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ABSTRACT: The objective of this experiment was to evaluate alternative sources of tropically adapted cattle germplasm and compare them with Angus- (AN) and Hereford- (HE) sired steers. Carcass, yield, and longissimus thoracis palatability traits from F_1 steers (n = 621) obtained from mating AN and MARC III cows to HE, AN, Brangus (BR), Beefmaster (BM), Bonsmara (BO), or Romosinuano (RO) sires were compared. Data were adjusted to constant age (426 d), carcass weight (340 kg), fat thickness (1.0 cm), fat trim percentage (25%), and marbling (Small^{00}) endpoints. For Warner-Bratzler and slice shear force and trained and untrained sensory panel traits, data were obtained on LM from ribeye steaks stored at 2°C for 14 or 15 d postmortem. The following comparisons were from the age-constant endpoint. Carcasses from BM-, AN-, and BR-sired steers (358, 355, and 351 kg, respectively) were heavier ($P < 0.05$) than carcasses from steers from HE (343 kg) and BO (331 kg) sires; RO-sired steers (318 kg) had the lightest ($P < 0.05$) carcasses. Adjusted fat thicknesses for AN- and BM-sired steers (1.3 and 1.2 cm, respectively) were greater ($P < 0.05$) than for steers from BR (1.0 cm) and BO (0.9 cm) sires; RO-sired steers (0.8 cm) had the least fat thickness. Longissimus areas were larger ($P < 0.05$) for BO- and BR-sired steers (84.4 and 84.1 cm^2, respectively) than for BM- and HE-sired steers (80.8 and 80.2 cm^2, respectively). A greater ($P < 0.05$) percentage of carcasses from AN-sired steers graded USDA Choice (69%) than other sire breeds (17 to 47%) except HE (52%). Carcass yield of boneless, totally trimmed retail product was least ($P < 0.05$) for AN-sired steers (60.1%) and greatest ($P < 0.05$) for RO- and BO-sired steers (64.4 to 63.5%). Considering all measurements, AN LM tended to be more tender and BM LM tended to be least tender. American composite breeds BM and BR were heavier, fatter, lesser yielding, with similar marbling scores but less tender LM than BO and RO. Angus carcasses were similar in size, fatter, lesser yielding, with more marbling and more tender LM compared with BM and BR. Bonsmara and RO provide tropically adapted germplasm and produce carcasses that are lighter, leaner, greater yielding, with similar marbling and LM that tend to be more tender than carcasses from BM and BR.

Key words: beef, breed, carcass, palatability, quality, tenderness

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INTRODUCTION

The Germplasm Evaluation (**GPE**) program at the Roman L. Hruska US Meat Animal Research Center (**USMARC**) characterizes cattle breeds representing diverse biological types for carcass and LM palatability traits that affect the quantity, quality, and value of production. The first 7 cycles of GPE have compared 37 breeds representing several biological types of cattle to Hereford (**HE**) and Angus (**AN**) and to one another. Carcass and LM palatability traits from these studies have been reported by Koch et al. (1976, 1979, 1982b) and Wheeler et al. (1996, 2001, 2004, 2005). Diverse breeds are required to exploit heterosis and complementarity through crossbreeding and to match genetic potential with diverse markets, feed resources, and climates. Evaluation of carcass traits and meat palatability from different breeds or breed crosses is important in determining the potential value of alternative germplasm resources for profitable beef production.

It has been shown that *Bos taurus* × *Bos indicus* cows were exceptionally productive and efficient, especially in subtropical climates (Olson et al., 1991; Cundiff, 2005). However, as the proportion of *B. indicus*

[1]Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.

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Table 1. Number of sires used per breed and number of steers in each sire breed × dam breed subclass

Sire breed	Number of sires	Dam breed and number of steer progeny: Angus	MARC III[1]	Total
Hereford	22	54	48	102
Angus	22	—	103	103
Brangus	21	59	48	107
Beefmaster	22	47	56	103
Bonsmara	19	57	47	104
Romosinuano	20	50	52	102
Total	116	267	354	621

[1]Composite consisting of 1/4 each of Hereford, Angus, Pinzgauer, and Red Poll.

increased, the advantages of *B. indicus* crosses were tempered by older age at puberty and temperament (Turner, 1980; Thrift and Thrift, 2005) and reduced meat tenderness (Crouse et al., 1989). Thus, one goal of the GPE program has been to identify alternative tropically adapted germplasm that minimizes or eliminates the detrimental traits of *B. indicus* breeds. This experiment (Cycle VIII of the GPE program) evaluated 6 breeds including 2 tropically adapted composite breeds of American origin (BR and BM), 2 tropically adapted non-*B. indicus* breeds [Bonsmara (**BO**) from South Africa and Romosinuano (**RO**) from Colombia] and 2 *B. taurus* breeds, HE and AN. Thus, the objective of Cycle VIII was to compare alternative tropically adapted breeds to tropically adapted breeds commonly used in the United States.

MATERIALS AND METHODS

All experimental procedures were reviewed and approved by the US Meat Animal Research Center Animal Care and Use Committee and were in accordance with the Guide to the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2009).

Animals

Angus and MARC III composite (1/4 AN, 1/4 HE, 1/4 Pinzgauer, and 1/4 Red Poll) dams were mated by AI to 22 AN, 22 HE, 21 Brangus (**BR**), 22 Beefmaster (**BM**), 19 BO, and 20 RO bulls to produce 621 steer calves (Table 1). In contrast to GPE cycles I to VI, when only young, unproven sires were sampled, about one-half of the sires sampled from the AN, HE, BR, and BM breeds were among the top in progeny registrations in their respective herd books, and about one-half were young unproven sires of each breed (considered to be excellent herd sire prospects). In cooperation with seedstock breeders and commercial AI organizations, young sires (2 to 3 yr old) identified as herd sire prospects, based on EPD for growth and other traits, were selected to represent the breeds. The BO and RO bulls used were a representative sample of the young sires available for these respective breeds, which had recently been introduced into the United States when they were sampled for this experiment.

AN. Semen from 22 AN sires was used in cycle VIII. Nine of the sires had been used previously in cycles VI or VII and 13 were used for the first time in cycle VIII. One-half of the sires ranked in the top 100 (4 repeated sires and 7 new sires) in registrations within the AN breed. The remainder were young unproven sires, considered to be outstanding herd sire prospects. Average expected progeny differences from the 2009 genetic evaluations of the AN bulls used were 2.3, 37.6, 73.6, and 18.5 for birth weight, weaning weight, yearling weight, and milk, respectively. Birth year 2007 breed average EPD were 2.2, 43.7, 80, and 18.5 for birth weight, weaning weight, yearling weight, and milk, respectively (2007 is the most recent birth year of individuals with complete actual yearling weight records available for the 2009 genetic evaluations; Kuehn et al., 2009).

HE. Semen from 22 HE bulls was used in cycle VIII (11 polled and 11 horned). Ten of the sires had been used in cycles VI or VII and 12 were used for the first time in cycle VIII of the program. One-half of the sires ranked in the top 100 sires in registrations within the HE breed at the time of sampling. The remainder were young unproven bulls. Average EPD from the 2009 genetic evaluations of the HE bulls used were 3.6, 40.8, 65.8, and 16.5 for birth weight, weaning weight, yearling weight, and milk, respectively. Birth year 2007 breed average EPD for HE were 3.5, 41, 68, and 16 for birth weight, weaning weight, yearling weight, and milk, respectively (Kuehn et al., 2009).

BR. Semen from 21 BR bulls was used. About one-half of the bulls represented the top 50 most widely used sires of the breed according to registrations, and one-half were young, unproven sires. Brangus is an American composite breed (5/8 AN and 3/8 Brahman) developed in the United States that ranks eighth among beef breeds in registrations (NPLC, 2008). Average EPD from the 2009 genetic evaluations of the BR sires for birth weight, weaning weight, yearling weight, and milk were 0.8, 22.3, 32.3, and 2.4 compared with birth year 2007 breed averages of 0.6, 21.9, 40.2, and 7.3, respectively (Kuehn et al., 2009).

BM. Semen from 22 BM bulls was used. About one-half of the bulls represented the top 50 most widely used sires of the breed, and one-half were young, unproven sires. Beefmaster also is an American composite breed (approximately 1/2 Brahman, 1/4 HE, and 1/4 Shorthorn). Beefmaster ranks tenth among beef breeds in registrations in the United States (NPLC, 2008). Average EPD from the 2009 genetic evaluations of the BM sires for birth weight, weaning weight, yearling weight, and milk were 0.9, 13.4, 21.7, and −0.6 compared with birth year 2007 breed averages of 0.5, 7.3, 12.5, and 2.0, respectively (Kuehn et al., 2009).

BO. Semen from 19 BO bulls was used. Bonsmara is a composite breed that was developed in South Africa from 50% Afrikaner (an African Sanga breed), 25% HE, and 25% Shorthorn foundation matings. The semen was purchased from George Chapman, Amarillo, TX, who imported the breed into the United States.

RO. Semen from 20 RO bulls was used. The RO breed was developed primarily in Colombia and introduced into the United States from Venezuela at the Subtropical Agricultural Research Station, ARS, USDA, and the University of Florida, Brooksville. The RO is considered a Criollo (domestic) breed of Central America that traces back to *B. taurus* cattle introduced from Europe about 400 to 500 yr ago. The RO are believed to have become reasonably adapted to tropical conditions.

Animal Management and Slaughter

Calves were born in mid-March through mid-April of 2001 and 2002. Male calves were castrated within 24 h of birth. In 2001, calves were weaned in early October at an average age of 193 d. In 2002, due to drought, calves were weaned early in September at an average age of 153 d. For about 30 d after weaning, a diet containing about 2.55 Mcal of ME/kg and 14.25% CP (43.6% ground alfalfa hay, 34.0% corn, 20.0% corn silage, and 2.4% liquid supplement) was fed. After this postweaning adjustment period, steers were assigned to 2 pens within sire breed and fed separately by sire breed. Then steers were switched to a growing diet (2.73 Mcal of ME/kg of DM and 11.8% CP) containing 66.0% corn silage, 29.5% high moisture corn, and 4.5% liquid supplement that was fed until steers weighed approximately 320 kg (late January). During a 2-wk period, the percentage of high-moisture corn was gradually increased and corn silage was reduced to transition to the finishing diet. A finishing diet (3.05 Mcal of ME/kg of DM and 13.1% CP) containing 25% corn silage, 70% corn, and 5% liquid supplement (DM basis) was fed from approximately 320 kg to slaughter. Time on feed averaged 255 d (range from 237 to 273 d). Steers were implanted with Synovex S (200 mg of progesterone and 20 mg of estradiol benzoate, Fort Dodge Animal Health, Fort Dodge, IA) in mid-December and again in mid-March of each year.

The steers born in 2001 were slaughtered serially in 4 groups spanning 36 d (May 13, May 20, June 10, and June 17, 2002). Representative samples of steers born in 2002 were slaughtered serially in 5 groups spanning 36 d (May 12, May 19, June 2, June 9, and June 16, 2003). Final unshrunk BW were obtained 1 wk before slaughter. The steers were slaughtered in a commercial beef processing facility. Carcass sides were electrically stimulated within 45 min postmortem (27, 33, 38, and 45 V, each for 3 to 5 s). After a 36-h chill at 0°C, USDA yield and quality grade data (USDA, 1997) were obtained by trained USMARC personnel.

Samples

The wholesale rib (#103; NAMP, 1997) from the right side of each carcass was returned to the meat laboratory at USMARC. At 3 d postmortem, the wholesale rib was dissected into the ribeye roll (NAMP #112), lean trim, fat trim, and short ribs for prediction of retail product yield as described by Shackelford et al. (1995). The ribeye roll was vacuum-packaged and stored at 2°C until 14 d (2002) or 15 d (2003) postmortem. Then the posterior end of the ribeye roll was squared off by removing a wedge-shaped slice that was trimmed of all fat, epimysium, and non-LM muscles, then vacuum-packaged, and stored at −30°C for later proximate analysis of the raw LM. One 2.54-cm-thick ribeye steak was hand-cut from the posterior end of the ribeye roll for fresh slice shear force. Ribeye rolls were then frozen at –30°C, and subsequently 5 additional 2.54-cm-thick steaks were cut on a band saw. The first 2 of these steaks (steaks 2 and 3 after squaring-up and removing one steak fresh for slice shear force) were used for trained sensory panel evaluation. The fourth steak was used for determination of Warner-Bratzler shear force and for proximate composition of the cooked LM. Steaks 5 and 6 were used for untrained laboratory panel evaluation. Steaks were stored frozen at –30°C for 3 to 5 mo before thawing for evaluation.

Slice Shear Force

Fresh steaks for slice shear force were cooked on a conveyorized electric belt grill to a final internal temperature of 71°C as described by Wheeler et al. (1998). Slice shear force was determined as described by Shackelford et al. (1999).

Warner-Bratzler Shear Force

Frozen steaks were thawed at 5°C for 24 h and then cooked on a conveyorized electric belt grill to a final internal temperature of 71°C as described by Wheeler et al. (1998). Warner-Bratzler shear force was determined as described by Wheeler et al. (1998).

Trained Sensory Evaluation

Steaks were cooked as described above and then the LM was cut into 1 cm × 1 cm × cooked steak thickness pieces. Three pieces were served warm to each panel member. An 8-member descriptive attribute sensory panel, trained according to procedures described by Cross et al. (1978), evaluated cooked steaks for tenderness, juiciness, and beef flavor intensity on an 8-point scale (8 = extremely tender, juicy, or intense to 1 = extremely tough, dry, or bland). A warm-up sample was served first and then 5 experimental steaks were served in each of 2 sessions per day (5 min between sessions) and 3 evaluation days each week. The warm-up sample was a duplicate sample to one of the experimental samples for monitoring panelist and panel performance.

Untrained Sensory Evaluation and Proximate Composition Analyses

Steaks were cooked as described above, and then the LM was cut into 1 cm × 1 cm × cooked-steak-thickness pieces. Three pieces were served warm to each panel member. An untrained, laboratory consumer panel was recruited from among USMARC employees. Thirty-two panelists participated. Each panelist attended one 1-h session per week for 9 wk. Ten samples were evaluated per session. Each sample was evaluated by 8 panelists, and each panelist evaluated 90 samples. Panelists rated each sample for tenderness, juiciness, flavor like, and overall satisfaction on 8-point scales (8 = extremely tender, extremely juicy, like extremely, and extremely satisfied; 1 = extremely tough, extremely dry, dislike extremely, and extremely dissatisfied). Raw and cooked LM proximate composition (wet-weight basis) was determined according to AOAC (1985) methods as described by Wheeler et al. (2001).

Statistical Analyses

Data were analyzed by least squares, mixed model procedures (Harvey, 1985) using a model that included a random effect for sires nested within sire breed and fixed effects for sire breed, dam breed, age of dam (4 to 5, 6 to 7, 8 to 9, ≥10 yr), birth year, interaction of sire breed × dam breed, and covariates for age at weaning (mean = 170 d) and days fed postweaning (mean = 256 d). Sire nested within sire breed was used to test sire breed, and residual variance was used to test other fixed effects. Estimates of heritability and genetic and phenotypic correlations were derived following procedures outlined by Harvey (1985).

The regression of traits on days fed provides a method of adjusting the age-constant sire breed means to alternative endpoints. The regressions were used for estimating values that would have been obtained if all animals in a sire breed had been fed fewer or more days until the breed group average reached a given endpoint (the mean for this experiment) with regard to age (426 d), carcass weight (340 kg), fat thickness (1.0 cm), fat trim percentage (24%; for cuts trimmed to 0 cm of fat cover), or marbling (Small^{00}) following procedures used in previous cycles of GPE (Koch et al., 1979, 1982b; Wheeler et al., 1996, 2001, 2004, 2005).

Consistent with previous reports (Koch et al., 1979, 1982b; Wheeler et al., 1996, 2001, 2004, 2005), the average regression over all sire breeds was modified by a proportionate adjustment of the sire breed mean to the general mean as described by Wheeler et al. (1996). Sire breeds were compared using the average LSD for $\alpha = 0.05$ computed for all possible pairwise contrasts using the sire within sire breed mean square as the error term in the linear contrast procedure of Harvey (1985).

RESULTS AND DISCUSSION

The ANOVA indicated that sire breed, sire, and dam breed were sources of variation ($P < 0.05$) for most traits (Table 2). The sire breed × dam breed interaction was not a source of variation ($P > 0.05$) for any trait. Linear regression of weaning age was significant ($P < 0.05$) for some carcass and yield traits, but not

Table 2. Analysis of variance for selected traits

		Mean square						
Source	df	HCW, kg	Adjusted fat thickness, cm	LM area, cm^2	Marbling score	Yield grade	Boneless retail product yield, %	Warner-Bratzler shear force, kg
Sire breed (SB)	5	23,005*	3.4*	303*	53,810*	11.9*	210.2*	4.2*
Sire (SB)	119	913*	0.3*	87*	7,115*	0.7*	13.7*	0.6*
Dam breed (DB)	1	24,688*	4.0*	3	15,893*	8.9*	73.2*	4.5*
Dam age	2	2,605*	0.1	73	1,270	0.7	6.2	0.6
Year	1	761	0.0	268*	2,812	1.3	80.1*	0.0
SB × DB	4	403	0.1	28	4,177	0.3	1.3	0.2
b1 (weaning age)[1]	1	15,914*	0.5	115	11,321	1.8*	40.7*	0.0
b2 (days fed)[1]	1	74,405*	6.4*	851*	89,807*	16.3*	239.4*	9.1*
Residual	486	651	0.2	39	3,666	0.4	6.9	0.4

[1]b1 = regression coefficient for weaning age; b2 = regression coefficient for days on feed.

*$P < 0.05$.

Table 3. Least squares means for carcass traits adjusted to a common age, carcass weight, fat thickness, marbling, or fat trim percentage[1]

Trait, μ ± SEM, b1, b2[2]	Sire breed, LSD[3]	Endpoint: Age (426 d)	Carcass wt (340 kg)	Fat thickness (1.0 cm)	Marbling (Small[00])	Fat trim (24%)
Days on feed	Hereford	—	252	242	241	255
μ = 256	Angus	—	240	226	211	228
SD = 20	Brangus	—	244	256	259	260
	Beefmaster	—	237	234	274	245
	Bonsmara	—	267	267	270	267
	Romosinuano	—	282	290	269	294
BW, kg	Hereford	565	—	549	547	562
μ = 560 ± 2.3	Angus	582	—	545	528	547
b1 = 1.2976 ± 0.249	Brangus	570	—	570	574	575
b2 = 1.2174 ± 0.131	Beefmaster	588	—	561	611	573
	Bonsmara	538	—	551	555	550
	Romosinuano	521	—	563	537	568
	LSD	13	—	17	17	16
HCW, kg	Hereford	343	—	332	330	342
μ = 343 ± 1.5	Angus	355	—	328	316	329
b1 = 0.7849 ± 0.159	Brangus	351	—	351	354	355
b2 = 0.8973 ± 0.084	Beefmaster	358	—	338	375	347
	Bonsmara	331	—	341	343	340
	Romosinuano	318	—	349	330	352
	LSD	9	—	11	11	10
Dressing percentage	Hereford	60.8	60.7	60.4	60.3	60.7
μ = 61.1 ± 0.09	Angus	61.0	60.5	60.2	59.8	60.2
b1 = −0.0013 ± 0.009	Brangus	61.6	61.2	61.6	61.7	61.7
b2 = 0.0278 ± 0.005	Beefmaster	60.8	60.3	60.2	61.4	60.5
	Bonsmara	61.5	61.8	61.8	61.9	61.8
	Romosinuano	61.0	61.8	62.0	61.4	62.1
	LSD	0.5	0.6	0.6	0.6	0.6
Adjusted fat thickness, cm	Hereford	1.11	1.08	—	0.99	1.09
μ = 1.05 ± 0.027	Angus	1.30	1.16	—	0.94	1.06
b1 = 0.0045 ± 0.0025	Brangus	0.99	0.89	—	1.02	1.03
b2 = 0.0083 ± 0.0013	Beefmaster	1.21	1.04	—	1.37	1.11
	Bonsmara	0.91	1.00	—	1.03	1.00
	Romosinuano	0.78	1.00	—	0.89	1.10
	LSD	0.15	0.18	—	0.19	0.19
LM area, cm^2	Hereford	80.2	79.8	79.0	78.8	80.0
μ = 82.2 ± 0.5	Angus	81.5	79.9	78.6	77.3	78.7
b1 = 0.0667 ± 0.0389	Brangus	84.1	83.0	84.1	84.4	84.5
b2 = 0.0960 ± 0.0206	Beefmaster	80.8	78.9	78.7	82.7	79.7
	Bonsmara	84.4	85.4	85.5	85.8	85.4
	Romosinuano	82.0	84.5	85.3	83.3	85.7
	LSD	2.6	3.0	3.3	3.3	3.2
KPH,[4] %	Hereford	2.03	1.98	1.88	1.86	2.01
μ = 2.17 ± 0.03	Angus	2.26	2.07	1.91	1.75	1.93
b1 = 0.0037 ± 0.0040	Brangus	2.20	2.06	2.20	2.23	2.24
b2 = 0.0116 ± 0.0021	Beefmaster	2.12	1.89	1.87	2.34	1.98
	Bonsmara	2.19	2.31	2.32	2.35	2.31
	Romosinuano	2.19	2.50	2.59	2.34	2.63
	LSD	0.18	0.21	0.22	0.22	0.22
Yield grade	Hereford	2.9	2.8	2.7	2.7	2.9
μ = 2.76 ± 0.04	Angus	3.2	2.9	2.8	2.6	2.8
b1 = 0.0084 ± 0.0038	Brangus	2.7	2.5	2.7	2.7	2.7
b2 = 0.0133 ± 0.0020	Beefmaster	3.1	2.8	2.8	3.4	2.9
	Bonsmara	2.4	2.6	2.6	2.6	2.6
	Romosinuano	2.3	2.7	2.8	2.5	2.8
	LSD	0.2	0.3	0.3	0.3	0.3
Marbling[5]	Hereford	515	511	502	—	513
μ = 502.9 ± 4.2	Angus	548	531	518	—	519
b1 = 0.662 ± 0.377	Brangus	497	486	497	—	501
b2 = 0.986 ± 0.199	Beefmaster	483	463	461	—	471
	Bonsmara	487	496	497	—	496
	Romosinuano	488	514	521	—	525
	LSD	24	27	29	—	29

Continued

Table 3 (Continued). Least squares means for carcass traits adjusted to a common age, carcass weight, fat thickness, marbling, or fat trim percentage[1]

Trait, μ ± SEM, b1, b2[2]	Sire breed, LSD[3]	Endpoint				
		Age (426 d)	Carcass wt (340 kg)	Fat thickness (1.0 cm)	Marbling (Small[00])	Fat trim (24%)
USDA Choice,[6] %	Hereford	52	50	48	—	51
$\mu = 45.4 \pm 3.0$	Angus	69	64	61	—	61
$b1 = 0.298 \pm 0.28$	Brangus	47	44	47	—	49
$b2 = 0.279 \pm 0.15$	Beefmaster	32	27	26	—	29
	Bonsmara	39	42	42	—	42
	Romosinuano	34	41	43	—	44
	LSD	17	20	21	—	21

[1]Endpoints represent the overall mean for that trait in this experiment.
[2]b1 = regression coefficient for weaning age; b2 = regression coefficient for days on feed.
[3]LSD among means ($P < 0.05$).
[4]Estimated percentage of HCW as KPH.
[5]400 = Slight[00]; 500 = Small[00] (USDA, 1997).
[6]Percentage of carcasses grading USDA Choice or greater.

palatability traits. Linear regression of days fed was significant ($P < 0.05$) for most traits.

Carcass Traits

Final BW and carcass weights at a constant age of 426 d were heavier ($P < 0.05$) for BM-, AN-, and BR-sired steers than for BO- and RO-sired steers (Table 3). At the fat thickness and fat trim endpoints, fewer differences existed in BW and carcass weights among sire breeds than at constant age. Smaller BW and carcass weights for BO and RO compared with the other sire breeds may be a reflection of both genetic antagonisms associated with adaptation to the stress of a tropical climate and less selection pressure for growth than is applied in the United States. Angus-sired steers were the earliest maturing; they required the fewest days on feed to reach the fatness endpoints.

Dressing percentage was greater ($P < 0.05$) at 426 d of age for carcasses from BR- and BO-sired steers than for carcasses from HE- and BM-sired steers (Table 3). At constant BW, RO, BO, and BR steers had greater ($P < 0.05$) dressing percentages than BM and AN steers. The AN, HE, and BM steers had smaller ($P < 0.05$) dressing percentages than the other sire breeds at the fat thickness and fat trim endpoints.

At constant age, adjusted fat thickness was greater ($P < 0.05$) for carcasses from AN-sired steers than carcasses from all other sire breeds except BM (Table 3). Romosinuano steers had less ($P < 0.05$) fat thickness than all other sire breeds except BO. At constant BW, BR steers had less ($P < 0.05$) fat thickness than AN or HE steers. At constant marbling, BM steers had the greatest ($P < 0.05$) adjusted fat thickness. At constant fat trim percentage, there were no sire breed differences ($P > 0.05$) in adjusted fat thickness.

At constant age, carcasses from BO and BR sire breeds had larger ($P < 0.05$) LM areas than carcasses from BM and HE sire breeds (Table 3). At constant age and all fatness endpoints, LM areas were smaller ($P < 0.05$) for AN, BM, and HE steers than for all other sire breeds. Carcasses from BO steers tended ($P < 0.10$) to have larger LM areas than all other sire breeds regardless of endpoint.

At constant age, carcasses from AN-sired steers had greater ($P < 0.05$) percentages of KPH than carcasses from HE-sired steers (Table 3). At constant BW, the percentage of KPH was greater ($P < 0.05$) for RO and BO steers than for steers of all other sire breeds. Carcasses from HE, AN, and BM steers had smaller ($P < 0.05$) percentages of KPH at the constant fat thickness endpoint than the other 3 sire breeds. At constant marbling or fat trim, there was no effect ($P > 0.05$) of sire breed on percentages of KPH fat.

Numerical USDA yield grade was not different ($P > 0.05$) among sire breeds at constant fat thickness or fat trim endpoints. At constant age endpoint, yield grade was greater ($P < 0.05$) for carcasses from BM and AN sire breeds than for BR, BO, and RO sire breeds. At constant BW endpoint, AN steers had greater ($P < 0.05$) yield grade than BR steers. At constant marbling, BM steers had the greatest ($P > 0.05$) yield grades. Six carcasses had yield grades of 4.0 or greater, including 1 or 2 each from AN, BR, and BM.

At constant age, marbling score was greater ($P < 0.05$) in carcasses from AN-sired steers than for all other sire breeds (Table 3), whereas the HE sire breed had a greater ($P < 0.05$) marbling score than RO, BO, and BM sire breeds. At constant BW, AN had greater ($P < 0.05$) marbling scores than BO, BR, and BM. At constant BW, BM steers had smaller ($P < 0.05$) marbling scores than all other sire breeds except BR. At constant fat thickness and fat trim, BM steers had the least ($P < 0.05$) marbling scores. Sire breed differences for the percentage of carcasses grading USDA Choice at each endpoint were similar to marbling differences.

Ten carcasses in the experiment graded USDA Standard with 2 or more from each of the tropically adapted sire breeds.

Gruber et al. (2007) reported that when fed to an estimated optimal BW, BM steers had lighter final BW and HCW than British- or Continental-cross steers. Crockett et al. (1979) reported that Brahman and Maine Anjou steers had the heaviest final BW, BR steers were the lightest, and BM and Limousin steers were lighter than Simmental steers. Bidner et al. (2002) and Wyatt et al. (2002) reported that when fed to 10-mm fat thickness, BR and BM steers were lighter than AN steers. Strydom et al. (2000) found that when fed to 75, 90, or 105% of 112 d final test BW, BO bulls were heavier than other Sanga breeds (Afrikaner and Nguni) but lighter than Pinzgauer, Brown Swiss, and Santa Gertrudis bulls. However, Muchenje et al. (2008) reported that when fed on grass pasture until 19 mo of age, BO steers were heavier than Aberdeen AN steers.

Crockett et al. (1979) reported that carcasses from Brahman- and BM-sired steers had the greatest fat thickness, BR were intermediate, and continental breeds (Limousin, Simmental, Maine Anjou) had the least. Crockett et al. (1979) also reported that BR had the smallest LM areas and the continental sire breeds had larger LM areas than those from BM and Brahman. Brangus and BM had smaller yield grades than the Brahman sire breed, and marbling score was not affected by sire breed (Crockett et al., 1979). Bidner et al. (2002) found that AN-sired steers had greater marbling scores and quality grades than BR-sired steers, which were greater than for BM-sired steers. Bidner et al. (2002) also reported that AN-sired steers had greater fat thickness and smaller LM areas than BR- and BM-sired steers. Gruber et al. (2007) reported that BM and Continental steers had smaller yield grades and less fat thickness than British steers, but BM and British steers had smaller LM areas than Continental steers. Newman et al. (2002) reported that Belmont Red (Australian composite similar to BO) had carcasses lighter than AN, HE, Shorthorn, and Santa Gertrudis, but heavier than Brahman carcasses. Newman et al. (2002) also reported Belmont Red had similar percentage retail product as the other sire breeds studied.

Carcass Yield

At a constant age of 426 d, carcasses from RO and BO sire breeds had the greatest ($P < 0.05$), carcasses from BR-, HE-, and BM-sired steers intermediate ($P < 0.05$), and carcasses from AN-sired steers had the least ($P < 0.05$) percentage retail product yield (Table 4). At constant BW, AN steers had smaller ($P < 0.05$) percentage retail product yield than all other sire breeds except HE. At constant fat thickness, sire breed did not affect ($P > 0.05$) percentage retail product yield and there were only minor sire breed effects at constant fat trim. At constant marbling, BM steers had the smallest ($P < 0.05$) percentage of retail product yield and RO had the greatest ($P < 0.05$) percentage of retail product yield. Differences among sire breeds in fat yield were similar to differences in retail product yield for all endpoints.

At constant age, carcasses from AN- and BO-sired steers had smaller ($P < 0.05$) percentages of bone than carcasses from all other sire breeds (Table 4). At constant BW, AN, RO, and BO had smaller ($P < 0.05$) percentage bone than BR and BM. At constant fat thickness, BM steers had a greater ($P < 0.05$) percentage of bone than AN steers, but BO and RO had the least ($P < 0.05$) percentage bone. At constant marbling, HE and AN steers had greater ($P < 0.05$) percentage of bone than for BO or BM. At constant fat trim, BO and RO had smaller ($P < 0.05$) percentage bone than all other sire breeds.

Carcasses from BM- and BR-sired steers had heavier ($P < 0.05$) weights of retail product at constant age than carcasses from BO- and RO-sired steers. At constant fat thickness, BR and RO steers had heavier ($P < 0.05$) weights of retail product than BM steers, whereas AN steers had the least ($P < 0.05$) weights of retail product. At constant marbling, BM steers had the heaviest ($P < 0.05$) weights of retail product and AN steers had the lightest ($P < 0.05$) weights of retail product. At constant fat trim, RO and BR steers had heavier ($P < 0.05$) weights of retail product than HE or AN steers.

At constant age, carcasses from AN and BM sire breeds had the heaviest ($P < 0.05$) fat weights and carcasses from the RO sire breed had the lightest (Table 4). At constant BW, AN steers had heavier ($P < 0.05$) fat weight than BR steers. At constant fat thickness, RO had heavier ($P < 0.05$) fat weights than HE. At constant marbling, BM steers had the heaviest ($P < 0.05$) fat weight followed by BR and BO, whereas HE, RO, and AN steers had the lightest ($P < 0.05$) fat weight. At constant fat trim, sire breed did not affect ($P > 0.05$) fat weights. Regardless of endpoint, BM and BR steers tended to have the heaviest ($P < 0.05$) bone weights.

Bidner et al. (2002) compared 9th-, 10th-, 11th-rib section composition after feeding AN-, BR-, BM-, Gelbray-, and Simbrah-sired steers to a constant fat thickness endpoint. Bidner et al. (2002) reported that BM-sired steers had a smaller percentage of fat and a greater percentage of lean in the rib section than AN- or BR-sired steers. They also found that BR- and BM-sired steers had a greater percentage of bone than AN-sired steers.

Palatability Traits

At constant age, LM from BM-sired steers had greater ($P < 0.05$) Warner-Bratzler shear force values than did the LM from carcasses of steers of all other sire breeds except BR. The LM of AN steers had the least ($P < 0.05$) Warner-Bratzler shear force (Table 5). At constant BW, LM from RO steers had greater ($P <$

Table 4. Least squares means for carcass yield traits adjusted to a common age, carcass weight, fat thickness, fat trim percentage, or marbling endpoint[1]

Trait, μ ± SEM, b1, b2[2]	Sire breed, LSD[3]	Endpoint				
		Age (426 d)	Carcass wt (340 kg)	Fat thickness (1.0 cm)	Marbling (Small^{00})	Fat trim (24%)
Retail product yield,[4] %	Hereford	61.8	62.0	62.5	62.6	61.9
μ = 62.2 ± 0.19	Angus	60.1	61.0	61.7	62.4	61.6
b1 = −0.0403 ± 0.0166	Brangus	62.1	62.7	62.1	62.0	61.9
b2 = −0.0518 ± 0.0088	Beefmaster	61.3	62.3	62.4	60.3	61.9
	Bonsmara	63.5	63.0	62.9	62.7	63.0
	Romosinuano	64.4	63.1	62.6	63.7	62.4
	LSD	1.1	1.2	1.3	1.3	1.3
Fat yield,[4] %	Hereford	24.7	24.4	23.7	23.5	—
μ = 24.5 ± 0.24	Angus	27.0	25.7	24.7	23.6	—
b1 = 0.0443 ± 0.0204	Brangus	24.3	23.4	24.3	24.5	—
b2 = 0.0754 ± 0.0108	Beefmaster	25.5	24.0	23.8	26.9	—
	Bonsmara	23.8	24.6	24.7	24.9	—
	Romosinuano	22.0	24.0	24.6	23.0	—
	LSD	1.3	1.5	1.7	1.5	—
Bone yield,[4] %	Hereford	14.5	14.6	14.8	14.9	14.6
μ = 14.4 ± 0.06	Angus	13.9	14.2	14.5	14.8	14.5
b1 = −0.0074 ± 0.0050	Brangus	14.6	14.9	14.6	14.5	14.5
b2 = −0.0218 ± 0.0026	Beefmaster	14.5	14.9	15.0	14.1	14.7
	Bonsmara	14.1	13.9	13.9	13.8	13.9
	Romosinuano	14.7	14.2	14.0	14.4	13.9
	LSD	0.3	0.4	0.4	0.5	0.5
Retail product wt,[5] kg	Hereford	212	210	207	206	211
μ = 213 ± 1.1	Angus	213	206	201	196	202
b1 = 0.3732 ± 0.0965	Brangus	218	213	218	219	219
b2 = 0.3853 ± 0.0512	Beefmaster	219	211	210	226	214
	Bonsmara	210	214	214	216	214
	Romosinuano	205	215	218	210	220
	LSD	6	7	7	7	7
Fat weight,[5] kg	Hereford	85	83	79	78	84
μ = 85 ± 1.0	Angus	96	88	82	75	82
b1 = 0.3406 ± 0.0194	Brangus	86	80	86	87	88
b2 = 0.4849 ± 0.0485	Beefmaster	92	82	81	101	86
	Bonsmara	79	84	85	86	84
	Romosinuano	71	83	87	77	89
	LSD	5	6	7	7	7
Bone weight,[5] kg	Hereford	50	49	49	49	50
μ = 49 ± 0.3	Angus	49	48	47	47	47
b1 = 0.0916 ± 0.0235	Brangus	51	50	51	51	51
b2 = 0.0562 ± 0.0125	Beefmaster	52	51	50	53	51
	Bonsmara	47	47	47	47	47
	Romosinuano	47	48	49	48	49
	LSD	1	2	2	2	2

[1]Endpoints represent the overall mean for that trait in this experiment.
[2]b1 = regression coefficient for weaning age; b2 = regression coefficient for days on feed.
[3]LSD among means ($P < 0.05$).
[4]Predicted from wholesale rib dissection.
[5]Calculated from HCW and predicted yields.

0.05) Warner-Bratzler shear force values than BR and HE steers, whereas AN steers had the least ($P < 0.05$) Warner-Bratzler shear force. At constant fat thickness and fat trim percentage, LM from RO steers had greater ($P < 0.05$) Warner-Bratzler shear force values than BO- and HE steers, whereas AN steers had the least ($P < 0.05$) shear force. At constant marbling, Warner-Bratzler shear force values were least ($P < 0.05$) for AN steers and greatest ($P < 0.05$) for BM steers.

From the trained sensory panel, LM from BR-sired steers had lesser ($P < 0.05$) tenderness ratings than LM from AN-sired steers fed to a constant age (Table 5). Beefmaster steers had LM that was less tender ($P < 0.05$) than AN- and BO-sired steers. At all endpoints except marbling, the LM from AN steers received greater ($P < 0.05$) juiciness ratings than all other sire breeds except HE. At constant marbling, juiciness ratings were greatest ($P < 0.05$) for AN steers ($P < 0.05$),

Table 5. Least squares means for longissimus thoracis steak palatability traits adjusted to a common age, carcass weight, fat thickness, fat trim percentage, or marbling endpoint[1]

Trait, μ ± SEM, b1, b2[2]	Sire breed, LSD[3]	Endpoint Age (426 d)	Carcass wt (340 kg)	Fat thickness (1.0 cm)	Marbling (Small^{00})	Fat trim (24%)
Warner-Bratzler shear force, kg	Hereford	3.67	3.63	3.54	3.52	3.65
μ = 3.76 ± 0.04	Angus	3.44	3.27	3.13	2.99	3.14
b1 = −0.0005 ± 0.0042	Brangus	3.89	3.77	3.89	3.92	3.93
b2 = 0.0101 ± 0.0022	Beefmaster	4.08	3.88	3.86	4.27	3.96
	Bonsmara	3.69	3.80	3.81	3.84	3.80
	Romosinuano	3.78	4.05	4.13	3.92	4.17
	LSD	0.22	0.25	0.27	0.27	0.27
Tenderness[4]	Hereford	5.77	5.81	5.89	5.91	5.79
μ = 5.79 ± 0.03	Angus	5.91	6.07	6.20	6.33	6.19
b1 = −0.0008 ± 0.0030	Brangus	5.72	5.83	5.72	5.69	5.68
b2 = −0.0094 ± 0.0016	Beefmaster	5.66	5.85	5.87	5.49	5.78
	Bonsmara	5.86	5.77	5.76	5.73	5.77
	Romosinuano	5.79	5.55	5.47	5.67	5.43
	LSD	0.17	0.19	0.21	0.21	0.21
Juiciness[5]	Hereford	5.53	5.54	5.56	5.57	5.53
μ = 5.50 ± 0.01	Angus	5.57	5.61	5.65	5.68	5.64
b1 = 0.0019 ± 0.0013	Brangus	5.47	5.50	5.47	5.46	5.46
b2 = −0.0026 ± 0.0007	Beefmaster	5.46	5.51	5.52	5.41	5.49
	Bonsmara	5.46	5.44	5.43	5.43	5.44
	Romosinuano	5.48	5.42	5.40	5.45	5.39
	LSD	0.07	0.08	0.09	0.09	0.09
Beef flavor intensity[6]	Hereford	4.61	4.61	4.61	4.61	4.61
μ = 4.57 ± 0.01	Angus	4.64	4.65	4.66	4.67	4.66
b1 = 0.0006 ± 0.0016	Brangus	4.53	4.54	4.53	4.53	4.53
b2 = −0.0005 ± 0.0008	Beefmaster	4.55	4.56	4.56	4.54	4.55
	Bonsmara	4.57	4.56	4.56	4.56	4.56
	Romosinuano	4.54	4.52	4.52	4.53	4.52
	LSD	0.07	0.08	0.09	0.09	0.09

[1]Endpoints represent the overall mean for that trait in this experiment.
[2]b1 = regression coefficient for weaning age; b2 = regression coefficient for days on feed.
[3]LSD among means ($P < 0.05$).
[4]1 = extremely tough, 4 = slightly tough, 5 = slightly tender, 8 = extremely tender.
[5]1 = extremely dry, 4 = slightly dry, 5 = slightly juicy, 8 = extremely juicy.
[6]1 = extremely bland, 4 = slightly bland, 5 = slightly intense, 8 = extremely intense.

intermediate for HE steers, and least ($P < 0.05$) for all other sire breeds. Beef flavor intensity ratings followed a similar pattern as for juiciness ratings except that sire breed did not affect ($P > 0.05$) beef flavor intensity ratings when adjusted to constant carcass weight.

Based on slice shear force, LM from BO-sired steers was more tender ($P < 0.05$) than LM from BR- and BM-sired steers at constant age (Table 6). Beefmaster steers also had greater ($P < 0.05$) slice shear force than AN and RO steers. The untrained sensory panel

Table 6. Effect of sire breed on least squares means for slice shear force and untrained consumer panel ratings for longissimus thoracis at 426 d of age

Item	Slice shear force, kg	Tenderness[1]	Juiciness[1]	Flavor like[1]	Overall satisfaction[1]
μ ± SEM	14.07 ± 0.25	5.38 ± 0.06	5.31 ± 0.04	5.64 ± 0.03	5.46 ± 0.04
Sire breed					
Hereford	14.31	5.47	5.56	5.77	5.61
Angus	13.44	5.77	5.43	5.80	5.75
Brangus	14.63	5.24	5.17	5.54	5.35
Beefmaster	15.24	5.12	5.23	5.53	5.27
Bonsmara	13.03	5.31	5.13	5.52	5.31
Romosinuano	13.75	5.36	5.34	5.65	5.46
LSD[2]	1.42	0.32	0.21	0.17	0.25

[1]Scale: 8 = extremely tender, extremely juicy, like extremely, or extremely satisfied; 1 = extremely tough, extremely dry, dislike extremely, or extremely dissatisfied.
[2]LSD among means ($P < 0.05$).

Table 7. Effect of sire breed on least squares means for chemical composition of raw and cooked longissimus thoracis at 426 d of age

	Raw			Cooked		
Item	Lipid, %	Moisture, %	Protein,[1] %	Lipid, %	Moisture, %	Protein,[1] %
μ ± SEM	4.4 ± 0.09	72.3 ± 0.07	23.3 ± 0.03	6.0 ± 0.12	64.3 ± 0.08	29.7 ± 0.07
Sire breed						
Hereford	4.8	72.1	23.1	6.4	64.1	29.5
Angus	5.7	71.3	23.0	7.5	63.3	29.2
Brangus	4.1	72.6	23.3	5.6	64.6	29.8
Beefmaster	3.9	72.7	23.4	5.4	64.6	30.0
Bonsmara	4.2	72.4	23.4	5.6	64.5	29.9
Romosinuano	3.9	72.6	23.5	5.4	64.8	29.8
LSD[2]	0.5	0.4	0.4	0.7	0.5	0.4

[1]Calculated by difference.

[2]LSD among means ($P < 0.05$).

rated LM from AN steers as more tender ($P < 0.05$) than all other sire breeds except HE. Juiciness ratings were greater ($P < 0.05$) for HE and AN steers than for BR and BO steers. Flavor like ratings were greater ($P < 0.05$) for HE and AN steers than for BR, BM, and BO steers. Overall satisfaction ratings by the untrained sensory panel were greater ($P < 0.05$) for LM from AN steers than for all other sire breeds except HE. The subjective evaluation by the untrained sensory panel, in general, ranked the sire breeds similarly as the objective measures from the trained sensory panel; Warner-Bratzler shear force and slice shear force except that LM from BO steers was rated less relative to other sire breeds by the untrained panel.

It is well documented that LM from *B. indicus* cattle breeds have reduced tenderness on average (e.g., Crouse et al., 1989). Although there is evidence to indicate that LM from cattle with 25% or less *B. indicus* are not different in tenderness from *B. taurus* breeds (Johnson et al., 1990), data from Crouse et al. (1989) does not support that conclusion. Composite breeds with 3/8 to 1/2 Brahman have become very popular in southern parts of the United States, but relatively little scientific information is available comparing their carcass and palatability traits to other breeds. O'Connor et al. (1997) reported that Braford, Red Brangus, and Simbrah had greater LM Warner-Bratzler shear force than Red Angus × Simmental crosses and HE at 4, 7, 14, 21, and 35 d postmortem and a greater percentage of Warner-Bratzler shear force values greater than 3.85 kg at 1, 4, 7, and 14 d postmortem. Bidner et al. (2002) reported that at 10 d postmortem, LM from AN had greater tenderness ratings, the same juiciness ratings, and reduced Warner-Bratzler shear force than BR, BM, Gelbray, and Simbrah. Strydom et al. (2000) found that at 7 d postmortem, LM from BO bulls had less Warner-Bratzler shear force than Santa Gertrudis bulls, but similar Warner-Bratzler shear force as Pinzgauer, Brown Swiss, Afrikaner, and Nguni bulls and no breed effect on trained sensory panel tenderness ratings. Muchenje et al. (2008) reported that with grass pasture finishing, LM from BO had the same Warner-Bratzler shear force as Aberdeen Angus at 21 d postmortem. This is consistent with data on other Sanga breeds such as Tuli (Wheeler et al., 2004). Collectively, these data indicate that among the heat-tolerant breeds, the Sanga breed, BO, has no detrimental effect on meat tenderness, but the progeny of Brahman-derivative breeds with 3/8 Brahman breed, such as BR, have slightly less tender LM and progeny of those with up to 50% Brahman, such as BM, on average have less tender LM than progeny of *Bos taurus* breeds.

LM Proximate Composition

Chemical composition of raw and cooked LM adjusted to 445 d of age indicated that the LM from carcasses from AN-sired steers had greater ($P < 0.05$) percentages of lipid and lesser ($P < 0.05$) percentages of moisture than the LM from carcasses from all other sire breeds (Table 7). Hereford steers had LM intermediate in percentage lipid. Differences among sire breeds for percentage protein in the raw and cooked LM were small in magnitude and appeared to be of little practical importance. Differences among sire breeds in percentage LM lipid were similar to differences in marbling score and were consistent with previous results (Koch et al., 1976; Wheeler et al., 2001, 2005).

Heritability Estimates and Correlation Coefficients

The range of differences among sire breed means from topcross progeny estimates one-half of the breed differences (Table 8). Thus, the range was doubled to assess purebred genetic variation relative to within sire breed genetic (σ_g) and phenotypic (σ_p) variation. However, phenotypic variation was expressed without doubling the range, thus representing F_1 progeny phenotypic variation. Heritability estimates for various carcass, yield, and palatability traits ranged from low ($h^2 = 0.01$ for KPH percentage) to high ($h^2 = 0.81$ for LM area). Heritability estimates of carcass traits were mostly moderate to very high, and were similar

Table 8. Variation among sire breeds for carcass and palatability traits at 426 d of age

Trait	R[1]	$h^2 \pm SE$[2]	σ_g[3]	$2R/\sigma_g$	σ_p[4]	R/σ_p
BW, kg	67	0.32 ± 0.14	23.61	5.68	41.65	1.61
HCW, kg	40	0.31 ± 0.14	14.74	5.43	26.56	1.51
Dressing percentage	0.8	0.49 ± 0.15	1.03	1.55	1.48	0.54
Adjusted fat thickness, cm	0.52	0.61 ± 0.16	0.34	3.06	0.44	1.18
LM area, cm^2	4.2	0.81 ± 0.17	6.31	1.33	7.00	0.60
KPH, %	0.23	0.01 ± 0.12	0.06	7.67	0.64	0.36
Yield grade	0.9	0.67 ± 0.16	0.54	3.33	0.66	1.36
Marbling	65	0.65 ± 0.16	53.43	2.43	66.18	0.98
Retail product yield, %	4.3	0.69 ± 0.16	2.40	3.58	2.89	1.49
Retail product weight, kg	14	0.64 ± 0.16	13.28	2.11	16.66	0.84
Raw LM lipid, %	1.8	0.77 ± 0.17	1.14	3.16	1.29	1.40
Cooked LM lipid, %	2.1	0.79 ± 0.17	1.58	2.66	1.77	1.19
Warner-Bratzler shear force, kg	0.64	0.27 ± 0.14	0.36	3.56	0.69	0.93
Slice shear force, kg	2.21	0.40 ± 0.15	2.68	1.65	4.24	0.52
Trained sensory panel						
Tenderness	0.25	0.37 ± 0.15	0.31	1.61	0.51	0.49
Juiciness	0.11	0.29 ± 0.14	0.12	1.83	0.22	0.50
Beef flavor intensity	0.11	0.05 ± 0.13	0.06	3.67	0.25	0.44
Untrained sensory panel						
Tenderness	0.65	0.46 ± 0.15	0.64	2.03	0.95	0.68
Juiciness	0.43	0.45 ± 0.15	0.41	2.10	0.62	0.69
Flavor like	0.28	0.32 ± 0.14	0.30	1.87	0.53	0.53
Overall satisfaction	0.48	0.46 ± 0.15	0.49	1.96	0.72	0.67

[1]R = range in sire breed means.
[2]h^2 = heritability.
[3]σ_g = genetic SD.
[4]σ_p = phenotypic SD.

to those reported by Wheeler et al. (1996, 2001, 2005), Riley et al. (2002), and Koch et al. (1982a), but greater for many carcass traits than those reported by others (Arnold et al., 1991; Wulf et al., 1996; Wheeler et al., 2004). Newman et al. (2002) reported a heritability estimate for carcass weight that was similar (0.40) and estimates for retail yield and intramuscular fat that were less (0.44 and 0.33, respectively) compared with our experiment.

Heritability estimates of marbling and measures of LM chemical lipid were high and similar to one another (Table 8). Tenderness, as measured by Warner-Bratzler shear force, slice shear force, and trained and untrained sensory tenderness rating, had low to moderate heritability estimates. These values are consistent with the average of heritability estimates reported in the literature (reviewed by Koch et al., 1982a; O'Connor et al., 1997; Wheeler et al., 2001, 2004, 2005). Some estimates of the heritability of LM tenderness (or shear force) have been greater ($h^2 = 0.53$, Shackelford et al., 1994; $h^2 = 0.50$, Wheeler et al., 1996) and others less ($h^2 =$ 0.21 or 0.12, Gregory et al., 1994; $h^2 = 0.08$, Wulf et al., 1996; $h^2 = 0.11$ or 0.14, Riley et al., 2003). Heritability estimates for LM juiciness ratings were similar to those reported by Wheeler et al., (2004, 2005) and Gregory et al. (1994) and greater than estimates reported by others (Wheeler et al., 2001; Riley et al., 2003). Heritability estimates for LM trained panel beef flavor intensity ratings were low and similar to those reported by Wheeler et al. (2001), Riley et al. (2003), and Gregory et al. (1994), and less than estimates reported by others (Wheeler et al., 1996, 2004, 2005). The heritability estimate for untrained panel overall satisfaction rating was moderately high. Dikeman et al. (2005) reported heritabilities of 0.68 for marbling score, 0.40 for Warner-Bratzler shear force, 0.37 for tenderness rating, 0.46 for juiciness rating, and 0.07 for flavor intensity rating.

Estimates of the amount of variation between the 2 extreme breeds for a given trait in SD units (2 × range/σ_g) in our study (Table 8) were similar for most traits when compared with values reported by Wheeler et al. (1996, 2001, 2004, 2005). All traits except KPH fat percentage and BW and carcass weights had more variation within breeds than among breeds. These results are consistent with previous data indicating that there is as much or more variation in LM tenderness within breeds as there is among the most extreme breeds for LM tenderness (Wheeler et al., 1996, 2001, 2004, 2005). Phenotypic variation in carcass and palatability traits was similar to that reported by Wheeler et al. (1996, 2001, 2004, 2005). As was observed in cycles I to VII of GPE, little inherent genetic variation in juiciness and beef flavor intensity was detected in cycle VIII. Phenotypic variation in tenderness rating was about twice that of variation in ratings of juiciness and beef flavor intensity, as has been reported previously for GPE data and by Riley et al. (2002).

The genetic correlation between fat thickness and marbling was low, suggesting that it would be possible to decrease subcutaneous fat thickness without reduc-

Table 9. Genetic and phenotypic correlation coefficients among carcass and palatability traits at 426 d of age[1]

	Trait												
Trait	BW	HCW	AFT	LMA	YG	MARB	RPY	RLIPID	CLIPID	WBS	TEND	JUICY	FLAV
BW		0.95	0.26	0.38	0.32	0.12	−0.26	0.07	0.07	−0.04	−0.01	−0.02	−0.01
HCW	0.91 ± 0.06		0.31	0.44	0.34	0.14	−0.27	0.10	0.08	−0.04	−0.01	−0.05	−0.01
Adjusted fat thickness (AFT)	0.02 ± 0.27	0.18 ± 0.26		−0.15	0.88	0.19	−0.68	0.33	0.35	−0.01	0.06	0.10	0.08
LM area (LMA)	0.45 ± 0.20	0.56 ± 0.19	−0.50 ± 0.20		−0.47	−0.04	0.27	−0.17	−0.18	0.02	−0.07	−0.09	−0.01
Yield grade (YG)	−0.13 ± 0.26	−0.05 ± 0.27	0.91 ± 0.04	−0.80 ± 0.24		0.22	−0.73	0.37	0.38	−0.03	0.08	0.10	0.06
Marbling score (MARB)	−0.32 ± 0.25	−0.28 ± 0.26	0.08 ± 0.20	−0.13 ± 0.18	0.01 ± 0.20		−0.42	0.74	0.67	−0.19	0.15	0.33	0.16
Retail product yield (RPY)	0.16 ± 0.25	0.03 ± 0.24	−0.82 ± 0.31	0.46 ± 0.16	−0.77 ± 0.30	−0.35 ± 0.23		−0.53	−0.53	0.07	−0.10	−0.14	−0.10
Raw lipid[2] (RLIPID)	−0.35 ± 0.22	−0.30 ± 0.22	0.18 ± 0.19	−0.22 ± 0.18	0.12 ± 0.18	0.89 ± 0.06	−0.49 ± 0.23		0.83	−0.19	0.18	0.32	0.19
Cooked lipid[2] (CLIPID)	−0.07 ± 0.23	−0.04 ± 0.23	0.26 ± 0.18	−0.14 ± 0.18	0.19 ± 0.18	0.83 ± 0.08	−0.56 ± 0.23	0.96 ± 0.03		−0.26	0.19	0.30	0.15
Warner-Bratzler shear force (WBS)	0.42 ± 0.36	0.46 ± 0.36	0.12 ± 0.29	0.28 ± 0.26	0.12 ± 0.28	−0.52 ± 0.33	0.09 ± 0.27	−0.52 ± 0.31	−0.74 ± 0.34		−0.74	−0.34	−0.24
Tenderness (TEND)	−0.38 ± 0.30	−0.47 ± 0.30	0.11 ± 0.25	−0.46 ± 0.24	0.13 ± 0.24	0.40 ± 0.23	−0.34 ± 0.25	0.35 ± 0.21	0.53 ± 0.20	−0.96 ± 0.67		0.49	0.32
Juiciness (JUICY)	−0.37 ± 0.34	−0.50 ± 0.35	0.28 ± 0.27	−0.48 ± 0.27	0.23 ± 0.26	0.94 ± 0.21	−0.37 ± 0.29	0.87 ± 0.20	0.77 ± 0.21	−0.79 ± 0.55	0.81 ± 0.20		0.40
Beef flavor intensity (FLAV)	−1.00[3] ± 1.68	−1.00[3] ± 2.18	−0.45 ± 0.78	−0.78 ± 1.09	−0.32 ± 0.68	0.60 ± 0.84	−0.87 ± 1.27	1.00[3] ± 1.58	1.00[3] ± 1.35	1.00[3] ± 1.90	1.00[3] ± 1.16	0.69 ± 0.80	

[1]Genetic correlation coefficients and their SE are below the diagonal; phenotypic correlation coefficients are above the diagonal.
[2]Chemical analysis of the LM (wet-weight basis).
[3]Estimate exceeded 1.00 and, thus, was set at 1.00.

ing amount of marbling (Table 9). This low genetic correlation between fat thickness and marbling was similar to that reported by Wheeler et al. (1996), but much less than reported by Wheeler et al. (2001, 2004, 2005) and Riley et al. (2003). Marbling had relatively high genetic correlations with all meat quality and composition traits, which is consistent with those reported by Wheeler et al. (1996, 2001, 2005), but in contrast to correlations reported by Wheeler et al. (2004). Retail product yield had moderate to high genetic correlations with most traits, except for BW and carcass weight. Palatability traits had moderate to high genetic correlations with most traits. Beef flavor intensity rating had very high genetic correlations with many traits, which likely was an artifact of low heritability estimates.

Phenotypic correlations were not as high as genetic correlations (Table 9). Body weight traits had low phenotypic correlations with most traits. Marbling had high phenotypic correlations to measures of LM lipid and retail product yield. Yield traits had moderate to high phenotypic correlations with most carcass traits. Phenotypically, LM shear force and tenderness rating were strongly correlated only to each other. Measures of tenderness were moderately related to beef flavor intensity and juiciness ratings, which is consistent with previous reports (Wheeler et al., 1996, 2001, 2005), but a weaker relationship among these traits also has been reported (Riley et al., 2002; Wheeler et al., 2004).

These results indicate that the tropical adaptation of the American composite breeds provides little advantage for BW and tends to compromise marbling and meat tenderness. Bonsmara and RO, which are sources of tropically adapted germplasm, are slower growing, but have leaner, greater yielding carcasses with similar marbling and LM that tend to be more tender than carcasses from the American composite breeds. Of all the alternative tropically adapted germplasm, BO comes closest to providing desirable growth, carcass, and palatability traits and may be most likely to succeed if incorporated into mainstream beef production in the southern United States.

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