).
[**]$P < 0.01$ (H_o: heterosis or maternal effect = 0).

Milk Fat. Least square means, heterosis, maternal breed effects and direct breed effects for average milk fat are given in Table 10. Milk fat for cows on ROT was greater than that of cows on BG or E+ ($P < 0.05$), possibly due to a better sustained plane of nutrition for cows on ROT. There was little evidence of heterosis or maternal breed effects for milk fat, but direct breed effects averaged 0.86% in favor of B x B. Criss (1986) reported negative and nonsignificant heterosis for milk fat in crosses of Brahman and Angus. Cundiff et al. (1974) reported negative estimates of heterosis for percent milk fat in British cows and Robison et al. (1981) reported small and(or) negative heterosis for this trait in dairy cows. Criss (1986) and Brown et al. (1993b) reported higher levels of milk fat for Brahman than Angus.

Milk Protein. Least square means, heterosis, maternal breed effects and direct breed effects for average milk protein are given in Table 11. Milk protein was relatively stable across both breed group and forage with two exceptions: B x A on E+ had higher milk protein than contemporaries on BG and ROT ($P < 0.05$) and Bx B on ROT had higher protein than contemporaries on BG ($P < .05$). Reasons for these differences are not evident nor is the practical significance of these observations. Heterosis for milk protein was negative on ROT ($P < 0.10$) but there was little evidence of heterosis on BG or E+. There was also little evidence of maternal or direct breed effects for this trait. Criss (1986) reported similar milk protein estimates for Brahman and Angus with little evidence of heterosis for this trait.

Somatic Cell Count. Least square means, heterosis, maternal breed effects and direct breed effects for somatic cell count are given in Table 12. Angus on E+ tended to have higher SCC than A x A on BG ($P < 0.11$) but there was little evidence of other forage differences in SCC. There was evidence of favorable heterosis on BG ($P < 0.05$), E+ ($P < 0.01$), and averaged over forage ($P < 0.01$), maternal breed effects on ROT favoring A x A ($P < 0.10$), and direct breed effects on ROT favoring B x B ($P < 0.10$). Brown et al. (1996) reported heterosis for SCC on E+ but not BG and Brown et al. (1998) reported favorable heterosis for presence of mastitis-causing organisms in Brahman-Angus reciprocal crosses. Criss (1986) reported Brahman and Angus scored similarly but higher than crossbreds for Wisconsin Mastitis Scores; this is consistent with our findings from this study.

Hereford-sired Calves from Angus, Brahman, and Reciprocal-cross Cows

Birth weight. Least squares means for birth weight are presented in Table 13. Calves from A x A dams were heavier on BG than E+ ($P < 0.05$), calves from A x B dams were heavier on ROT and E+ than BG ($P < 0.01$), and calves from B x A dams were heavier on ROT than E+ ($P < 0.10$). There was evidence of favorable maternal heterosis for birth weight on BG ($P < 0.11$) and unfavorable maternal heterosis on ROT and E+ ($P < 0.10$) with maternal heterosis interacting with forage ($P < 0.05$). Similarly, there was evidence of grandmaternal effects favoring Angus on E+ ($P < 0.01$) and Brahman on BG ($P < 0.10$). Interactions of grandmaternal effects with forage environment were significant ($P < 0.05$). Brown et al. (1997) found little evidence of forage effects on birth weight comparing BG and E+ but reported favorable maternal heterosis on BG in crosses of Brahman and Angus and grandmaternal effects in favor of Brahman on BG. Olson et al. (1993) reported 6.39 lb maternal heterosis for birth weight in crosses of Angus and Brahman but estimates

Table 9. Least squares means, heterosis, maternal effects, and SE for 24-h milk yield (lb) for cows from bermudagrass, tall fescue, and rotational forage environments, Phase II

Preweaning Environment	Breed group[a] A x A	A x B	B x A	B x B	Average	Direct heterosis [j]	Maternal breed effects [j]	Direct breed effects [j]
Bermudagrass	16.64 1.79[a]	23.26 1.90[g]	22.46 1.65[a]	20.32 1.72[g]	20.68 1.08[a]	4.39 1.41[**]	0.79 2.47	2.89 3.75
Tall Fescue	7.47 1.87[b]	16.75 1.85[h]	15.92 1.54[b]	13.91 1.68[h]	13.51 1.04[b]	5.64 1.46[**]	0.84 2.31	5.60 3.70
Rotational	12.68 1.72[c]	20.24 1.63[g]	21.60 1.74[a]	17.37 1.72[g]	17.97 1.04[c]	5.91 1.34[**]	-1.34 2.31	6.06 3.66[‡]
Average	12.26 1.34	20.08 1.32	20.00 1.17	17.22 1.21		5.31 0.86[**]	0.09 1.63	4.85 2.80[‡]

[a]A = Angus and B = Brahman; breed of sire listed first.
[‡]$P < 0.11$ (H_0: heterosis, direct effect, or maternal effect = 0)
[**]$P < 0.01$ (H_0: heterosis, direct effect, or maternal effect = 0)
[a,b,c]Means in the same column with differing superscripts differ ($P < 0.01$).
[d,e,f]Means in the same column with differing superscripts differ ($P < 0.05$).
[g,h,i]Means in the same column with differing superscripts differ ($P < 0.10$).
[j]Heterosis=(A x B + B x A)/2 - (A x A + B x B)/2; Maternal breed effects=A x B – B x A; Direct breed effects = 2*((B x A + B x B)/2) - (A x B + A x A)/2)

Table 10. Least squares means, heterosis, maternal effects, and SE for milk fat (%) for cows from bermudagrass, tall fescue, and rotational forage environments, Phase II

Preweaning Environment	Breed group[a] A x A	A x B	B x A	B x B	Average	Direct heterosis [j]	Maternal breed effects [j]	Direct breed effects [j]
Bermudagrass	2.94 0.30	3.29 0.35	3.08 0.28	3.73 0.29[d]	3.26 0.20[d]	-0.15 0.27	0.21 0.39	0.58 0.54
Tall Fescue	2.90 0.33	3.19 0.32	3.43 0.26	3.67 0.27[d]	3.30 0.19[d]	0.02 0.26	-0.25 0.37	1.02 0.56[†]
Rotational	3.57 0.29	3.72 0.27	3.70 0.30	4.58 0.30[e]	3.89 0.19[e]	-0.36 0.25	0.02 0.35	0.99 0.50[†]
Average	3.14 0.18	3.40 0.18	3.40 0.16	4.00 0.17		-0.16 0.15	0.00 0.22	0.86 0.31[**]

[a]A = Angus and B = Brahman; breed of sire listed first.
[†]$P < 0.10$ (H_0: heterosis, direct effect, or maternal effect = 0)
[**]$P < 0.01$ (H_0: heterosis, direct effect, or maternal effect = 0)
[d,e,] Means in the same column with differing superscripts differ ($P < 0.05$).
[j]Heterosis=(A x B + B x A)/2 - (A x A + B x B)/2; Maternal breed effects=A x B – B x A; Direct breed effects = 2*((B x A + B x B)/2) - (A x B + A x A)/2)

Table 11. Least squares means, heterosis, maternal effects, and SE for milk protein (%) for cows from bermudagrass, tall fescue, and rotational forage environments, Phase II

Preweaning Environment	Breed group[a] A x A	A x B	B x A	B x B	Average	Direct heterosis [j]	Maternal breed effects [j]	Direct breed effects [j]
Bermudagrass	3.30 0.10	3.24 0.10	3.24 0.09[d]	3.34 0.09[d]	3.31 0.06	-0.01 0.07	0.13 0.14	-0.04 0.23
Tall Fescue	3.37 0.11	3.42 0.09	3.44 0.09[e]	3.39 0.09[d,e]	3.36 0.06	-0.04 0.07	-0.20 0.14	0.23 0.23
Rotational	3.35 0.09	3.24 0.09	3.21 0.10[d]	3.54 0.09[e]	3.38 0.05	-0.13 0.07[†]	0.20 0.14	0.00 0.22
Average	3.34 0.08	3.34 0.08	3.30 0..07	3.42 0.07		-0.06 0.05	0.04 0.10	0.04 0.18

[a]A = Angus and B = Brahman; breed of sire listed first.
[†]$P < 0.10$ (H_0: heterosis, direct effect, or maternal effect = 0)
[d,e,] Means in the same column with differing superscripts differ ($P < 0.05$).
[j]Heterosis=(A x B + B x A)/2 - (A x A + B x B)/2; Maternal breed effects=A x B – B x A; Direct breed effects = 2*((B x A + B x B)/2) - (A x B + A x A)/2)

Table 12. Least squares means, heterosis, maternal effects, and SE for somatic cell count (x 10^{-3}) for cows from bermudagrass, tall fescue, and rotational forage environments, Phase II

Preweaning Environment	Breed group[a] A x A	A x B	B x A	B x B	Average	Direct heterosis [j]	Maternal breed effects [j]	Direct breed effects [j]
Bermudagrass	178 91[g]	149 88	0 85	229 86	133 53	-139 66[*]	171 123	-120 174
Tall Fescue	340 96[h]	128 88	55 82	246 82	192 52	-202 70[**]	74 118	-168 175
Rotational	273 87[gh]	249 84	42 85	151 85	179 51	-67 65	208 118[†]	-329 171[†]
Average	264 73	176 69	25 66	209 67		-136 51[**]	151 102	-150

[a]A = Angus and B = Brahman; breed of sire listed first.
[†]$P < 0.10$ (H_0: heterosis, direct effect, or maternal effect = 0)
[**]$P < 0.01$ (H_0: heterosis, direct effect, or maternal effect = 0)
[g, h] Means in the same column with differing superscripts differ ($P < 0.11$)
[j]Heterosis=(A x B + B x A)/2 - (A x A + B x B)/2; Maternal breed effects=A x B – B x A; Direct breed effects = 2*((B x A + B x B)/2) - (A x B + A x A)/2)

Table 13. Least squares means, maternal heterosis, grandmaternal effects, and SE for birth weight (lb) for calves from bermudagrass, tall fescue, and rotational preweaning environments, Phase II

Preweaning Environment	Breed Group[a] A x A	A x B	B x A	B x B	Mean	Maternal heterosis	Grandmaternal breed effects
Bermudagrass	90.2 3.7[d]	73.2 4.4[b]	82.5 3.3[fg]	77.2 3.7	80.7 2.2	-5.7 3.5[d]	-9.3 5.3[†d]
Tall Fescue	75.0 6.4[c]	91.3 4.6[c]	76.7 6.2[f]	73.2 4.4	79.1 2.9	9.9 5.3[†c]	14.5 7.5[**c]
Rotation	86.4 3.1[de]	86.9 2.9[c]	90.0 3.3[g]	78.7 4.4	85.5 .20	5.7 3.3[†e]	-3.1 4.0[d]
Mean	83.8 2.9	83.8 2.4	83.1 2.6	76.3 2.6		3.3 2.4	0.7 3.4

[a]A = Angus grandparent and B = Brahman grandparent; breed of sire listed first.
[b,c]Means in the same column with differing superscripts differ ($P < 0.01$).
[d,e]Means in the same column with differing superscripts differ ($P < 0.05$).
[f,g]Means in the same column with differing superscripts differ ($P < 0.10$).
$P < 0.11$, [†]$P < 0.10$, [**]$P < 0.01$ (H_o: maternal heterosis or grandmaternal effect = 0).

Table 14. Least squares means, maternal heterosis, grandmaternal effects, and SE for 205-d weight (lb) for calves from bermudagrass, tall fescue, and rotational preweaning environments, Phase II

Preweaning Environment	Breed Group[a] A x A	A x B	B x A	B x B	Mean	Maternal heterosis	Grandmaternal breed effects
Bermudagrass	489.3 15.9[b]	551.5 15.9[e]	577.3 14.5[g]	549.7 15.9[b]	542.0 11.0	45.0 9.7[**g]	-25.8 18.5
Tall Fescue	377.3 26.9[c]	500.1 19.0[f]	510.2 20.3[h]	491.9 18.1[c]	469.9 16.1	70.6 13.2[**h]	-9.9 20.9
Rotation	436.4 14.1[d]	542.6 13.0[e]	547.9 14.3[i]	525.7 16.8[bc]	513.1 10.1	64.4 9.5[**gh]	-5.1 17.2
Mean	434.4 14.1	531.4 11.5	545.1 11.9	522.4 12.1		60.0 6.4[**]	-13.7 15.2

[a]A = Angus grandparent and B = Brahman grandparent; breed of sire listed first.
[b,c,d]Means in the same column with differing superscripts differ ($P < 0.01$).
[e,f]Means in the same column with differing superscripts differ ($P < 0.05$).
[g,h,i]Means in the same column with differing superscripts differ ($P < 0.10$).
[**]$P < 0.01$ (H_o: maternal heterosis or grandmaternal effect = 0).

in crosses of Angus and Charolais and Brahman and Charolais were not significant. Sacco et al. (1989) did not find significant maternal heterosis for birth weight in Brahman x British crosses. Dearborn et al. (1987) reported maternal heterosis estimates for birth weights in crosses among Red Poll, Brown Swiss, Hereford, and Angus ranging from 3.09 lb to 1.10 lb.

205 d Weight. Least squares means for 205 d weight are given in Table 14. There was evidence of breed group and forage effects in 205-d weight ($P < 0.01$). Additionally, there was evidence of substantial maternal heterosis for this trait ($P < 0.01$) with maternal heterosis for 205-day weight larger on E+ compared to BG ($P < 0.10$). There was little evidence of grandmaternal effects but estimates favored the Angus granddams for this trait for calves on all forages. Brown et al. (1997) reported significantly higher maternal heterosis in 205 d weight in calves from Brahman and Angus crosses on E+ compared to BG. Estimates of maternal heterosis for weaning weight in crosses of Brahman with Charolais and Angus reported by Olson et al. (1993) were similar to estimates from this research on BG but were lower than estimates on E+ and ROT. Long (1980) reported estimates of maternal heterosis in weaning weight from Brahman x British crosses ranging from 30.43 lb to 63.95 lb while estimates in British crosses ranged from 15.44 lb to 22.05 lb. Sacco et al. (1989) reported maternal heterosis for weaning weight of 38.81 lb and 61.08 lb for calves from crosses of Brahman with Angus and Hereford, respectively. Koger et al. (1975) reported levels of maternal heterosis in calves from crosses of Brahman and Shorthorn similar to those in current study.

Weaning Hip Height. Least squares means for weaning hip height are given in Table 15. Calves from A x A on BG and ROT exceeded those on E+ ($P < 0.05$); calves from A x B and B x A on ROT exceeded those on BG and E+ ($P < 0.05$); and calves from B x B on ROT exceeded those on BG ($P < 0.10$). Maternal heterosis for this trait was important in all forages ($P < 0.01$ for E+ and ROT; $P < 0.10$ for BG) but larger on E+ and ROT than BG ($P < 0.01$). Grandmaternal effects were not evident on any forage. Brown et al. (1997) reported significantly higher maternal heterosis in hip height for calves from crosses of Brahman and Angus on E+ compared to BG. Sacco et al. (1989) reported maternal heterosis for weaning hip height of 0.71 in and 1.06 in for calves from crosses of Brahman with Angus and Hereford, respectively.

Weaning Weight:Height Ratio. Least squares means for weaning weight to hip height ratio are given in Table 16. Calves from A x A on BG exceeded those on ROT and E+ ($P < 0.01$) and calves from A x A on ROT exceeded those on E+ ($P < 0.05$); and calves from A x B, B x A, and B x B on BG exceeded contemporary calves from E+ and ROT ($P < 0.05$). Maternal heterosis for weight:height ratio was important ($P < 0.01$) and similar among forages. There was little evidence of grandmaternal effects for any forage. Estimates of maternal heterosis for this ratio for calves from Brahman and Angus crosses reported by Brown et al. (1997) were higher in calves managed on E+ than calves on BG. Olson et al. (1993) reported substantial maternal heterosis for weaning condition score in calves from crosses of Brahman with Angus and Charolais, but estimates in crosses of Angus and Charolais were smaller. Koger et al. (1975) reported maternal heterosis for weaning condition score in calves from Brahman x Shorthorn crosses similar to Olson et al. (1993).

Weaning Weight per Cow Exposed. The combination of reproductive and maternal performance of the cow and growth of the calf is reflected in weaning weight per cow exposed (Table 17). Heterosis for this trait was important ($P < 0.01$) and was larger on E+ compared to BG and ROT ($P < 0.01$). On BG and ROT, crossbred cows weaned 98.56 and 112.23 lb ($P < 0.01$) more calf per cow exposed, respectively compared to purebred cows while crossbred cows on E+ weaned 277.39 lb ($P < 0.01$) more calf per cow exposed compared to purebreds. In this trait, tolerance by the crossbred cows and their calves to endophyte-infected fescue is suggested. Heterosis for 205 d weight per cow exposed reported by Brown et al. (1997) was numerically higher in Brahman-Angus crosses on E+ compared to contemporaries on BG. Winder et al. (1992) reported heterosis of 76.29 lb in weaning weight per year. Koger et al. (1975) reported heterosis of 101.65 lb in annual production per cow in Brahman x British crosses while Dearborn et al. (1987) reported values ranging from –10.36 lb to 79.16 lb in crosses among Red Poll, Brown Swiss, Hereford, and Angus.

Implications

Heterosis, maternal effects, and direct breed effects are important components of cow-calf productions systems. It is important to know whether these genetic effects vary across production environments and the nature of this variation, if it exits. Our research did not find evidence of relationships of the level of direct heterosis to forage environment but did suggest that maternal effects and direct breed effects for weaning weight and hip height may be larger on

Table 15. Least squares means, maternal heterosis, grandmaternal effects, and SE for weaning hip height (in) for calves from bermudagrass, tall fescue, and rotational preweaning environments, Phase II

Preweaning Environment	Breed Group[a] A x A	A x B	B x A	B x B	Mean	Maternal heterosis	Grandmaternal breed effects
Bermudagrass	43.5 0.5[d]	45.2 0.5[d]	45.7 0.5[d]	46.2 0.5[f]	45.1 0.4	0.6 0.3[†b]	-0.5 0.6
Tall Fescue	41.3 0.9[c]	45.8 0.6[d]	45.6 0.6[d]	46.4 0.6[fg]	44.8 0.5	1.9 0.4[**c]	0.2 0.7
Rotation	43.9 0.4[d]	47.3 0.4[e]	47.4 0.5[e]	47.4 0.6[g]	46.5 0.3	1.7 0.3[**c]	-0.2 0.6
Mean	42.9 0.4	46.1 0.4	46.3 0.4	46.7 0.4		1.4 0.2[**]	-0.2 0.5

[a]A = Angus grandparent and B = Brahman grandparent; breed of sire listed first.
[b,c]Means in the same column with differing superscripts differ ($P < 0.01$).
[d,e]Means in the same column with differing superscripts differ ($P < 0.05$).
[f,g]Means in the same column with differing superscripts differ ($P < 0.10$).
[†]$P < 0.10$, [**]$P < 0.01$ (H_o: maternal heterosis or grandmaternal effect = 0).

Table 16. Least squares means, maternal heterosis, grandmaternal effects, and SE for weight:height ratio (lb/in) for calves from bermudagrass, tall fescue, and rotational preweaning environments, Phase II

Preweaning Environment	Breed Group[a] A x A	A x B	B x A	B x B	Mean	Maternal heterosis	Grandmaternal breed effects
Bermudagrass	11.23 0.28[d]	12.57 0.28[b]	12.57 0.28[b]	11.85 0.28[d]	11.96 0.17	0.84 0.17[**]	-0.39 0.34
Tall Fescue	9.05 0.50[e]	11.12 0.34[c]	11.12 0.34[c]	10.56 0.34[e]	10.39 0.28	1.17 0.22[**]	-0.22 0.39
Rotation	9.89 0.22[f]	11.51 0.22[c]	11.51 0.28[c]	11.06 0.28[e]	10.95 0.17	1.01 0.17[**]	-0.11 0.28
Mean	10.06 0.22[a]	11.73 0.22[a]	11.73 0.22[a]	11.18 0.22[a]		1.01 0.11[**]	-0.28 0.28

[a]A = Angus grandparent and B = Brahman grandparent; breed of sire listed first.
[b,c]Means in the same column with differing superscripts differ ($P < 0.01$).
[d,e,f]Means in the same column with differing superscripts differ ($P < 0.05$).
[**]$P < 0.01$ (H_o: maternal heterosis or grandmaternal effect = 0).

Table 17. Least squares means, heterosis, maternal effects, and SE for weaning weight per cow exposed (lb) for cows from bermudagrass, tall fescue, and rotational preweaning environments, Phase II

Preweaning Environment	Breed Group[a] A x A	A x B	B x A	B x B	Mean	Direct heterosis	Maternal Breed effects
Bermudagrass	488.2 44.1[b]	581.7 41.4[f]	515.7 39.9	412.1 37.9[d]	499.4 22.0	98.6 37.0[**b]	65.9 57.5
Tall Fescue	164.3 51.6[c]	533.2 48.3[fg]	487.1 44.1	301.2 37.3[e]	371.3 24.0	277.4 43.2[**c]	46.3 65.5
Rotation	405.5 38.6[b]	503.0 36.4[g]	532.7 38.6	405.7 41.2[d]	461.7 21.2	112.2 34.6[**b]	-29.8 53.1
Mean	352.6 30.0	539.3 28.7	511.8 26.9	372.9 25.6		162.7 22.3[**]	27.6 39.2

[a]A = Angus and B = Brahman; breed of sire listed first.
[b,c]Means in the same column with differing superscripts differ ($P < 0.01$).
[d,e]Means in the same column with differing superscripts differ ($P < 0.05$).
[f,g]Means in the same column with differing superscripts differ ($P < 0.11$).
[**]$P < 0.01$ (H_o: maternal heterosis or grandmaternal effect = 0).

common bermudagrass than on endophyte-infected tall fescue. Consequently, choices of breeds in crossbreeding systems may depend on the production environment for optimal combinations. Results from this research suggest that heterosis in milk yield in crosses of Angus and Brahman is enhanced in a better nutritional environment for the cow. However, because of other factors influencing calf-weaning weight, this does not necessarily translate to higher maternal heterosis for weaning weight. Additional research investigating the relationships of milk yield and quality to calf growth in different environments is needed. Additionally, more research is needed to evaluate the relationship of forage environment to immune response in purebred and crossbred cattle to determine if disease prevention might be impacted through grazing management.

It appears that the use of Brahman x Angus or Angus x Brahman crossbred cows bred to a bull of a third breed could be a beneficial management tool for producers faced with the management of endophyte-infected tall fescue due to the apparent tolerance of the Brahman-cross cows and their calves to endophyte-infected tall fescue. Rotating cows and calves from endophyte-infected tall fescue to bermudagrass in the summer moderated some of the effects of endophyte-infected tall fescue on calf growth but was not always comparable to bermudagrass. The rotation did appear to be more beneficial for purebred cows than crossbred cows, considering reproductive traits. Although this technology does not eliminate production losses attributable to endophyte-infected tall fescue, it appears to reduce these losses substantially. In combination with other technology available for the management of endophyte-infected tall fescue, it may be possible to reduce losses to more acceptable levels by the use of Brahman-cross cows on endophyte-infected tall fescue.

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Varying Differences Between Sexes in Birth Weight and Weaning Weight of Calves Sired by Tropically Adapted Breeds at Six Diverse U.S. Locations

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ABSTRACT: A joint effort to evaluate several tropically adapted breeds (Brahman, Tuli, Boran, Senepol) as sire breeds through production of F_1 calves was initiated at several locations in the early 1990s. Evaluations included six locations that used *Bos taurus* dams: Brooksville, FL; Clay Center, NE; Tifton, GA; El Reno, OK; and McGregor and Uvalde, TX. Sires of each breed were used at multiple locations, and Brahman and Tuli were used at each location. Location was partly confounded with dam breed type. All locations used Angus purebred and/or crossbred females for at least part of their dams, but some locations used only purebred cows (Angus, or Angus and Hereford), and one used only Angus-Hereford crossbred dams. Birth weight (BWT) and 205-d weaning weight (WWT) were analyzed through mixed model procedures with fixed effects of sire breed-location (single effect), calf sex, age of dam, and the interaction of sire breed-location with calf sex. Sire nested within sire breed was included as a random effect. All fixed effects accounted for variation in both traits ($P < 0.01$). The regressions of birth date within year-location combination on BWT and WWT were significant but were left out of final analyses due to producing unrealistic least squares means for many sire breed-location combinations. Generally, sire breed comparisons across locations were similar, with *Bos indicus* sires producing heavier calves and tropically adapted, non-zebu breeds producing lighter calves for both BWT and WWT. However, differences in BWT and WWT in male vs. female calves were quite variable across sire breed-location combinations. The interaction involving calf sex, sire breed, and environment may be a more important consideration, especially for BWT when *Bos indicus* sires and *Bos taurus* dams are involved, than the two-way genotype x environment interaction.

Key Words: Birth Weight, Genotype x Environment Interaction, Tropically Adapted Cattle, Weaning Weight

Introduction

Tropically adapted cattle and their crosses have historically been important genetic resources in many regions of the United States, particularly in the Southwest and the Gulf Coast areas. Historically, these cattle have been Brahman and Brahman-influenced breeds and crossbreds. There have been numerous reports of the very desirable fertility, productivity, and longevity aspects of F_1 *Bos indicus-Bos taurus* cows, but there has not been a sire type that could be bred to this type of cow that would produce replacement females of comparable performance. In the early 1990s, Tuli and Boran semen became available from Australia. Several research stations became interested in evaluating Tuli or Tuli and Boran, particularly as compared to Brahman for calf and cow traits. Different locations involved were Brooksville, Florida (Chase et al., 2000); Clay Center, Nebraska (Cundiff et al., 1999); El Reno, Oklahoma; Las Cruces, New Mexico (Winder and Bailey, 1995); Tifton, Georgia (Baker, 1996); and McGregor (Herring et al., 1996), Overton (Browning et al., 1995), and Uvalde (Holloway et al., 2002), Texas. This analysis is from data collected at six of these locations to study genotype x environment interaction considerations related to birth weight and weaning weight in F_1 calves produced from straight *Bos taurus* cows.

Materials and Methods

Information regarding specific management protocols at each location can be found in the publications that were specific to individual locations,

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and many participants have already reported F_1 calf performance at their individual locations; however, a joint analysis that studied genotype x environment interactions was desired. Calves and cows were managed relatively similarly across locations, but certain management considerations such as breeding/calving season time and/or length may be unique to certain locations, and these differences would be included as part of the location effect and are part of each production environment. Due to differences in average age of calves at weaning across locations, weaning weight was adjusted to 205-d basis.

Table 1 shows the distribution of years of data collection, sire breed, type of dam, and calf numbers for the data set. Locations that evaluated the same sire breeds used many of the same sires through artificial insemination. There were 196 sires represented including 50 Angus, 8 Boran, 69 Brahman, 39 Hereford, 21 Senepol, and 9 Tuli. Brahman and Tuli sires were used across all locations, and all 9 Tuli sires were used at every location.

Several records were excluded from final analyses. Although some locations used Angus and/or Hereford sires and/or dams, no purebred calves were included in these analyses. Data from 2-yr-old (first parity) cows were removed, and cows that were 12 yr or older were grouped together in one class. All locations used dams that were Angus-influenced, and all locations except Tifton, GA, used purebred Angus cows as at least part of the dams. Brahman crossbred dams from Tifton were excluded from this analysis. Only calves produced from straight *Bos taurus* dams are included in this analysis, but there was no distinction made between purebred (Angus or Hereford) dams or crossbred (MARC III or Angus-Hereford cross) dams due to the high degree of confounding between dam breed type and location. As a result, interpretation of location effects from this analysis should include consideration of the exact type(s) of dam used at each location. Angus- and Hereford-sired calves from MARC III cows at MARC and from Angus-Hereford crossbred cows at Tifton are expected to exhibit less than 100% direct heterosis, but all other calves would exhibit 100% direct heterosis. Furthermore, calves produced from crossbred cows would benefit from maternal heterosis, whereas calves from Angus and Hereford cows would not. Only calves born in 1992 through 1994 are included in this analysis. A total of 3,192 birth weight and 2,999 weaning weight records were included in the analyses.

Preliminary analyses for birth weight and 205-d weaning weight included a mixed model with sire breed, location, cowage, birth year, calf sex, sire breed x calf sex, sire breed x location, sire breed x location x calf sex and the regression on julian birth date with year-location combination, as fixed effects, along with sire nested with sire breed as a random effect. Although this approach yielded estimable least squares means for sire breed x location, and sire breed x location x calf sex, all other least squares means were not estimable.

Further analysis through mixed model procedures included fixed effects of sire breed-location combination (as a single effect; similar to approach reported by Olson et al., 1991), age of dam, sex of calf, the interaction between sire breed-location combination and sex of calf, and the regression on julian birth date within year x site combination to account for seasonality differences within environments. Individual sire nested with sire breed was included in both analyses as a random effect. However, the least squares means from these analyses seemed unrealistic as differences among certain locations appeared to become highly exaggerated. The coefficients for regression of birth weight and 205-d weaning weight on birth date within location-year combinations from these analyses as well as the calving seasons are presented in Table 2.

Final analyses for birth weight and 205-d weaning weight through mixed model procedures of SAS included sire breed-location (as a single effect), cow age (in years), calf sex, and sire breed-location x calf sex as fixed effects, and sire nested with sire breed as a random effect. A series of linear contrasts among least squares means for sire breed-location combinations were also used for specific comparisons among groups of sire breeds with t-tests.

Results and Discussion

Birth weight. Differences in birth weight were accounted for by sire breed-location, age of dam, calf sex, and the interaction of sire breed-location x calf sex ($P < 0.001$). The means for sire breed-location combinations are presented in Table 3. Tuli-sired calves had average birth weight of 85 lb at MARC, 81.5 lb at McGregor, 76.3 lb at El Reno, 71.8 lb at Uvalde, 69.2 lb at Tifton, and 66.4 lb at Brooksville. In contrast, Brahman-sired calves had average birth weights of 102.0 lb at MARC, 98.9 lb at McGregor, 91.3 lb at El Reno, 85.7 lb at Tifton, 84.2 lb at Uvalde, and 77.9 lb at Brooksville. Hereford-sired calves weighed 12.8 lb more for birth weight at MARC than at Tifton, whereas Angus-sired calves weighed 20.3 lb more at MARC than at Tifton. Although several Angus and Hereford sires used at Tifton were also used at MARC, there were many more Angus and Hereford sires and many more calves evaluated at MARC than at Tifton. Across all sire breed and

Table 1. Summary of calf records across locations, years and sire breeds for complete data set

Location	Years	Sire breeds	n	Dam types	Cow age	Weaning age
Brooksville, FL	1993-94	Brahman, Senepol, Tuli	261	Angus	3-12+	235
El Reno, OK	1992-95	Boran, Brahman, Tuli	145	Angus, British, Hereford	2-3, 5-12+	234
MARC, Clay Center, NE	1992-94	Angus, Boran, Brahman, Hereford, Tuli	2,108	Angus, MARC III, Hereford	4-12+	184
McGregor, TX	1992-93	Boran, Brahman, Tuli	312	Angus, Hereford	3-12+	219
Tifton, GA	1992-96	Angus, Brahman, Hereford, Senepol, Tuli	864	½ Brahman, ¼ Brahman, British	2-12+	223
Uvalde, TX	1992-95	Angus, Brahman, Senepol, Tuli	578	Angus	2-6	201
Total			4,268			

Table 2. Summary of calving seasons and coefficients for regression of birth weight and 205-d weaning weight on julian birth date for each year-location combination

Year-location	n	Mean birth date	Range in birth dates	Birth weight (lb/d)		205-d weaning weight (lb/d)	
1992-El Reno	18	Mar 7	Feb 20 – Mar 23	0.063	0.114	0.588	0.574
1992-MARC	540	Apr 15	Feb 23 – May 17	0.219	0.021***	-0.250	0.104*
1992-McGregor	157	Mar 9	Feb 14 – Apr 12	0.125	0.030***	0.846	0.150***
1992-Tifton	73	Feb 8	Jan 5 – Mar 31	0.099	0.055	-0.123	0.267
1992-Uvalde	84	Mar 10	Feb 13 – Apr 23	0.097	0.041*	0.195	0.211
1993-Brooksville	129	Jan 27	Dec 29 – Mar 12	0.061	0.049	0.046	0.248
1993-El Reno	41	Mar 22	Mar 5 – Apr 24	0.052	0.089	0.147	0.453
1993-MARC	758	Apr 12	Mar 14 – May 13	0.189	0.021***	-0.299	0.104**
1993-McGregor	153	Mar 9	Feb 13 – Apr 9	-0.011	0.027	0.356	0.129**
1993-Tifton	65	Feb 4	Dec 27 – Apr 1	0.194	0.061**	0.648	0.319*
1993-Uvalde	97	Feb 24	Jan 30 – Apr 8	-0.032	0.047	0.014	0.239
1994-Brooksville	132	Jan 16	Dec 25 – Feb 24	0.063	0.065	-0.005	0.330
1994-El Reno	36	Mar 27	Feb 20 – May 1	0.115	0.081	0.804	0.411*
1994-MARC	810	Apr 9	Mar 13 – May 18	0.166	0.022***	-0.229	0.107*
1994-Tifton	64	Feb 5	Jan 3 – Mar 15	0.016	0.072	0.479	0.356
1994-Uvalde	111	Mar 11	Jan 30 – May 11	0.058	0.036	0.311	0.181

*** $P < 0.001$
** $P < 0.01$
* $P < 0.05$

location combinations represented here, Brahman-sired calves at MARC were the heaviest (102.0 lb), and Tuli-sired calves at Brooksville were the lightest (66.4 lb).

In regard to sire breed comparisons across locations and calf sex (Table 4), Brahman-sired calves weighed 22 lb more ($P < 0.001$) than Angus-sired calves and 13.8 lb more ($P < 0.001$) than Hereford-sired calves. Calves sired by Brahman bulls also weighed more than calves sired by Tuli (15.0 lb), Senepol (6.5 lb), and Boran (6.6) bulls. Angus-sired calves did not differ from Tuli-sired calves; however, Hereford- (9.6 lb), Boran- (9.9 lb), and Senepol-sired (5.5 lb) calves were substantially heavier for birth weight than Tuli-sired calves.

A typical difference in average birth weights between male and female calves is approximately 4 to 6 lb within most breeds of beef cattle. However, it has been widely documented that large sire breed x calf sex interactions for birth weight exist in *Bos indicus-Bos taurus* crosses as compared to crosses involving only *Bos taurus* or only *Bos indicus*. Furthermore, the

Table 3. Least squares means (LSM) for birth weight and 205-d weaning weight for sire breed-location combinations

	Birth weight (lb)			205-d weaning weight (lb)		
Sire breed-location	n	LSM	SE	n	LSM	SE
Angus-MARC	321	88.6	0.90	310	532.9	4.15
Angus-Tifton	22	68.3	2.93	22	446.9	13.58
Boran-El Reno	32	86.7	2.47	32	457.4	11.42
Boran-MARC	462	95.5	1.42	443	521.8	6.36
Boran-McGregor	104	90.2	1.79	94	452.8	8.31
Brahman-Brooksville	68	77.9	1.70	61	445.3	8.30
Brahman-El Reno	29	91.3	2.47	26	501.0	11.95
Brahman-MARC	446	102.0	0.80	416	558.7	3.73
Brahman-McGregor	101	98.9	1.41	96	493.5	6.68
Brahman-Tifton	111	85.7	1.55	96	521.1	7.56
Brahman-Uvalde	92	84.2	1.51	84	428.8	7.28
Hereford-MARC	349	93.1	0.94	334	553.0	4.32
Hereford-Tifton	40	80.3	2.79	38	474.2	12.80
Senepol-Brooksville	53	72.6	2.21	49	386.8	10.34
Senepol-Uvalde	85	76.6	1.66	77	404.1	7.93
Tuli-Brooksville	91	66.4	1.76	87	385.7	8.10
Tuli-El Reno	34	76.3	2.39	31	451.8	11.34
Tuli-MARC	511	85.0	1.34	488	508.8	6.01
Tuli-McGregor	104	81.5	1.70	97	435.2	7.86
Tuli-Tifton	29	69.2	2.55	28	450.3	11.90
Tuli-Uvalde	108	71.8	1.77	97	396.0	8.24

Table 4. Linear contrasts (LC) for birth weight and 205-d weaning weight for specific sire breed comparisons.

		Birth weight (lb)			Weaning weight (lb)		
Comparison	Locations	LC	SE	Significance	LC	SE	Significance
Angus – Brahman	MARC, Tifton	-22.0	1.8	0.001	-36.2	8.3	0.001
Angus – Boran	MARC	-6.9	1.7	0.001	11.2	7.5	0.139
Angus – Tuli	MARC, Tifton	1.3	2.3	0.555	10.4	10.5	0.323
Hereford – Brahman	MARC, Tifton	-13.8	1.7	0.001	-12.5	8.0	0.117
Hereford – Boran	MARC	-2.4	1.7	0.159	31.3	7.6	0.001
Hereford – Tuli	MARC, Tifton	9.6	2.2	0.001	34.1	10.2	0.001
Brahman – Boran	El Reno, MARC, McGregor	6.6	1.9	0.004	40.4	8.6	0.001
Brahman – Tuli	All locations	15.0	1.6	0.001	53.4	7.2	0.001
Boran – Tuli	El Reno, MARC, McGregor	9.9	2.1	0.001	12.1	9.7	0.212
Brahman – Senepol	Brooksville, Uvalde	6.5	1.8	0.001	41.6	8.5	0.001
Tuli – Senepol	Brooksville, Uvalde	-5.5	2.0	0.007	-4.6	9.3	0.619

magnitude in difference in male vs. female calves has been shown to be very large when *Bos indicus* influence comes solely from the sire, and it may be very small when *Bos indicus* influence comes solely from the dam. The means for sire breed-location x calf sex combinations are in Table 5. The increased birth weight of male calves over female calves that were Brahman-sired was 17.4 lb at MARC, 16.0 lb at El Reno, 15.6 lb at McGregor, 11.3 lb at Brooksville, 11.0 lb at Tifton, and 7.5 lb at Uvalde. In contrast to this for the Tuli-sired calves, the male calves were heavier than female calves by 14.3 lb at Tifton, 6.7 lb at Brooksville, 6.1 lb at El Reno, 5.9 lb at McGregor, 5.5 lb at MARC, and 4.9 lb at Uvalde. The sex difference in Tuli-sired calves is comparable to what would be expected from a *Bos taurus* sire breed bred to these types of cows. There is not an obvious explanation for the large sex difference in Tuli-sired

Table 5. Least squares means (LSM) for birth weight and 205-d weaning weight for combinations of sire breed-location and calf sex.

		Birth weight (lb)			205-d weaning weight (lb)		
Sire breed-location	Sex	n	LSM	SE	n	LSM	SE
Angus-MARC	F	139	84.6	1.17	135	512.8	5.49
Angus-MARC	M	182	92.7	1.07	175	553.0	5.00
Angus-Tifton	F	14	62.6	3.56	14	416.9	16.51
Angus-Tifton	M	8	73.9	4.34	8	477.0	20.28
Boran-El Reno	F	15	84.4	3.31	15	447.1	15.39
Boran-El Reno	M	17	89.0	3.16	17	467.7	14.69
Boran-MARC	F	218	88.7	1.54	207	500.9	6.95
Boran-MARC	M	244	102.3	1.51	236	542.6	6.82
Boran-McGregor	F	37	85.7	2.35	35	442.3	11.04
Boran-McGregor	M	67	94.8	1.95	59	463.3	9.25
Brahman-Brooksville	F	38	72.2	2.11	35	421.6	10.17
Brahman-Brooksville	M	30	83.5	2.35	26	469.0	11.68
Brahman-El Reno	F	18	83.3	2.94	15	473.2	15.00
Brahman-El Reno	M	11	99.3	3.73	11	528.7	17.45
Brahman-MARC	F	226	93.4	0.97	216	530.7	4.56
Brahman-MARC	M	220	110.7	0.98	200	586.8	4.69
Brahman-McGregor	F	54	91.2	1.78	52	467.5	8.42
Brahman-McGregor	M	47	106.7	1.90	44	519.5	9.10
Brahman-Tifton	F	54	81.2	1.98	52	496.7	9.36
Brahman-Tifton	M	58	90.2	1.86	45	545.6	9.66
Brahman-Uvalde	F	44	80.5	1.88	41	418.7	9.12
Brahman-Uvalde	M	38	88.0	2.06	35	438.9	10.00
Hereford-MARC	F	164	89.9	1.16	156	541.7	5.45
Hereford-MARC	M	185	96.3	1.11	178	564.4	5.15
Hereford-Tifton	F	12	77.0	4.01	12	475.6	18.60
Hereford-Tifton	M	27	83.6	2.82	25	472.8	13.21
Senepol-Brooksville	F	28	69.8	2.68	27	385.8	12.50
Senepol-Brooksville	M	25	75.3	2.82	22	387.8	13.54
Senepol-Uvalde	F	38	75.4	2.16	35	389.0	10.38
Senepol-Uvalde	M	47	77.8	2.07	42	419.3	10.02
Tuli-Brooksville	F	52	63.0	2.05	50	378.1	9.52
Tuli-Brooksville	M	39	69.7	2.26	37	393.2	10.59
Tuli-El Reno	F	15	73.2	3.29	15	454.0	15.29
Tuli-El Reno	M	19	79.3	2.97	16	449.5	14.82
Tuli-MARC	F	258	82.2	1.44	246	489.3	6.49
Tuli-MARC	M	253	87.7	1.44	242	528.4	6.53
Tuli-McGregor	F	57	78.5	1.98	51	419.2	9.47
Tuli-McGregor	M	47	84.5	2.12	46	451.2	9.83
Tuli-Tifton	F	12	62.1	3.62	12	410.2	16.87
Tuli-Tifton	M	17	76.3	3.11	16	490.4	14.85
Tuli-Uvalde	F	49	69.3	2.15	41	389.3	10.36
Tuli-Uvalde	M	55	74.3	2.05	51	402.7	9.61

calves produced at Tifton and may be an artifact of smaller sample size. Hereford-sired male calves outweighed females by 6.5 lb at Tifton and 6.4 lb at MARC; however, Angus-sired male calves weighed 10.2 lb more than females at Tifton and 7.8 lb more at MARC. The Senepol-sired calves had the least difference in birth weight between sexes of 5.5 lb at Brooksville and 2.3 lb at Uvalde. Boran-sired male calves outweighed female calves by 13.5 lb at MARC, 9.1 lb at McGregor, and 4.7 lb at El Reno.

Several reports have documented a sire breed x calf sex interaction for birth weight when *Bos indicus* and *Bos taurus* sires have been bred to *Bos taurus* dams (Cartwright et al., 1964; Comerford et al., 1987; Paschal et al., 1991) where *Bos indicus*-sired male calves have much larger birth weights than *Bos indicus*-sired female calves as compared to the difference between *Bos taurus*-sired male vs. female calves. These differences are not constant across production environments, but this same phenomenon is illustrated in this report. From this standpoint, Boran appears similar to Brahman, and Tuli and Senepol appear more similar to British breeds than *Bos indicus* breeds. Olson et al. (1991) studied calves produced from F_1 *Bos indicus-Bos taurus* cows and F_1 *Bos taurus-Bos taurus* cows in Florida and Nebraska and found important genotype x environment interaction for birth weight and weaning weight, but did not report about the interaction involving cow breed type x location x calf sex. Brown et al. (1993) reported heterosis between Angus and Brahman to be constant across two production environments within a location for preweaning traits but that maternal and direct effects differed across environments. Interactions in that study involving both calf sex and production environment were not significant for birth weight or weaning weight. Thrift et al. (1999) reported significant interactions of calf sex with calf genetic type, and calf genetic type with location for birth weight and weaning weight with Angus, Brahman-Angus, and Brahman calves produced in Florida and Louisiana, but did not report a three-way interaction of calf sex x genetic type x location.

Weaning weight. Sire breed-location, age of dam, calf sex, and sire breed-location x calf sex interaction all accounted for variation ($P < 0.001$) seen in 205-d weaning weight. The means for the sire breed-location combinations are in Table 3. Brahman-sired calves averaged 559 lb at MARC, 521 lb at Tifton, 501 lb at El Reno, 494 lb at McGregor, 445 lb at Brooksville, and 429 lb at Uvalde. Tuli-sired calves had average 205-d weight of 509 lb at MARC, 452 lb at El Reno, 450 lb at Tifton, 435 lb at McGregor, 396 lb at Uvalde, and 386 lb at Brooksville. Hereford-sired calves averaged 553 lb at MARC and 474 lb at Tifton, whereas Angus-sired calves at MARC averaged 533 lb at MARC and 447 lb at Tifton. Boran-sired calves averaged 522 lb at MARC, 457 lb at El Reno, and 453 lb at McGregor. Senepol-sired calves averaged 404 lb at Uvalde and 387 lb at Brooksville. Some of these weights for certain sire breeds appear to be quite different from those reported earlier at individual locations; however, the weights in this report are standardized to 205 d, and many of these reports used average weaning age at the location.

Brahman-sired calves weighed more ($P < 0.001$) than Angus- (36 lb), Boran- (40 lb), Tuli- (53 lb) and Senepol-sired (42 lb) calves and were not different from Hereford-sired calves (Table 4). Boran-sired calves did not differ from Angus-sired calves or Tuli-sired calves, but weighed 31 lb less ($P < 0.001$) than Hereford-sired calves. Tuli-sired calves weighed 34 lb less ($P < 0.001$) than Hereford-sired calves, but did not differ from Angus- or Senepol-sired calves.

Table 5 illustrates sex differences across sire breeds and locations (Table 5). Brahman-sired male calves outweighed female calves by 56 lb at MARC, 55 lb at El Reno, 52 lb at McGregor, 49 lb at Tifton, 47 lb at Brooksville, and 20 lb at Uvalde (where cows were younger average age). The difference between male minus female weaning weight in Tuli-sired calves was not as consistent across locations, and was 80 lb at Tifton, 39 lb at MARC, 32 lb at McGregor, 15 lb at Brooksville, 13 lb at Uvalde, and –4 lb (heifers 4 lb heavier) at El Reno. The weight advantage of males over females in Boran-sired calves was 42 lb at MARC, but was 21 lb at both McGregor and El Reno. Angus-sired male calves weighed 60 lb more than females at Tifton and 40 lb more at MARC, whereas Hereford-sired male calves weighed 23 lb more than heifers at MARC, but 3 lb less than heifers at Tifton. Senepol-sired male calves weighed 30 lb more than heifers at Uvalde but only 2 lb more than heifers at Brooksville.

It is evident from these data that there may be large differences in birth weight and weaning weight of calves of the same genetic makeup across production environments, and that performance between sire breeds and differences between male vs. female calves can be quite different across combinations of sire breeds and environments. Although it was not investigated in this analysis, interactions between individual sires within breed and environments have been reported in Angus (Notter et al., 1992), Hereford (Bertrand et al., 1985), and Simmental-sired calves (Tess et al., 1979), and it is likely that there could also be individual sire x location interactions present in these data.

Implications

Generally, sire breed comparisons across locations were similar, with *Bos indicus* sires producing heavier calves and tropically adapted, non-Zebu breeds producing lighter calves for both birth weight and weaning weight. However, differences in these traits in male vs. female calves were quite variable across sire breed-location combinations, and the interaction involving calf sex, sire breed, and environment may be a more important consideration, particularly for birth weight when *Bos indicus* sires and *Bos taurus* dams are involved, than the two-way genotype x environment interaction.

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Genetic Parameters for Growth, Carcass, and Tenderness Traits of Brahman Steers

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ABSTRACT: The Brahman breed has contributed significantly to cow-calf production in the Gulf Coast region. However, questions remain about the influence of high percentage Brahman inheritance on growth, carcass, and consumer traits. Purebred Brahman bull calves (n = 467) were purchased at weaning from 17 private producers in Louisiana (1996 through 2000) for study. The calves were sired by 68 bulls. After purchase, calves were castrated, vaccinated, dewormed, and backgrounded until winter grazing was available. Steers grazed ryegrass annually for an average of 120 d over the five yr. Each April, the steers were shipped to south Texas for feeding. Steers were harvested when about one-third of the steers in a pen reached 1,100 to 1,250 lb BW and 0.3 to 0.4 in fat thickness. Carcasses were electrically stimulated with high voltage during processing and then chilled for 24 hr. A half-ounce 24-hr postmortem longissimus muscle sample was taken for calpastatin assay. A primal rib was purchased and a one in-thick steak cut, trimmed and vacuum packaged for 14 d aging at 40°F. Steaks were cooked to an internal temperature of 158°F (medium doneness). Tenderness was determined by averaging the force required to shear 6 half-inch cores taken parallel to muscle fibers. A full animal model was used to estimate heritability and genetic correlations. A total of 2,155 animals were included in the A^{-1} matrix. Heritability estimates were 0.33 0.14 for feedlot ADG, 0.56 0.15 for hot carcass weight, 0.51 0.16 for longissimus muscle area, 0.38 0.17 for fat thickness, 0.49 0.17 for yield grade, 0.38 0.16 for marbling score, 0.21 0.11 for 14-d shear force, and 0.44 0.17 for calpastatin activity. Most genetic correlations were below 0.25 with SE near 0.25. Exceptions were 0.54 0.18 for ADG and hot carcass weight, and -0.63 0.25 for yield grade and 14-d shear force. Sire EPDs for all traits ranged approximately two genetic standard deviations about the mean EPD.

Key Words: Brahman, Carcass Traits, Genetic Parameters

Introduction

Breeds adapted to tropical climates are known for their ability to be productive in hot and humid environments. The Brahman is the most common tropically adapted breed in the Gulf Coast Region. Many commercial cow-calf producers benefit from reproductive and maternal advantages of Brahman crossbred cows in their herds. However, producers with high percentage Brahman calves have received discounts of up to 15% in auction markets and from order buyers. Most of these discounts have been attributed to perceived lower meat quality, especially tenderness and marbling. Researchers have reported that as the percentage of *Bos indicus* breeding increased, the level of tenderness decreased and variability of tenderness increased (Damon et al., 1960; Carpenter et al., 1961; Peacock et al., 1982). Beef from Brahman cattle also has been less tender than beef from *Bos taurus* cattle (Koch et al., 1982; Crouse et al., 1989). In order to learn more about the purebred Brahman, objectives of this study were to estimate heritability and genetic correlations for growth, carcass and tenderness traits in purebred Brahman steers.

Materials and Methods

Source of Data

Paternal half-sib Brahman male calves (n = 467) sired by 68 bulls were purchased from 17 purebred Brahman breeders in Louisiana over a five-yr period. Calves were spring born and weaned in the fall. Calves were transported from breeders' farms to the LSU AgCenter Central Research Station in Baton Rouge at weaning. The LSU Animal Use and Care Committee approved this research.

Management

Calves were castrated, dehorned if necessary, given appropriate vaccinations, and dewormed within two weeks after arrival. Each calf was assigned an LSU identification number for data collection and for association with its ancestoral pedigree. After processing, calves were placed on regrowth common bermudagrass (*Cynadon dactylon*) and dallisgrass

(*Paspalum dilatatum*) pastures with access to about 4 lb per head per day of a high roughage, corn-based diet (12% crude protein) and native hay. Calves were placed on ryegrass (*Lolium multiflorum*) around December 1 each year, stocked at approximately 650 lb of calf per acre and grazed for an annual average of 120 d. Steers were implanted with Synovex before placement on ryegrass the first yr and with Ralgro the remaining 4 yr. Upon completion of the grazing period, calves were shipped to South Texas for feeding.

Feedlot and Slaughter

Steers were weighed and implanted with Ralgro upon arrival at the feedlot. When about a third of the steers reached an average of 0.3 to 0.4 in of fat thickness and a slaughter weight of 1,100 to 1,250 lb BW, they were harvested. The remaining steers were harvested in two groups at similar endpoints. Overall, steers were harvested after an average of 148 d on feed. Steers were processed at Sam Kane Beef Processors in Corpus Christi, TX, at an average age of 545 d. Carcasses were electrically stimulated with high voltage during the slaughter process. After a 24-hr chill, carcasses were ribbed and carcass data recorded. A half-ounce longissimus muscle sample was collected at this time for measurement of calpastatin enzyme level. Calpastatin levels were assayed at Central Community College in Hastings, NE, following the procedures of Whipple et al. (1990a) and Shackelford et al. (1994). Calpastatin levels were not obtained the last year of the study.

Cooking and Shear Force Measurements

A primal rib section was obtained from the right side of each carcass at the time the carcasses were processed and transported to the Louisiana State University Animal Sciences Department Meats Laboratory. A 1-inch thick steak was cut from the large end of the primal rib, trimmed, vacuum packaged, aged for 14 d and then frozen at -4°F. When all the steers had been processed, steaks were thawed for 24 hr at 40°F and then broiled to an internal temperature of 158°F (medium doneness) on a Farberware Open-Hearth grill. Cooked steaks were then chilled 24 hr at 40°F and six half-inch cores were removed from each steak parallel to the orientation of the muscle fibers. Cores were sheared with an Instron testing machine equipped with a Warner-Bratzler attachment. The average of the six shear force measurements on each steak was used as the shear force observation for each steer. This procedure is consistent with guidelines established by the American Meat Science Association (AMSA, 1995).

Statistical Analysis

The Multiple Trait Derivative Free Restricted Maximum Likelihood (MTDFREML) programs of Boldman et al. (1995) were used to estimate heritability and genetic correlations for all traits. The MIXED procedure of SAS (2000) with sire as a random variable and year of record, slaughter group, and slaughter age as fixed effects was used to obtain starting values for variances for MTDFREML. The statistical model included the animal as a random effect, and year-slaughter group and steer slaughter age as fixed effects. A total of 2,155 animals contributed information to the genetic covariance matrix in the animal model program. Heritabilities were estimated with single-trait analyses while two-trait analyses were used to estimate phenotypic and genetic correlations. Response variables included feedlot ADG, slaughter weight, hot carcass weight, fat thickness, longissimus muscle area, marbling score, yield grade, calpastatin enzyme level, and shear force value.

Results and Discussion

Performance and Carcass Data

Descriptive statistics for growth, carcass, and tenderness traits are given in Table 1. Feedlot ADG averaged 3.29 lb per day over the five-yr study. This is similar to the ADG of Gray- and Red Brahman-sired steers reported by Paschal et al. (1995). Sherbeck et al. (1995) reported that ADG decreased as the proportion of Brahman breeding increased from 0 to 25% and from 25 to 50%. This is similar to the findings of Crews and Franke (1998), but only when the percentage of Brahman breeding exceeded 50%. Peacock et al. (1982) reported that the Brahman direct additive genetic effect for feedlot ADG was negative when compared to direct additive genetic effects of Angus and Charolais cattle.

Carcass Data

Average hot carcass weight of Brahman steers in this study was 741.7 lb. Bidner et al. (2002) reported that Angus straightbred steers had lower hot carcass weights than crossbred steers sired by bulls from four Brahman-derivative breeds. Other studies have shown that Brahman-cross steer carcasses were heavier than carcasses of steers sired by bulls of European breeds (Young et al., 1978; Koch et al., 1982; Huffman et al., 1990). Paschal et al. (1995) reported that carcasses from Red and Gray Brahman-sired steers were heavier than carcasses of calves sired by Angus, Gir, Indu-Brazil, and Nellore bulls. Comerford et al. (1988)

Table 1. Descriptive statistics for growth, carcass, and tenderness traits

Trait[1]	n	Mean	SD	Minimum value	Maximum value	CV
FADG, lb/d	430	3.29	0.52	1.41	5.53	15.67
HCWT, lb	430	741.7	81.3	432	932	10.96
FT, in	430	0.34	0.16	0.05	1.1	47.87
LMA, sq in	430	13.33	3.43	9.1	17	10.14
MS	430	390.3	61.68	220	680	15.8
YG	430	2.34	0.68	0.8	4.7	29.06
CALP	355	4.51	1.22	1.83	9.16	27.05
SF14, lb	427	8.5	1.89	3.68	15.52	22.25

[1]FADG = feedlot average daily gain, HCWT = hot carcass weight, FT = fat thickness, LMA = longissimus muscle area, MS = marbling score, YG = yield grade, CALP = calpastatin enzyme level, and SF14 = shear force of 14-d aged steaks.

found that Brahman carcasses weighed less than carcasses of Simmental, Limousine, and Hereford. DeRouen et al. (1992a) reported similar findings when Brahman carcasses were compared to Angus, Hereford, and Charolais. DeRouen et al. (1992b) reported that the Brahman had a negative direct additive genetic effect on hot carcass weight compared to direct additive genetic effects of Angus, Charolais, and Hereford breeds.

Carcass fat thickness averaged 0.34 in after a 24-hr chill. This average is midway between the 0.3 and 0.4 inch fat-thickness projected when the steers were selected for harvest. DeRouen et al. (1992a) found that Brahman steers averaged lower fat thickness than straightbred Angus and Hereford steers when fed for the same length of time. Luckett et al. (1975) reported similar results when Brahman steers were compared to Angus, Charolais, and Hereford steers.

Longissimus muscle area averaged 13.33 sq in at slaughter. Several studies reported that Brahman crossbred cattle had smaller longissimus muscle area than British breeds of cattle (Luckett et al., 1975; Peacock et al., 1982; Huffman et al., 1990). However, DeRouen et al. (1992a) found that Brahman steers had similar longissimus muscle area compared to Angus and Hereford steers but smaller muscle area than Charolais steers. Comerford et al. (1988) reported that longissimus muscle area from Brahman steers was smaller than longissimus muscle area of Hereford, Simmental, and Limousin steers. Other research has shown no difference in longissimus muscle area of Brahman crossbreds and British breeds (Koch et al. 1982; Crouse et al., 1989). Sherbeck et al. (1995) found that Brahman crossbreds had larger longissimus muscle area than straight Herefords. Bidner et al. (2002) reported that steers sired by Angus had smaller longissimus muscle area than steers from Brahman-derivative breeds.

Marbling score averaged 390.3 (high slight marbling). This corresponds to an average carcass quality grade of high Select. Marbling scores for Brahman crossbreds have generally been lower than those of other breeds of cattle (Luckett et al., 1975; Peacock et al., 1982; DeRouen et al., 1992a). Crouse et al. (1989) and Huffman et al. (1990) reported that as the proportion of Brahman breeding increased, marbling score decreased. Marbling scores in this study ranged from practically devoid to high modest, indicating the ability of some progeny to grade much higher than others.

Yield grade ranged from 0.8 to 4.7 with a mean of 2.34. Paschal et al. (1995) found that Red and Gray Brahman-sired steers had more desirable yield grades than steers sired by Angus, Indu-Brazil, Nellore, or Gir Bulls. However, Crockett et al. (1979) reported significantly higher and therefore less desirable yield grades for Brahman cross steers than for other breeds.

Table 2. Additive and residual variances and estimates of heritability

Trait	Additive variance	Residual variance	Heritability
Feedlot average daily gain, lb/d	0.0617	0.1269	0.33 ± 0.14
Hot carcass weight, lb	2,344.1	1,802.9	0.57 ± 0.15
Fat thickness, in	0.0076	0.0134	0.36 ± 0.16
Longissimus muscle area, sq in	5.35	5.24	0.51 ± 0.16
Marbling score	1,168.2	1,995.2	0.37 ± 0.16
Yield grade	0.1694	0.1976	0.46 ± 0.17
Calpastatin level	0.3745	0.4615	0.45 ± 0.17
14-day shear force, lb	0.5833	2.3118	0.20 ± 0.11

Tenderness Data

Calpastatin levels in this study ranged from 1.83 to 9.16 mg/g muscle with a mean of 4.51. This average is higher than the average calpastatin level of 2.69 mg/g reported by Riley et al. (2003a). The range indicates that there is significant variation in calpastatin levels. Whipple et al. (1990b) found that Sahiwal-sired steers had higher calpastatin levels than Hereford-Angus crossbred steers. A lower calpastatin level for Hereford calves than for Brahman calves was reported by Wheeler et al. (1990). Pringle et al. (1997) reported that calpastatin level increased linearly with increasing percentage Brahman breed composition.

Average Warner-Bratzler shear force for 14-d aged steaks in this study was 8.5 lb. This shear force is lower than the 11.6-lb shear force for non-electrically stimulated steers and heifers reported by Riley et al. (2003a). The average shear force found in this study was similar to that in Hereford cattle and lower than that for 0.75H:.25B and 0.50H:0.50B crossbred cattle reported by Sherbeck et al. (1995) when steaks were aged for 6 d. Many papers have reported that steaks became less tender as percentage of Brahman breeding increased (Damon et al., 1960; Carpenter et al., 1961; Peacock et al., 1982). In a review article, Marshall (1994) reported that Brahman steers ranked next to last among 15 breeds for shear force. Bidner et al. (2002) reported that steaks from Angus steers had lower shear force than steaks from steers from Brahman-derivative breeds when steaks were aged for 10 d. Luckett et al. (1975) reported similar findings. It is expected that electrical stimulation increased tenderness in this study, but the amount is not quantified. Wheeler et al. (1990) reported that purebred Brahman cattle that were not electrically stimulated were less tender and more variable in shear force than other breeds.

Variance Components and Heritabilities

Heritability estimates for traits discussed in this study are presented in Table 2. Relatively large heritability estimates were found for hot carcass weight and for longissimus muscle area, and a relative small heritability estimate was found for shear force. The estimate of heritability for feedlot ADG was similar to an estimate reported by Gregory et al. (1995) for Charolais- and Limousine-sired steers and heifers. Hot carcass weight was found to be moderately heritable by Gregory et al. (1995), and Wheeler et al. (2001) and in the review by Marshall (1994). Others reported a lower estimate of heritability for hot carcass weight (Wheeler et al., 1996; Wulf et al., 1996).

The heritability estimate for fat thickness was 0.36 ± 0.16. This is larger than the estimate reported by Gregory et al. (1995) and smaller than those presented by Wheeler et al. (1996; 2001) and Marshall (1994). For marbling score the estimate of 0.37 ± 0.16 reported in this study was at the low end of the range of heritability estimates reported for marbling score by several authors (Van Vleck et al., 1992; Shackelford et al., 1994; Wheeler et al., 2001).

The estimate of heritability for yield grade in these data was 0.46 ± 0.17, which is lower than those reported by Wheeler et al. (1996; 2001) and Wulf et al. (1996). Calpastatin was moderately heritable and lower than estimates by Wulf et al., (1996), Marshall (1994), and Shackelford et al. (1994). However, the estimate found in this study was higher than those from O'Conner et al. (1997) and Riley et al. (2003a), which were 0.15 and 0.07, respectively.

Estimates of heritability for shear force after different aging times have been known to fluctuate (Wulf et al., 1996; O'Conner et al., 1997; Riley et al., 2003a). Crews and Franke (1998) found that heritability estimates decreased as Brahman breeding decreased. This is contrary to the report of Elzo et al.

(1998). The estimate of heritability for shear force in this study is similar to those of Van Vleck et al. (1992), Wheeler et al. (2001), and Riley et al. (2003a).

Phenotypic and Genetic Correlations

Phenotypic and genotypic correlations are given in Table 3. Feedlot ADG was positively correlated with hot carcass weight. This was expected due to larger body weights as gain per day increases. Most phenotypic correlations were relatively small, with the exception of 0.34 for hot carcass weight and longissimus muscle area, 0.29 for hot carcass weight and yield grade, 0.79 between fat thickness and yield grade, and -0.54 between longissimus muscle area and yield grade.

Whipple et al. (1990b) identified level of calpastatin as one possible cause for the difference in tenderness between *Bos indicus* and *Bos taurus* crosses. Whipple et al. (1990a) and Shackelford et al. (1991) found that calpastatin measurements at 24 hr postmortem were strongly associated with beef tenderness (r = 0.66 and 0.39, respectively).

Table 3. Phenotypic and genetic correlations among growth, carcass and tenderness traits[1]

Trait[2]	FADG	HCWT	FT	LMA	MS	YG	CALP	SF14
FADG		0.56 ± 0.18	-0.13 ± 0.33	0.16 ± 0.28	0.27 ± 0.29	0.06 ± 0.30	-0.20 ± 0.31	-0.19 ± 0.35
HCWT	0.61		0.07 ± 0.26	-0.01 ± 0.25	-0.01 ± 0.29	0.15 ± 0.23	-0.71 ± 0.22	-0.48 ± 0.31
FT	0.12	0.25		-0.25 ± 0.28	-0.16 ± 0.32	0.77 ± 0.12	-0.58 ± 0.32	-0.36 ± 0.38
LMA	0.21	0.34	-0.07		0.09 ± 0.29	-0.66 ± 0.16	-0.46 ± 0.28	0.17 ± 0.32
MS	0.14	0.03	0.10	0.05		0.14 ± 0.30	-0.55 ± 0.38	-0.02 ± 0.36
YG	0.19	0.29	0.79	-0.54	0.13		-0.34 ± 0.30	-0.66 ± 0.30
CALP	0.02	-0.10	-0.13	-0.04	-0.08	-0.08		0.72 ± 0.23
SF14	0.03	-0.03	-0.03	0.12	-0.03	-0.11	0.28	

[1]Phenotypic correlations are in the lower triangle and genetic correlations with standard errors are in the upper triangle.

[2]FADG = feedlot average daily gain, HCWT = hot carcass weight, FT = fat thickness, LMA = longissimus muscle area, MS = marbling score, YG = yield grade, CALP = calpastatin enzyme level, and SF14 = shear force of 14-d aged steaks

The genetic correlation between hot carcass weight and feedlot ADG was 0.56, indicating some genes that influence ADG also influence heavy carcass weight. The genetic correlation between yield grade and fat thickness was relatively high in this study (0.77 ± 0.12) but lower than values reported by Wheeler et al. (1996; 2001). Yield grade was highly correlated genetically to longissimus muscle area (-0.66 ± 0.16). Larger, negative estimates of genetic correlations between yield grade and longissimus muscle area were reported by Wheeler et al. (1996; 2001). Calpastatin level was negatively correlated genetically with hot carcass weight (-0.71 ± 0.22).

Shear force was negatively correlated genetically with yield grade (-0.66 ± 0.30). Wheeler et al. (2001) also found a negative genetic correlation between these two traits. The genetic correlation between shear force and calpastatin was 0.72 ± 0.23. Other researchers reported a high positive correlation for these two traits (Marshal, 1994; Shackelford et al., 1994; Wulf et al., 1996). With these findings, selection of sires with lower calpastatin EPD would be expected to produce progeny with lower shear force values.

Implications

Genetic parameters for carcass and tenderness traits in Brahman cattle, an important tropically adapted breed, suggest that selection could improve the consumer-related traits. Progeny testing could be used to identify Brahman sires that have desirable breeding values for growth, carcass, and tenderness traits. Identification of genetic markers for carcass traits and tenderness-related traits could increase the rate of genetic change in the Brahman breed.

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Evaluation of Heterosis Retention for Cow Productivity Traits in *Bos indicus/Bos taurus* Crosses

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ABSTRACT: Heterosis and heterosis retention for cow reproduction and maternal traits are being evaluated in herds of Brahman, Angus, Nellore, Hereford, and various crosses involving these breeds. Average calf crop born for Brahman, Angus, and Hereford cows has been 0.68 ± 0.03, 0.93 ± 0.03, and 0.80 ± 0.03, respectively. Brahman/Angus and Brahman/Hereford F_1 averages have been 0.90 ± 0.03 and 0.89 ± 0.02, giving heterosis estimates of 0.095 and 0.15. Brahman/Angus and Brahman/Hereford F_2 averages have been 0.74 ± 0.03 and 0.87 ± 0.03, giving heterosis estimates in the F_2 of -0.065 and +0.13. Average calf crop weaned for Brahman, Angus, and Hereford cows has been 0.59 ± 0.03, 0.83 ± 0.04, and 0.72 ± 0.04, respectively. Brahman/Angus and Brahman/Hereford F_1 averages have been 0.82 ± 0.03 and 0.82 ± 0.02, giving heterosis estimates of 0.11 and 0.155. Brahman/Angus and Brahman/Hereford F_2 averages have been 0.64 ± 0.04 and 0.81 ± 0.04, giving heterosis estimates in the F_2 of -0.060 and +0.145. Reciprocal Brahman/Hereford F_1 calves were produced, allowing estimates of heterosis for calf survival and weaning weight. Survival rates in straightbred Brahman and Hereford calves were 0.79 ± 0.03 and 0.91 ± 0.03. Survival rates in Hereford-sired calves out of Brahman cows and Brahman-sired calves out of Hereford cows were 0.95 ± 0.03 and 0.98 ± 0.09, respectively, giving a heterosis estimate of 0.115 for direct effects on calf survival. Calf survival in Brahman/Hereford F_2 calves (reciprocals combined) was 0.98 ± 0.09. This gives an estimate of .13 for the combination of maternal heterosis plus retained heterosis for direct effects on calf survival. Weaning weights in straightbred Brahman and Hereford calves were 460.6 ± 9.9 and 386.3 ± 10.8 lb. Weaning weights in Hereford-sired calves out of Brahman cows and Brahman-sired calves out of Hereford cows were 494.6 ± 10.6 and 449.2 ± 21.6, respectively, giving a heterosis estimate of 48.5 lb for direct effects on weaning weight. Weaning weight in Brahman/Hereford F_2 calves (reciprocals combined) was 480.0 ± 7.9, giving an estimate of 56.6 lb for the combination of maternal heterosis plus retained heterosis for direct effects on weaning weight. Average cow weight at 4 years of age for Brahman, Angus, and Hereford cows was 1,111 ± 22, 1,142 ± 31, and 1,054 ± 24 lb, respectively. Brahman/Angus and Brahman/Hereford F_1 averages were 1,177 ± 24 and 1,153 ± 37 lb, giving heterosis estimates of 50 and 76 lb. Brahman/Angus and Brahman/Hereford F_2 averages were 1,087 ± 31 and 1,175 ± 31 lb, giving heterosis estimates in the F_2 of –40 ± 31 and +92 ± 31 lb.

Key Words: Beef Cattle, *Bos indicus*, *Bos taurus*, Cow Productivity, Heterosis Retention

Introduction

In numerous studies, the *Bos indicus*/British F_1 female has been found to be extremely productive; in most cases, it is more productive than anything else in the comparisons. However, the *Bos indicus*/British F_1 is difficult and expensive to produce due to dystocia in *Bos indicus*-sired F_1 calves (e.g., Notter et al., 1978) and the cost, availability, and low productivity in the straightbred females required to produce the F_1's.

As in any crossbred, the characteristics of the *Bos indicus*/British F_1 result from both the blend of characteristics of the parental breeds and heterosis (hybrid vigor) between the parental breeds. Although *Bos indicus*/British crosses do receive a desirable blend of characteristics from their parental breeds, a substantial amount of the F_1 female's productive advantage can be accounted for by heterosis (Franke, 1980). As is the case for other traits, the heterosis for cow productivity in *Bos indicus*/British F_1's is from two to three times as large as the heterosis between *Bos taurus* breeds (Koger, 1980).

In crosses other than F_1's, if there is any overlap in breed composition of the sire and dam, less heterosis is expressed than is expressed in F_1's involving the same breeds. In crosses among *Bos taurus* breeds, heterosis expressed in various crosses

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has been found to be accounted for adequately by the dominance model (i.e., proportional to expected degree of heterozygosity). Adequacy of the dominance model in crosses among *Bos taurus* breeds has been documented both in crosses where one of the parents is a purebred, such as in rotational crossbreeding programs (Gregory and Cundiff, 1980), and in crosses produced from *inter se* matings, such as in composite breeds (Gregory et al., 1995). It should be noted, however, that although results reported by Gregory et al. (1995) did not differ significantly from expectations from the dominance models, cow reproductive rates were numerically lower than predicted.

The dominance model has been found to adequately account for heterosis expression in rotational crossbred matings involving the Brahman and several *Bos taurus* breeds (Williams et al., 1990 and D.E. Franke, personal communication). However, heterosis retention in crosses resulting from *inter se* mating of *Bos indicus*/*Bos taurus* crosses has not been adequately evaluated; the limited results are inconclusive or even contradictory. Rendel (1980) reported very low (60.7%) calving rates in F_2 Brahman/British cows at the Belmont Station in Queensland, Australia, compared to the rate (81.2%) in F_1 cows (for F_1 vs. F_2 comparisons, expectations from the dominance model are that the F_2 cows will retain half the heterosis for cow reproduction and for maternal effects.). Also, MacKinnon et al. (1989) reported results from groups of F_1, F_2, and F_n (F_3 and greater) cows that were half Brahman and one-fourth each of Hereford and Shorthorn. These groups were also evaluated at the Belmont Station and formed from the animals used in the study reported by Rendel (1980); heterosis was estimated to be 16.4%, -5.2%, and 1.6% for the F_1, F_2, and F_n generations.

However, results in Florida (Olson et al., 1993 and T.A. Olson, personal communication) show moderately close agreement with the dominance model. In this Florida study, average pregnancy rate in F_2 Brahman/ Angus cows was 88.9%; in F_2 Brahman/Charolais cows, the rate was 87.0%, for an average of 88% in the F_2's. Averages for the Brahman/Angus and Brahman/Charolais F_1's were 94.7 and 88.8%, respectively, for an average of 91.8% in the F_1's. Purebred averages for the Angus, Brahman, and Charolais were 92.6, 79.2 and 85.5%, respectively, for a weighted average of 84.1%. Of the 7.7% higher pregnancy rate of F_1's over purebreds (F_1 heterosis), 3.9% higher pregnancy rate of F_2's over purebreds was retained (F_2 heterosis), which is 50.6% of the estimated heterosis and is in close agreement to expectations from the dominance model (Note that 45.5% of the Brahman/Angus heterosis was estimated to be retained in the F_2 cows and 72.1% was estimated to be retained in the Brahman/Charolais F_2 cows). In this same study, the survival rate in calves out of F_2 Brahman/Angus cows (92.4%) was intermediate to that of calves out of F_1 cows (95%) and the average of those out of purebred cows (91.9 and 89.1% out of Angus and Brahman cows for an average of 90.5%), giving close agreement with the dominance model for maternal heterosis. However, calves out of both the F_1 and F_2 Brahman/Charolais cows had lower survival rates (82.4 and 88.6%) than those out of cows of the parental breeds (89.1 and 95.2% for those out of Brahman and Charolais cows). Note that, although the averages for calves out of the Charolais and the F_1 Brahman/Charolais cows seem to have been influenced by sampling errors in opposite directions, the survival rates for the calves out of the F_2 cows were higher than those out of the F_1 cows. Combining results for pregnancy rates and calf survival would indicate calf crop percentage weaned from the F_2 cows was at least as high as would be predicted from the dominance model.

Since much of the *Bos indicus*/British F_1 female's productivity is due to heterosis, the amount of heterosis that is retained is of utmost importance in determining the value of cows resulting from *inter se* mating of crossbred bulls and females (including composites). This information is of practical importance because of (1) the high productivity and value of the F_1 cow, (2) the high cost of producing this F_1, and, correspondingly, (3) the lower cost of producing "substitutes" for the F_1 cow through *inter se* mating.

In 1994, a number of outstanding Brahman/Angus and Brahman/Hereford F_1 heifers were produced at the McGregor station; many of these were produced as part of a project to progeny test Brahman bulls. In the spring of 1995, prior to breeding these heifers, it was decided to initiate a project that would use these F_1 females, as well as the station's straightbred herds of Angus, Brahman, and Hereford, to evaluate heterosis retention in *Bos indicus*/British crosses. Since the primary reason for producing *Bos indicus*/British crosses in the southern and southwestern United States is because of the value of the females as brood cows, from the beginning the focus of the project was to evaluate heterosis retention for cow productivity characters. Initially, the plan was to produce Brahman/Angus and Brahman/Hereford F_2 females and compare their productivity to that of F_1 females of the same breed composition. However, before the first *inter se* matings were made, it was decided to include first and second generation 3/8 Brahman 5/8 Angus females in the evaluation. Within the next year, the decision was made to purchase foundation animals for a straight Nellore herd and to include herds of F_1 Nellore/Angus, first and second generation

3/8 Nellore 5/8 Angus, and the four way quarter blood cross of Brahman, Angus, Nellore, and Hereford in the evaluation.

More details about the results of this study were reported by Key (2004).

Materials and Methods

The breeding herds for this study have been established at McGregor, starting in 1994. The emphasis in the study is on cow productivity. The comparison herds are made up of a minimum of 50 cows each of 14 different groups. The 14 groups include four purebred groups, three F_1 groups, two F_2 (second generation half blood) groups, two first generation groups of 3/8 *Bos indicus* / 5/8 British breeding, two second generation groups of the same 3/8 *Bos indicus* / 5/8 British breeding, and one four-breed crossbred group. In all 14 groups, all females were (or will be) produced at McGregor. The four purebred groups are Angus, Brahman, Hereford, and Nellore. An adequate number (> 50) of all four of these breeds have now been produced. For the females in the comparison herds, Angus cows were born in each year from 1997 to 1999, the Herefords in each year from 1996 to 1999, the Brahmans in each year from 1995 to 2000, and the Nellores in each year from 1997 to 2004.

The three F_1 groups are Brahman/Angus, Brahman/Hereford, and Nellore/Angus. The two F_2 groups are Brahman/Angus and Brahman/Hereford. An adequate number of all five of these half blood types have also been produced. The Brahman/Hereford F_1 group includes both Brahman-sired (BH) and Hereford-sired (HB) cows, and the Brahman/Hereford F_2 group includes all four possible combinations of F_1 matings, giving the opportunity to evaluate cows differing in their source of X chromosomes and maternal cytoplasm. The Brahman/Angus and Nellore/Angus (NA) F_1 groups are all out of Angus cows; the sires of the Brahman/Angus F_2 cows include both Brahman-sired (BA) and Angus-sired (AB) F_1 bulls. This gives the opportunity to evaluate cows differing in their source of X chromosomes. For the females in the comparison herds, BH cows (34 head) were born in each year from 1994 to 1996, and the HB cows (18 head) were born in 1994 and 1996. Cows in the BA and NA groups were born in each year from 1997 to 1999. The two types of F_2 cows sired by BH bulls were born in both 1997 and 1998; both of the two types sired by HB bulls were born in 1996, 1997, and 1999. F_2 cows sired by BA bulls were born in each year from 1997 to 1999; those by AB bulls were born in 1998 and 1999.

The 3/8 *Bos indicus* / 5/8 British combinations are 3/8 Brahman / 5/8 Angus and 3/8 Nellore / 5/8 Angus. An adequate number of the first and second generation 3/8 Brahman / 5/8 Angus (3B5A) and of the first generation 3/8 Nellore / 5/8 Angus (3N5A) females have been produced. About 25 of the second-generation 3/8 Nellore / 5/8 Angus females have been produced. All of the first generation 3B5A females were born in 1996; second generation 3B5A cows were born in each year from 1998 to 2001. The first generation 3N5A cows are the dams of the second-generation cows, which are still being produced. Therefore, the cows for the first generation evaluation herd have not been designated yet.

The four-breed crossbred group is 25% each of Angus, Brahman, Hereford, and Nellore (BANH). These were all produced from the mating of 50% *Bos indicus*/50% British males mated to 50% *Bos indicus*/British females. Of course, animals of this type are expected to exhibit less heterosis than those resulting from mating F_1 Brahman/Nellore animals to F_1 Angus/Hereford crosses. Of the 54 cows of this breeding group, 15 were sired by F_1 Brahman/Angus bulls and out of F_1 Nellore/Hereford cows and 39 were sired by F_1 Nellore/Angus bulls and out of either F_1 (29) or F_2 (10) Brahman/Hereford females. Cows in the BANH evaluation herd were born in 1996 and in each year from 1998 to 2001.

All project breeding females are exposed to breeding as yearlings to give them the opportunity to calve as two year olds. In the early stages of the study, all of the Brahman and Nellore females were needed to produce purebred replacements. After the minimum number of purebred Brahman females was produced, the Brahman cows were bred for purebred and F_1 Hereford/Brahman calves to allow for the estimation of heterosis for calf survival. Some Angus cows were bred to Brahman and to Nellore bulls and Hereford cows were bred to Brahman bulls for the same purpose. Some Nellore cows will be bred to Angus bulls in future years. Among the various groups of crossbred females, the main concern will be to make comparisons between first- and second-generation females of the same breed composition. Therefore, after the evaluation herds were established, the first- and second-generation females of the same breed composition have been bred to the same bulls in multiple sire breeding pastures. In different years, the crossbred females will be bred to both bulls of their own breed composition and to bulls of a third breed or cross to attempt to separate the effects of heterosis in the calf from maternal heterosis on calf survival.

The females of the 14 groups will be retained to evaluate lifetime cow productivity. Birth and weaning weight is recorded for all calves, and weight and

pregnancy status are recorded for the cows in the fall when their calves are weaned.

Cows calve from about February 10 to May 10 of each year. Their calves are weaned in October or November, depending on the year. Cows are culled for severe injuries, poor health, or at least two failures to have or wean a calf. Because of the later puberty in straight *Bos indicus* cattle, the straightbred Brahman and Nellore females are culled after their third failure to have or wean a calf after reaching two years of age. Cows are also culled if udders and/or teats are so large or pendulous that it is apparent that future calves would be unable to nurse without assistance.

Reproduction data and weight on the cows and weight and survival on calves have been analyzed by least squares mixed model procedures. In the analyses reported in this paper, the models for reproductive traits and calf survival (as a trait of the cow) included the fixed effects of breed of cow and age of cow. Year could not be included because of partial confounding with age of cow. Interactions among these main effects were investigated and included if important ($P < 0.25$). Dam of cow within breed and cow within dam within breed were included as random effects. Most females in the study and most of their calves are produced in multiple sire matings, so individual sires are not known.

Due to the impact of calf breed on calf survival, this trait was analyzed for all Brahman, Hereford, and Brahman/Hereford crossbred calves by breed of calf. The model used to evaluate calf survival included calf breed and age of cow as fixed effects and dam of cow within breed and cow within dam within breed as random effects.

The model used to evaluate weaning weight included the fixed effects of breed of calf, year, age of cow, and sex of calf and the random effects of dam of cow within breed and cow within dam within breed.

The model used to evaluate four-year-old cow weight included the fixed effects of breed of cow, year, and lactation status within breed. Dam of cow within breed was also included in the model as a random effect. More details about the statistical analyses were reported by Key (2004).

The traits of primary emphasis are female reproduction, maternal effects on survival and growth, and longevity. Differences between F_1's and parental purebreds have been used to estimate heterosis. Differences between first- and second-generation crosses have been evaluated to measure heterosis retention. For F_1 vs. F_2 comparisons, expectations from the dominance model are that the F_2 cows will retain half the heterosis for cow reproduction and for maternal effects.

For the comparisons of first- and second-generation 3/8 *Bos indicus* / 5/8 British crosses, second generation cows are expected to retain 15/32 of the heterosis for reproduction and maternal effects. For *inter se* matings, calves from both first and second-generation cows are expected to retain 15/32 of the heterosis for direct effects. The amount of heterosis expected in first generation 3/8 / 5/8 cows depends on how they were produced. Some of ours were produced by mating 3/4 *Bos indicus* bulls to Angus cows, where 3/4 of the heterosis is expected to be retained under the dominance model. Some of our 3/8 Brahman cattle were produced by breeding 1/4 Brahman bulls to F_1 cows. In our 3/8 Nellore crosses, some were produced from 1/4-blood bulls and F_1 cows and some from F_1 bulls and 1/4-blood cows. In each of these cases, the first generation 3/8 *Bos indicus* cows are expected to retain half of the heterosis for reproduction and maternal effects under the dominance model.

Although this study was initiated 10 years ago, because of the time required to produce second-generation crossbreds and because of the time required to evaluate lifetime production, the current results should be considered to be preliminary. Since the crosses involving the Nellore were initiated at a later date than those involving the Brahman, most of the results reported in this paper involve only those crosses involving Angus, Brahman, and Hereford. In particular, reproductive and maternal traits in and survival of calves out of Angus, Brahman, Hereford, and Brahman/Angus and Brahman/Hereford F_1 and F_2 cows are considered.

Results and Discussion

Female Reproductive Characters and Calf Survival

Least squares means and standard errors for calf crop born of cows exposed are presented by breed group of the cow in Table 1. The cows of different breed groups have been bred to different breeds of sires in different years, depending on the need for different types of crossbred animals for use in the project; therefore, the breed of service sire is partially confounded with both year and breed group of the cow. Consequently, in at least some cases, the breed group of cow effects and heterosis estimated from results in the table (and also in Table 3) are confounded with breed and/or heterosis differences in the calves being produced.

The F_1 Brahman/Angus females expressed heterosis ($P < 0.01$) for calf crop born of 0.095 (calculated as the difference between the value for the F_1 Brahman/Angus females and the average of the values for the straight Angus and straight Brahman

Table 1. Least squares means, standard errors, and numbers of observations for calf crop born and calf crop weaned of cows exposed by cow breed[a] group

Cow breed group	Calf crop born	n	Calf crop weaned	N
A	0.93 ± 0.03	176	0.83 ± 0.04	173
B	0.68 ± 0.03	238	0.59 ± 0.03	238
H	0.80 ± 0.03	202	0.72 ± 0.04	201
F_1 BA[b]	0.90 ± 0.03	217	0.82 ± 0.03	217
F_1 BH[c]	0.89 ± 0.02	358	0.82 ± 0.02	357
F_2 BA[d]	0.74 ± 0.03	180	0.64 ± 0.04	179
F_2 BH[e]	0.87 ± 0.03	185	0.81 ± 0.04	184

[a]A – Angus, B – Brahman, H – Hereford
[b]Pairs of letters indicate a crossbred group with sire breed listed first and dam breed listed second.
[c]Includes both BH and HB.
[d]Includes both AB x BA and BA x BA, where first pair of letters designates crossbred sire and second pair of letters designates crossbred dam.
[e]Includes BH x BH, HB x HB, BH x HB, and HB x BH.

females). However, the F_2 Brahman/Angus group adjusted mean was below the midparent (average of the straightbred Angus and straightbred Brahman) value ($P < 0.10$). Consequently, the F_2 Brahman/Angus group showed a substantial loss of heterosis ($P < 0.001$) for calf crop born when compared to the F_1 Brahman/Angus group (calculated as the difference between the value for the F_1 and F_2 crosses); the loss was more than the 50% of the F_1 value that would have been predicted from the dominance model. As reported by Key (2004), within the F_2 Brahman/Angus group, the females sired by AB bulls (sired by Angus bulls and out of Brahman cows) had a higher adjusted mean (0.77 0.05) for calf crop born than the females sired by BA bulls (sired by Brahman bulls and out of Angus cows) (0.71 0.05).

The F_1 Brahman/Hereford females expressed heterosis ($P < 0.01$) for calf crop born of 0.15. Note that the heterosis estimated for the F_1 Brahman/Hereford group was higher than that estimated for the F_1 Brahman/Angus group, although the average for the F_1 Brahman/Angus females was slightly higher than that of the F_1 Brahman/Hereford group. This is because heterosis is estimated as the difference between the F_1 and the midparent average, and the average of the straightbred Angus (0.93) was considerably higher than that of the Hereford (0.80). As reported by Key (2004), the F_1 HB cows (sired by Hereford bulls and out of Brahman cows) had a higher calf crop born (0.92 0.03) than the F_1 BH (sired by Brahman bulls and out of Hereford cows) cows (0.87 0.03).

The F_2 Brahman/Hereford group showed a small loss ($P > 0.10$) of heterosis for calf crop born when compared to the F_1 Brahman/Hereford group; the loss was less than the 50% of the F_1 value that would have been predicted from the dominance model. As reported by Key (2004), there were large differences among the different types of F_2 Brahman/Hereford females. Adjusted means and standard errors were 0.69 0.06, 0.98 0.06, 0.79 0.07, and 0.97 0.06 for F_2 BH (sired by F_1 BH bulls and out of F_1 BH females), F_2 HB (sired by F_1 HB bulls and out of F_1 HB females), F_2 BH x HB (sired by F_1 BH bulls and out of F_1 HB females), and F_2 HB x BH (sired by F_1 HB bulls and out of F_1 BH females), respectively. The F_2 females with HB sires showed higher performance for calf crop born than those with BH sires.

The results of the study to this point indicate that more heterosis for calf crop born was lost in the F_2 Brahman/Angus group than would be predicted from the dominance model and that less heterosis was lost in the F_2 Brahman/Hereford group than would be predicted from the dominance model. Taken together, the average for the two groups of F_1 cows was 0.895, and the weighted average of the straightbreds was 0.7725, giving an estimate of 0.1225 for heterosis in the F_1 cross. The average for the two F_2 crosses was 0.805, giving a combined estimate of 0.0325 for the heterosis retained in the F_2 crosses, which is 27% of the heterosis in the F_1 (50% is predicted from the dominance model).

Reciprocal Brahman/Hereford F_1 calves were produced, allowing estimates of heterosis for calf survival. Least squares means and standard errors for calf survival in Brahman- and/or Hereford-influenced calves are presented by calf breed group in Table 2. Straightbred Brahman calves had the lowest adjusted mean (0.79 ± 0.03) for survival among all of the calf breed groups. Survival in the straightbred Hereford calves was 0.91 ± 0.03, giving a straightbred (midparent) average of 0.85. The F_1 calves by Brahman bulls and out of Hereford cows had a slightly higher ($P > 0.10$) survival rate (0.98) than the reciprocal cross (0.95). The average of the reciprocal F_1 crosses was 0.965, giving a heterosis ($P < 0.10$) estimate of 0.115 for direct effects on calf survival. The adjusted average survival for the F_2 Brahman/Hereford calves was 0.98, giving an estimate

Table 2. Least squares means, standard errors, and numbers of observations for calf survival and weaning weight by breed of calf

Breed of calf	Calf survival	n	Weaning weight (lb)	n
Brahman	0.79 ± 0.03	65	459.1 ± 9.9	52
Hereford	0.91 ± 0.03	97	387.0 ± 10.3	88
F_1 HB[a]	0.95 ± 0.03	71	495.2 ± 10.8	68
F_1 BH	0.98 ± 0.09	8	449.5 ± 25.5	8
F_2 BH[b]	0.98 ± 0.09	110	480.7 ± 7.9	108
$F_{2.5}$ BH[c]	1.06 ± 0.14	4	465.3 ± 27.9	4
BANH[d]	0.89 ± 0.02	198	526.0 ± 6.6	176
$BANH_2$[e]	0.93 ± 0.03	124	485.3 ± 10.6	110

[a]Pairs of letters indicate a crossbred group with sire breed listed first and dam breed listed second.
[b]Includes BH x BH, HB x HB, BH x HB, and HB x BH.
[c]$F_{2.5}$ BH – BH x F_2 BH.
[d]BANH – four breed cross, resulting from breeding F_1 Nellore / Angus bulls to F_1 Brahman / Hereford cows.
[e]$BANH_2$ – four breed cross, resulting from breeding F_1 Nellore / Angus bulls to F_2 Brahman / Hereford cows.

of 0.13 for the combination of maternal hybrid vigor in the F_1 cow plus retained heterosis for direct effects on survival in the F_2 calf ($P < 0.001$).

Results for calf survival in Table 2 allow for two comparisons for calves of the same breed composition but out of F_1 vs. F_2 dams. In both cases, survival of calves out of the F_2 dams ($F_{2.5}$ and $BANH_2$) was at least as high as that in calves out of F_1 dams (F_2 and BANH). That is, in the first case, in calves sired by F_1 Brahman/Hereford bulls, those out of F_2 cows ($F_{2.5}$ calves) had at least as high survival as those out of F_1 cows (F_2 calves). Again, in the second case, in calves sired by F_1 Nellore/Angus bulls, those out of F_2 cows ($BANH_2$ calves) had at least as high survival as those out of F_1 cows (BANH calves). Note that the adjusted survival rate in the $F_{2.5}$ calves of 1.06 corresponds to 100% survival in a small number of calves (four). These results would seem to indicate that most of the heterosis for maternal effects on calf survival was retained in the F_2 Brahman/Hereford cows.

Note that the lower adjusted means for calf survival in the BANH calves compared to the F_2 BH calves and in the $BANH_2$ calves compared to the $F_{2.5}$ BH calves seem to indicate that the heterosis estimates of 0.115 for direct effects on calf survival and of 0.13 for the combination of maternal heterosis plus retained heterosis for direct effects on survival are over-estimates of the real values.

Least squares means, standard errors, and numbers of observations for calf survival are presented by cow breed group in Table 3. As noted earlier, cows of different breed groups have been bred to different breeds of sires in different years, causing the breed group of cow effects and heterosis estimated from results in the table to be confounded with breed and/or heterosis differences in the calves being produced. With that disclaimer, survival in calves out of Brahman/Angus F_1 cows (0.91) was higher ($P > 0.10$) than in the midparent average, giving an estimate of heterosis for maternal effects on calf survival of 0.04. Survival in calves out of Brahman/Angus F_2 cows (0.85) was lower ($P > 0.10$) than in the midparent average, indicating that most of the maternal heterosis for calf survival was lost in the F_2 Brahman/Angus cows. As with calf crop born, within the F_2 Brahman/Angus group, the females sired by AB bulls (sired by Angus bulls and out of Brahman cows) had a higher adjusted mean (0.88) for calf survival than the females sired by BA bulls (sired by Brahman bulls and out of Angus cows) (0.82).

Survival in calves out of Brahman/Hereford F_1 cows (0.91) was also higher ($P > 0.10$) than in the midparent average, giving an estimate of heterosis for maternal effects on calf survival of 0.035. As with calf crop born, within the F_1 Brahman/Hereford group, the females sired by Hereford bulls and out of Brahman cows had a higher adjusted mean (0.95) for calf survival than the females sired by Brahman bulls and out of Hereford cows (0.89). Survival in calves out of Brahman/Hereford F_2 cows (0.92) was higher ($P > 0.10$) than in those out of F_1 cows, indicating that most of the maternal heterosis for calf survival was retained in the F_2 Brahman/Hereford cows. Within the F_2 Brahman/Hereford group, the females sired by BH bulls (sired by Brahman bulls and out of Hereford cows) and out of BH cows had a lower adjusted mean (0.88) for calf survival than the three other types of F_2 females (0.92 to 0.94).

As was the case for calf crop born, the results from the study indicate that more heterosis for maternal effects on calf survival was lost in the F_2 Brahman/Angus group than would be predicted from the dominance model and that less heterosis was lost in the F_2 Brahman/Hereford group than would be predicted from the dominance model.

Least squares means and standard errors for calf crop weaned are presented by breed group of the cow in Table 1. Of course, calf crop weaned is a combination of calf crop born and calf survival. Consequently, the results for calf crop weaned follow

the pattern already discussed for these two characters. Calf crop weaned in F_1 Brahman/Angus cows (0.82) compared to the values for Angus and Brahman cows (0.83 and 0.59, respectively) gives a heterosis estimate of 0.11 ($P < 0.01$). However, as was the case for calf crop born and calf survival, calf crop weaned in the F_2 Brahman/Angus cows (0.64) was lower than the average of the Angus and Brahman straightbred cows. Also, as with calf crop born and calf survival, within the F_2 Brahman/Angus group, the females sired by AB bulls (sired by Angus bulls and out of Brahman cows) had a higher adjusted mean (0.67) for calf crop weaned than the females sired by BA bulls (sired by Brahman bulls and out of Angus cows) (0.59).

Calf crop weaned in F_1 Brahman/Hereford cows (0.82) compared to the values for Hereford and Brahman cows (0.72 and 0.59, respectively), gives a heterosis estimate of 0.165 ($P < 0.001$). As with calf crop born and calf survival, the F_1 HB cows (sired by Hereford bulls and out of Brahman cows) had a higher calf crop weaned (0.88) than the F_1 BH (sired by Brahman bulls and out of Hereford cows) cows (0.79) (Key, 2004). Calf crop weaned in the F_2 Brahman/Hereford cows (0.81) was only slightly lower than that of the F_1 cows, indicating, as was the case for calf crop born and calf survival, that most of the heterosis was retained in the F_2 Brahman/Hereford cows. As with calf crop born, there were large differences in calf crop weaned among the different types of F_2 Brahman/Hereford females. Adjusted means were 0.61, 0.91, 0.75, and 0.92 for F_2 BH (sired by F_1 BH bulls and out of F_1 BH females), F_2 HB (sired by F_1 HB bulls and out of F_1 HB females), F_2 BH x HB (sired by F_1 BH bulls and out of F_1 HB females), and F_2 HB x BH (sired by F_1 HB bulls and out of F_1 BH females), respectively. As with calf crop born, the F_2 females with HB sires showed higher performance for calf crop weaned than those with BH sires.

Weaning Weight

Least squares means and standard errors for weaning weight in Brahman, Hereford, and Brahman x Hereford crossbred calves are presented by breed group of the calf in Table 2. Adjusted average weaning weight in the F_1 calves out of Brahman cows (495.2 lb) was 45.7 lb heavier ($P < 0.10$) than those out of Hereford cows (449.5 lb). The average of the reciprocal F_1 crosses was 472.4 lb which, compared to the midparent average of 423.1 lb, gives a heterosis estimate of 49.3 lb for direct effects on weaning weight. The adjusted average of 480.7 lb in the F_2 calves gives an estimate of 57.6 lb for the combination of heterosis for maternal effects and retained heterosis for direct effects.

Weaning weight comparisons of both the $F_{2.5}$ to the F_2 and the $BANH_2$ to the BANH adjusted averages give estimates of the amount of maternal heterosis that is lost in the F_2 cow. These two estimates (differences of 15.4 lb and 40.7 lb, respectively) give a combined estimate of 28 lb for the maternal heterosis lost in the F_2 cow. If the estimate of 57.6 lb for the combination of heterosis for maternal effects and retained heterosis for direct effects is assumed to be the sum of the maternal heterosis plus one-half of the direct heterosis (as would be assumed under the dominance model), this would give an estimate of 33 lb for the heterosis for maternal effect on weaning weight. These estimates of heterosis for weaning weight between Brahman and Hereford (49.3 lb and 33 lb for direct and maternal effects, respectively) are consistent with results from earlier studies. For example, Roberson et al. (1986) reported estimates of 47.5 lb and 28.8 lb for heterosis for direct and maternal effects in Brahman/Hereford crosses.

Using the estimate of 28 lb for the maternal heterosis lost in the F_2 cow would imply that most of the maternal heterosis is lost in the F_2 cow. Alternatively, if only the comparison of the $F_{2.5}$ to the F_2 is used to estimate the amount of heterosis lost in the F_2 cow (15.4 lb), the amount of heterosis lost would be 33 minus 15.4 lb or 17.6 lb, which is close to (slightly less than) the amount predicted under the dominance model (16.5 lb). Remember that the average for the $F_{2.5}$ is based on a very small number (four) of calves.

Simple (unadjusted) means and standard deviations for weaning weight are presented by breed group of the cow in Table 3. Using these unadjusted means gives estimates of 29.5 lb and 88.4 lb for maternal heterosis in the Brahman/Angus and Brahman/Hereford F_1 cows, respectively. (Note that this estimate of 88.4 lb is much higher than the estimate of 33 lb calculated from the information in Table 2; also note that, in the 88.4 lb estimate, many of the calves out of both the Brahman and Hereford cows were straightbreds, and, of course, all calves out of the F_1 cows were crossbreds.) Comparing the weaning weights from calves out of the F_2 cows to those out of the straightbred parental breeds gives estimates of 2.0 and 42.2 lb for the amount of maternal heterosis retained in the Brahman/Angus and Brahman/Hereford F_2 cows, respectively. This is much less than predicted under the dominance model for the Brahman/Angus crosses but similar to what is predicted for the Brahman/Hereford crosses. Among calves out of the different types of F_2 Brahman/Hereford females, unadjusted means were 455, 482, 475, and 456 lb for calves out of F_2 BH (sired by F_1 BH bulls and out of F_1 BH females), F_2 HB (sired by F_1 HB bulls and out of F_1 HB females),

Table 3. Least squares means, standard errors, and numbers of observations for calf survival and unadjusted means, standard deviations, and numbers of observations for calf weaning weight by cow breed group[a]

Cow breed group	Calf survival	n	Weaning weight (lb)	n
A	0.88 ± 0.03	144	446.8 (88.0)	131
B	0.86 ± 0.03	144	467.5 (80.1)	127
H	0.89 ± 0.03	145	381.3 (79.6)	131
F_1 BA	0.91 ± 0.03	178	486.6 (81.8)	166
F_1 BH	0.91 ± 0.02	311	512.8 (71.5)	286
F_2 BA	0.85 ± 0.03	114	459.1 (81.0)	93
F_2 BH	0.92 ± 0.03	144	466.6 (70.4)	135

[a]See Table 1 for breed group designations.

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

Breed group	LS Mean ± SE (lb)	n
A	1140.7 ± 31.2	28
B	1110.3 ± 22.2	32
H	1052.7 ± 23.1	40
F_1 BA	1175.9 ± 23.3	47
F_1 BH	1153.5 ± 36.5	51
F_2 BA	1086.8 ± 30.1	30
F_2 BH	1174.1 ± 29.9	30

[a]See Table 1 for breed group designations.

F_2 BH x HB (sired by F_1 BH bulls and out of F_1 HB females), and F_2 HB x BH (sired by F_1 HB bulls and out of F_1 BH females) cows, respectively.

Cow Weight

Least squares means and standard errors for 4-yr-old cow weight are presented by breed group of the cow in Table 4. This was the oldest age that had weight records across all breed types in the analysis. The F_1 Brahman/Angus females expressed heterosis ($P < 0.10$) for cow weight of 50.4 lb (i.e., the difference between the F_1 average (1,175.9 lb) and the midparent average (1,125.5 lb)). As with the female reproductive characters, the adjusted cow weight average for the F_2 Brahman/Angus females (1086.8 lb) was less than the average of the straightbred Brahman (1,110.3 lb) and Angus (1,140.7 lb). The F_1 Brahman/Hereford females expressed heterosis ($P > 0.10$) for cow weight of 72.0 lb (i.e., the difference between the F_1 average (1,153.5 lb) and the midparent average (1,081.5 lb)).

The adjusted average 4-yr-old weight for the F_2 Brahman/Hereford group (1,174.1 lb) was slightly heavier ($P > 0.10$) than that of the F_1 Brahman/Hereford group (1,153.5 lb). As reported by Key (2004), there were large differences among the different types of cows within that group; the cows sired by BH bulls were heavier than those sired by HB bulls. Adjusted means were 1,212, 1,022, 1,115, and 1,090 lb for F_2 BH (sired by F_1 BH bulls and out of F_1 BH females), F_2 HB (sired by F_1 HB bulls and out of F_1 HB females), F_2 BH x HB (sired by F_1 BH bulls and out of F_1 HB females), and F_2 HB x BH (sired by F_1 HB bulls and out of F_1 BH females), respectively. Note that these differences are in the opposite direction of those for calf crop born and weaned. It appears that at least part of these weight differences are the result of the reproductive differences and/or that at least part of the higher reproductive rates are due to the more moderate-sized cows. Lactation status (dry or lactating) was in the statistical model, which should account for the current year's reproductive differences, but it would not account for the reproductive differences in previous years. Key (2004) gave both adjusted and unadjusted values for calf crop born and weaned by cow breed-type and age.

As was the case for the female reproductive characters, the results from the study indicate that more heterosis for 4-yr-old cow weight was lost in the F_2 Brahman/Angus group than would be predicted from the dominance model and that less heterosis was lost in the F_2 Brahman/Hereford group than would be predicted from the dominance model.

Summary

The results of this study present additional questions regarding the validity of the dominance model for prediction of heterosis and heterosis retention for reproductive and maternal traits in *Bos indicus* x *Bos taurus* females. Heterosis retention estimates for the traits of interest were found to be lower than expectations of the dominance model for some groups and higher than expectations of the dominance model for other groups. In particular, the results for the characters evaluated indicate that more heterosis was lost in the Brahman/Angus F_2 cows than would be predicted from the dominance model and that less was lost in the Brahman/Hereford F_2 cows than would be predicted from the dominance model. Cows in the present study will continue to be evaluated for lifetime production for reproductive and maternal traits to obtain additional information regarding heterosis retention in these types of crosses.

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Breed Direct and Maternal Additive and Heterosis Genetic Effects for Reproductive, Growth, and Carcass Traits

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ABSTRACT: Breed direct and maternal additive and heterosis genetic effects were estimated for reproductive, growth, and carcass traits in a multibreed crossbreeding program involving Angus, Brahman, Charolais, and Hereford breeds. Two-, three-, and four-breed rotational crossbreeding systems were designed with the restriction that each combination include Brahman, a breed tropically adapted to the Gulf Coast Region. Breed direct and maternal additive genetic and heterosis genetic effects were estimated with a linear regression model that included fixed effects of year of record, age of cow, calf gender (when appropriate), and fractions of genes from breeds in individuals and dams and fractions of gene pairs in individuals and dams from different breeds as linear covariates. Breed direct and maternal additive genetic effects were expressed as a deviation from Angus. Direct and maternal heterosis genetic effects were expressed as a deviation from zero. The Brahman direct additive genetic effect decreased calving and weaning rates, longissimus muscle area, fat thickness, and marbling score; it increased calving date, birth weight, and shear force compared to Angus ($P < 0.05$). Incidence of calving difficulty, birth weight, weaning weight, hot carcass weight, and longissimus muscle area were increased and fat thickness was decreased by the Charolais direct additive genetic effect, compared to Angus ($P < 0.05$). The Hereford direct additive genetic effect increased birth weight, weaning weight, and carcass weight compared to Angus ($P < 0.05$). Positive heterosis genetic effects existed for Angus-Brahman, Brahman-Charolais, and Brahman-Hereford breed combinations for birth weight, weaning weight, hot carcass weight, and longissimus muscle area, whereas negative heterosis genetic effects existed for shear force. It is clear in this study that the tropically adapted Brahman had lower genetic expression for reproduction and growth than less-adapted breeds but excelled in reproductive and maternal traits and in some carcass traits when crossed with the less-adapted breeds.

Key Words: Brahman, Genetic Effects, Production Traits

Introduction

Brahman was one of the first tropically adapted breeds used in the Gulf Coast region of the United States and continues to contribute to crossbreeding systems for cow-calf production. The advantages of Brahman breeding are clearly shown when Brahman F_1 cows are mated to produce backcross or terminal crossbred calves for market (Cartwright et al., 1964; Turner and McDonald, 1969; Koger et al., 1975).

Planning efficient crossbreeding systems requires knowledge of direct and maternal breed additive and heterosis genetic effects. Breed direct additive genetic effects indicate how breeds compare directly to each other for individual production traits, whereas maternal additive genetic effects define differences among maternal traits of dams. Direct heterosis genetic effects quantify the non-additive genetic effects of breed combinations on individual performance and maternal heterosis genetic effects define differences among maternal traits of dams.

The purpose of this paper is to report breed direct and maternal additive and heterosis genetic effects of Angus, Brahman, Charolais, and Hereford breeds and their crosses on reproduction, growth, and carcass traits in the Gulf Coast region of the United States.

Materials and Methods

Source of information

Data were generated in a long-term rotational crossbreeding study involving Angus, Brahman, Charolais, and Hereford breeds. The study was initiated in 1969 and continued through four generations ending in 1988. Two-, three-, and four-breed combinations were involved in the rotational crossbreeding study with the restriction that each combination include Brahman, a tropically adapted breed. Information for this paper was adapted from Williams et al. (1990; 1991), DeRouen et al. (1992a; 1992b), Crews (1996), and Franke et al. (2001).

Management of cattle

Detailed procedures on management of cows and calves, breeding season, winter supplementation, culling procedures, and postweaning management of steers were discussed by Williams et al. (1990), DeRouen et al. (1992a) and Franke et al. (2001). An overview of these procedures will be given here.

Straightbred herds of Angus, Brahman, Charolais, and Hereford were maintained as controls throughout the study. Rotation systems were initiated with Brahman F_1 cows mated to produce backcross calves in two-breed rotation systems and three-breed cross calves in three- and four-breed rotation systems. This study was initiated with cows obtained from other research stations and from private producers in Louisiana. Each generation lasted four years. About 75% of the heifers weaned each year were retained as replacements and managed separately. While being accumulated in each generation, replacement heifers were used to evaluate early fertility (DeRouen and Franke, 1989; DeRouen et al., 1994) and ease of calving of selected sire breeds (Thrift et al., 1986). All cows were sold at the end of each generation. Replacement females weaned the past four years were mated to next sire breed in their rotation breed combination. Sires were purchased from Louisiana purebred producers. Slight selection pressure for yearling weight was applied in the form of purchasing the heaviest yearling bulls or two yr olds available in respective private herds. Calves were springborn and weaned the first week of October at an average age of 220 d. Cows were culled for failing to calve in two consecutive years, injury, or disease.

Steers were randomly assigned at weaning within a rotation breed combination to a feedlot treatment or to a ryegrass pasture treatment before feeding. Steers were fed at the Central Research Station and harvested after a designated time on feed. All steers were processed in small packing plants in the Baton Rouge area. Carcass data were recorded after a 24-hr chill.

Traits of Interest

Reproductive traits of interest included calving rate, assistance at calving, calf survival, and weaning rate. For calving rate and weaning rate, cows were assigned a 1 if they calved or weaned a calf and a 0 if they did not calve or did not wean a calf. Cows that required assistance during calving were assigned a 1, and cows that calved unassisted were assigned a 0. Calves that were born and weaned were assigned a 1 for survival, and calves that were stillborn or died before weaning were assigned a 0 for calf survival.

Pre-weaning traits included calving date, birth weight, and adjusted 205-d weight. Calving date was recorded as the day of the year the cow calved, with January 1 as day 1. Actual weaning weight was adjusted to 205 d of age with the following formula: Adjusted 205-d wt = {[(actual weaning weight-birth weight)/age at weaning]*205}+ birth weight. A205-d weight was not adjusted for cow age.

Carcass traits discussed in this report include hot carcass weight, longissimus muscle area, fat thickness, marbling score, and shear force after a 7-d aging period. Carcass data were recorded after a 24-hr postmortem chill. A three-rib section of the primal rib was purchased from each steer at the time carcass data were collected and returned to the Louisiana State University Animal Science Department for measurement of shear force. A 1-inch steak was cut from the large end of the rib section and aged for 7 d before cooking. Steaks were cooked in a deep-fat cooker to an internal temperature of about 160°F and allowed to cool to room temperature. Three 1-inch cores were taken from each steak perpendicular to the steak surface and sheared in a Warner-Bratzler device. The average shear force of the three cores was recorded as the shear force for each animal.

Statistical Analysis

A total of 4,596 calving records, 3,728 calf weaning weight records, and 1,494 steer records were available for study. Statistical models to estimate direct and maternal additive and heterosis effects included the fixed effects of year of record, gender of calf (when appropriate), and the linear and quadratic effects of cow age, and linear covariances that represented the proportion of each breed present in the calf and in the cow and the expected frequency of genes paired coming from two different breeds in the calf and in the cow. Partial regression coefficients resulting from these analyses were interpreted as breed additive genetic effects or breed combination heterosis effects (Eisen et al., 1983). For all traits, breed direct and maternal additive genetic effects were expressed as a deviation from Angus.

Results and Discussion

Breed direct and maternal additive and heterosis genetic effects for reproductive traits, preweaning traits, and carcass traits are given in Tables 1, 2, and 3, respectively. The focus of this paper is on the additive genetic effects of the Brahman compared to Angus and on the expression of heterosis in Brahman combinations.

Reproductive traits

The overall means were 82.1% for calving rate, 4.2% for calving assistance, 92.8% for calf survival, and 76.2% for weaning rate (Williams et al., 1990).

Table 1. Direct and maternal additive and heterosis genetic effects for reproductive traits[1]

Effects	Calving rate, %	Calving assistance, %	Calf survival, %	Weaning rate, %
Overall means	82.1	4.2	92.8	76.2
Direct additive genetic effects[2]				
Brahman	-13.1 ± 4.0*	2.9 ± 2.1	-6.6 ± 2.9*	-17.7 ± 4.4*
Charolais	-4.8 ± 3.6	6.1 ± 1.9*	-1.8 ± 2.7	-7.0 ± 4.0
Hereford	3.5 ± 3.6	-1.8 ± 1.9	-1.6 ± 2.7	1.1 ± 4.0
Direct heterosis genetic effects[3]				
A-B	5.8 ± 6.6	5.9 ± 3.5	0.7 ± 4.9	4.8 ± 7.3
A-C	-0.7 ± 7.2	0.1 ± 3.8	-1.0 ± 5.3	-2.0 ± 7.9
A-H	1.8 ± 6.5	-0.5 ± 3.4	-2.4 ± 4.7	-0.3 ± 7.2
B-C	3.9 ± 6.7	3.0 ± 3.5	-4.8 ± 5.0	-1.0 ± 7.4
B-H	3.1 ± 7.1	5.9 ± 5.7	-0.2 ± 5.2	1.6 ± 7.8
C-H	-9.0 ± 7.5	4.3 ± 4.0	-0.4 ± 5.5	-8.5 ± 8.3
Maternal additive genetic effects[2]				
Brahman	-0.6 ± 3.9	-5.0 ± 2.1*	-3.7 ± 2.9	-1.4 ± 4.3
Charolais	6.6 ± 3.6	-2.4 ± 2.0	-1.5 ± 2.7	6.1 ± 4.0
Hereford	3.2 ± 3.7	1.8 ± 1.9	-3.2 ± 2.7	-4.7 ± 4.0
Maternal heterosis genetic effects[3]				
A-B	12.9 ± 6.1*	-6.5 ± 3.2*	5.7 ± 4.5	16.5 ± 3.2**
A-C	6.8 ± 7.3	-1.7 ± 3.9	3.7 ± 5.4	10.3 ± 8.0
A-H	7.6 ± 6.5	0.5 ± 3.5	-1.8 ± 4.8	6.0 ± 7.2
B-C	12.7 ± 6.0*	-7.0 ± 3.2	8.3 ± 4.4	18.0 ± 6.6**
B-H	20.5 ± 6.3**	-6.4 ± 3.3	10.5 ± 4.6*	27.8 ± 6.9**
C-H	13.1 ± 7.0	-6.8 ± 3.7	9.1 ± 5.2	19.8 ± 7.7*

[1] Adapted from Williams et al. (1990).
[2] Expressed as a deviation from Angus.
[3] A=Angus, B=Brahman, C=Charolais, H=Hereford.
*($P < 0.05$); **($P < 0.01$)

Two-, three-, and four-breed rotation cows had a 10.3% higher calving rate than straightbred cows.

Direct additive genetic effects are based on the calf record. The calving rate and weaning rate direct additive genetic effects for Brahman were smaller than for Angus (-13.1 4.0 and -17.7 4.4%, respectively; $P < 0.05$). The direct additive genetic effects of Charolais and Hereford for calving rate and weaning rate were not different from each other or from Angus. The Brahman direct additive genetic effect for calf survival was smaller than for Angus (-6.6 2.9%; $P < 0.05$). Charolais had a greater direct additive genetic effect for assistance at calving than Angus (6.1 1.9%; $P < 0.05$). The Brahman maternal additive genetic effect resulted in less assistance at calving than in Angus (-5.0 2.1%; $P < 0.05$).

Direct heterosis effects in the calf for calving rate, calving assistance, calf survival, or weaning rate were not different from zero. However, maternal heterosis was very important for reproductive traits. Brahman-Angus, Brahman-Charolais, and Brahman-Hereford maternal heterosis increased calving rate and weaning rate ($P < 0.05$).

Preweaning traits

The overall means for Julian day of birth, birth weight, and A205-d weight was 50.1 d (February 19), 75 lb, and 465 lb, respectively. Three-breed rotation calves were born 5 d earlier ($P < 0.05$) than straightbred calves and two- and four-breed rotation calves. Birth weight was greater for four-breed rotation calves (75.9 ± 0.7 lb; ($P < 0.05$) than for two-breed rotation calves (72.2 ± 0.4 lb), three-breed rotation calves (71.6 ± 0.4), and straightbred calves (70.3 ± 0.4 lb). Adjusted 205-d weaning weights were 418, 474, 479, and 488 lb for straightbred, two-breed, three-breed, and four-breed rotation calves, respectively.

Brahman direct additive genetic effects delayed calving date by 16.8 ± 5.0 d and increased birth weight by 12.3 ± 2.9 lb compared to Angus ($P < 0.01$). Charolais and Hereford direct additive genetic effects for birth and A205-d weight were greater than for Angus ($P < 0.01$). Brahman-Angus, Brahman-Charolais and Brahman-Hereford direct heterosis

Table 2. Direct and maternal additive and heterosis genetic effects for preweaning traits[1]

Effect	Calving date, d	Birth weight, lb	Adjusted 205-d weight, lb
Overall means	50.1	75	465
Direct additive genetic effects[2]			
Brahman	16.8 ± 5.0**	12.3 ± 2.9**	-0.0 ± 12.8
Charolais	5.2 ± 4.2	21.4 ± 2.4**	68.6 ± 10.8**
Hereford	-2.0 ± 3.9	6.6 ± 2.2**	20.3 ± 10.1*
Direct heterosis genetic effects[3]			
A-B	1.2 ± 4.9	11.2 ± 2.6**	85.1 ± 12.6**
A-C	-5.8 ± 4.3	-1.8 ± 2.5	18.9 ± 11.0
A-H	0.2 ± 3.5	5.5 ± 2.0**	29.5 ± 8.8**
B-C	1.6 ± 4.9	11.2 ± 2.6**	73.4 ± 12.6**
B-H	3.0 ± 5.1	11.7 ± 2.9**	76.9 ± 12.8**
C-H	-1.6 ± 4.4	3.7 ± 2.4	33.1 ± 11.0**
Maternal additive genetic effects[2]			
Brahman	5.1 ± 4.6	-15.2 ± 2.6**	28.4 ± 11.7*
Charolais	-1.0 ± 3.6	-1.1 ± 2.0	28.2 ± 9.3**
Hereford	0.2 ± 3.4	-2.0 ± 0.9	-38.8 ± 8.6**
Maternal heterosis genetic effects[3]			
A-B	-8.6 ± 4.4	-4.2 ± 2.4	-2.4 ± 11.5
A-C	4.6 ± 4.6	4.2 ± 2.4	23.1 ± 11.7
A-H	2.1 ± 3.9	2.0 ± 2.2	35.3 ± 9.9**
B-C	-5.1 ± 4.4	-6.4 ± 2.4**	-11.7 ± 11.2
B-H	-11.1 ± 4.5*	3.3 ± 2.4	23.8 ± 11.5*
C-H	-2.1 ± 4.3	2.6 ± 2.4	33.1 ± 11.0**

[1] Adapted from Franke et al. (2001).
[2] Expressed as a deviation from Angus.
[3] A=Angus, B=Brahman, C=Charolais, H=Hereford.
*($P < 0.05$); **($P < 0.01$).

genetic effects for birth weight and for A205-d weight were different from zero ($P < 0.01$). Birth and A205-d weight direct heterosis genetic effects were 11.2 ± 2.6 and 85.1 ± 12.6 lb for Angus-Brahman, 11.2 ± 2.6 and 73.4 ± 12.6 lb for Brahman-Charolais, and 11.7 ± 2.9 and 76.9 ± 12.8 lb for Brahman-Hereford, respectively.

The Brahman maternal additive genetic effects decreased birth weight (-15.2 ± 2.6 lb; $P < 0.01$) and increased A205-d weight (28.4 ± 11.7 lb; $P < 0.01$) compared to Angus. The Brahman maternal additive genetic effect for A205-d weight was not different from Charolais.

Brahman-Hereford maternal heterosis genetic effects resulted in an earlier calving date (-11.1 4.5 d; $P < 0.05$) and a heavier A205-d weaning weight (23.8 11.5 lb; $P < 0.05$). The Brahman-Charolais maternal heterosis genetic effect decreased birth weight (-6.4 2.4 lb; $P < 0.05$).

Carcass Traits

The Brahman direct additive genetic effect decreased longissimus muscle area (-0.8 0.2 in^2), fat thickness (-0.19 0.02 in), marbling score (-1.5 0.13 units), and it increased shear force (7.5 1.3 lb) compared to Angus ($P < 0.01$). The Charolais direct additive genetic effect increased carcass weight (93.7 11.7 lb) and longissimus muscle area (3.0 0.2 in^2) and decreased fat thickness (-0.28 0.02 in) and marbling score (-0.9 0.13 units) compared to Angus ($P < 0.05$). Angus-Brahman, Brahman-Charolais, and Brahman-Hereford direct heterosis genetic effects increased ($P < 0.05$) hot carcass weight and longissimus muscle area. The Angus-Brahman direct heterosis genetic effect increased fat thickness and lowered shear force and the Brahman-Hereford direct heterosis genetic effect increased marbling score ($P < 0.05$).

Brahman and Hereford maternal additive genetic effects decreased ($P < 0.05$) carcass weight by -30 10.8 and -54.1 9.0 lb, respectively, compared to Angus. The Charolais maternal additive genetic effect

Table 3. Direct and maternal additive and heterosis genetic effects for carcass traits[1]

Effects	Hot carcass weight, lb	Longissimus muscle area, sq in	Fat thickness, in	Marbling score, units	Shear force, lb
Overall means	660	11.1	0.32	3.93	22.5
Direct additive genetic effects[2]					
Brahman	-19.2 ± 11.7	-0.8 ± 0.2**	-0.19 ± 0.02**	-1.5 ± 0.13**	7.5 ± 1.3**
Charolais	93.7 ± 11.7**	3.0 ± 0.2**	-0.28 ± 0.02**	-0.9 ± 0.13*	1.1 ± 1.1
Hereford	28.7 ± 10.1*	-0.2 ± 0.2	0.00 ± 0.02	0.5 ± 0.11	-0.6 ± 0.9
Direct heterosis genetic effects[3]					
A-B	131.4 ± 13.4**	0.9 ± 0.3**	0.09 ± 0.03**	0.15 ± 0.15	-4.8 ± 1.1**
A-C	61.1 ± 20.3**	-0.6 ± 0.4	0.07 ± 0.04	0.20 ± 0.22	-0.2 ± 1.5
A-H	59.7 ± 15.4**	0.4 ± 0.3	0.03 ± 0.04	0.29 ± 0.17	1.8 ± 1.1
B-C	86.9 ± 13.9**	0.6 ± 0.3*	0.06 ± 0.03	0.17 ± 0.15	-3.5 ± 1.1
B-H	98.1 ± 14.1**	0.9 ± 0.3**	0.08 ± 0.03	0.35 ± 0.16*	-2.4 ± 1.1
C-H	27.1 ± 19.2	-0.6 ± 0.4	0.04 ± 0.04	0.37 ± 0.21	-1.1 ± 1.3
Maternal additive genetic effects[2]					
Brahman	-30.4 ± 10.8*	0.0 ± 0.2	-0.03 ± 0.02	-0.04 ± 0.12	0.4 ± 0.7
Charolais	21.8 ± 10.4	-0.1 ± 0.2	0.06 ± 0.02*	0.03 ± 0.11	-1.5 ± 0.9
Hereford	-54.1 ± 9.0**	-0.3 ± 0.2	-0.04 ± 0.02	-0.07 ± 0.10	1.3 ± 0.7
Maternal heterosis genetic effects[3]					
A-B	-13.0 ± 12.6	0.0 ± 0.3	-0.00 ± 0.02	-0.18 ± 0.14	--[4]
A-C	-26.2 ± 21.2	0.7 ± 0.4	0.02 ± 0.03	-0.03 ± 0.14	--
A-H	43.9 ± 17.4**	1.3 ± 0.3**	0.04 ± 0.04	-0.19 ± 0.19	--
B-C	-5.3 ± 13.0	-0.1 ± 0.3	0.02 ± 0.04	-0.03 ± 0.14	--
B-H	21.8 ± 12.6	0.4 ± 0.3	0.02 ± 0.03	-0.20 ± 0.14	--
C-H	48.3 ± 19.4*	1.1 ± 0.4**	0.03 ± 0.04	-0.25 ± 0.21	--

[1] Adapted from DeRouen et al. (1992b).
[2] Expressed as a deviation from Angus.
[3] A=Angus, B=Brahman, C=Charolais, H=Hereford.
[4] Not estimated.
*($P < 0.05$); **($P < 0.01$).

resulted in less fat thickness (-0.02 0.06 in; $P < 0.05$) than Angus. Maternal heterosis genetic effects for Angus-Brahman, Brahman-Charolais, and Brahman-Hereford were not important for any carcass traits.

Discussion

These data indicate that the tropically adapted Brahman generally contributes lower direct additive genetic effects for reproductive traits than the less-adapted Angus, but significant maternal heterosis effects are expressed for reproductive traits when the Brahman is combined with Angus, Charolais, or Hereford. The Brahman direct additive genetic effect for calving date resulted in later-born and heavier calves at birth than Angus. Longer gestation lengths of five to seven days for Brahman cattle do not fully explain the large direct additive genetic effect for later calving of Brahman. Brahman-sired calves from British type dams are known to be heavier at birth compared to calves sired by other breeds of bulls.

Crockett et al. (1978a) found the Brahman to have a significantly lower pregnancy rate and weaning rate than Angus and Hereford. However, Peacock et al. (1977) reported no differences in pregnancy rate, calf survival, or weaning rate among Angus, Brahman, and Charolais cows bred to produce straightbred calves. Turner et al. (1968) found no difference in weaning rate among Angus, Brahman, Hereford, and Brangus cows, but crossbred cows among these breeds had a 10% higher weaning rate than the straightbred cows, resulting in hybrid vigor advantages of 18.2, 17.4 and 28.1% for Angus-Brahman, Brangus-Brahman and Brahman-Hereford F_1 cows.

Wyatt and Franke (1986) analyzed crossbreeding data from the Southern Region Beef Cattle Breeding Project S-10. They reported rankings similar to those found in this study for Brahman direct additive genetic effects for preweaning traits and for direct heterosis genetic effects when the Brahman was crossed with Angus and Hereford. Brahman had a relatively large and significant direct additive genetic effect for birth weight (7.4 ± 0.25 lb) and a relatively large negative maternal additive genetic effect for birth weight (-6.1 ± 0.24 lb). Crockett et al. (1978b) reported that birth weights of Hereford and Brahman straightbreds were similar and greater than Angus. Crockett et al. (1978b) also reported that Angus-Brahman and Brahman-Hereford crossbred calves over three generations of rotational crossbreeding averaged 29 and 20% hybrid vigor for weaning weight, respectively. Wyatt and Franke (1986) reported similar direct additive genetic effects for Brahman, Angus, and Hereford for weaning weight, but the Brahman had significantly higher maternal additive genetic effects for weaning weight than Angus or Hereford. Crews (1996) reported a desirable direct heterosis effect of rotational crossbred steers on shear force (-0.61 0.30 kg; $P <$ 0.05).

The Brahman has contributed to the cattle industry because of its influence on hybrid vigor for fertility and preweaning traits when crossed primarily with British breeds. Emphasis on postweaning growth, carcass, and consumer-accepted traits has not been a high priority in the breed. Earlier papers citing carcass traits of Brahman clearly show that the Brahman was not competitive with British breeds for carcass quality traits (Damon et al., 1960; Turner, 1973). The data presented by DeRouen et al. (1992a) and Crews (1996) were collected between 1970 and 1988 and show that the Brahman may have become more competitive with Angus and Hereford for carcass traits. The data reported at this meeting by Smith et al. (2005) suggested that Brahman steers produced in Louisiana from 1996 through 2000 met industry standards for feedlot ADG, carcass weight, longissimum muscle area, and yield grade but were not competitive for marbling score and shear force.

Implications

The tropically adapted Brahman has contributed significantly to cow-calf production in the Gulf Coast region of the United States. Its contribution has been primarily in the area of greater fertility and maternal ability as a crossbred cow. There are indications that the Brahman breed has been improved for carcass traits over the past three decades, but more work is needed for the Brahman to be competitive.

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