Characterization of biological types of cattle (Cycle V): Carcass traits and longissimus palatability[1,2]

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ABSTRACT: Carcass (n = 854) and longissimus thoracis palatability (n = 802) traits from F_1 steers obtained from mating Hereford, Angus, and MARC III cows to Hereford or Angus (HA), Tuli (Tu), Boran (Bo), Brahman (Br), Piedmontese (Pm), or Belgian Blue (BB) sires were compared. Data were adjusted to constant age (444 d), carcass weight (333 kg), fat thickness (1.0 cm), fat trim percentage (21%), and marbling (Small^{00}) end points. Results presented in this abstract are for age-constant data. Carcasses from BB- and HA-sired steers were heaviest ($P < 0.05$) and carcasses from Bo- and Tu-sired steers were lightest ($P < 0.05$). Adjusted fat thickness was greatest ($P < 0.05$) on carcasses from HA-sired steers and least ($P < 0.05$) on carcasses from BB- and Pm-sired steers. Numerical USDA yield grades were lowest ($P < 0.05$) for carcasses from Pm- and BB-sired steers and highest ($P < 0.05$) for carcasses from HA- and Br-sired steers. Marbling scores were highest ($P < 0.05$) for carcasses from HA- and Tu-sired steers and lowest ($P < 0.05$) for carcasses from Br-, BB-, and Pm-sired steers. Longissimus thoracis from carcasses of HA-, Pm-, and Tu-sired steers had the lowest ($P < 0.05$) 14-d postmortem Warner-Bratzler shear force values. Carcasses from HA-sired steers had longissimus thoracis with the highest ($P < 0.05$) tenderness ratings at 7 d postmortem. Longissimus thoracis from carcasses of Br- and Bo-sired steers had the highest ($P < 0.05$) Warner-Bratzler shear forces and the lowest ($P < 0.05$) tenderness ratings at 7 d postmortem. Adjustment of traits to various slaughter end points resulted in some changes in sire breed differences for carcass traits but had little effect on palatability traits. Carcasses from BB- and Pm-sired steers provided the most desirable combination of yield grade and longissimus palatability, but carcasses from HA-cross steers provided the most desirable combination of quality grade and longissimus palatability. Tuli, a breed shown to be heat-tolerant, had longissimus tenderness similar to that of the non-heat-tolerant breeds and more tender longissimus than the heat-tolerant breeds in this study.

Key Words: Beef, Breeds, Carcass Composition, Meat Quality, Palatability, Tenderness

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Introduction

The first four cycles of the Germplasm Evaluation (**GPE**) program at the Roman L. Hruska U.S. Meat Animal Research Center (**MARC**) characterized 22 breeds representing several biological types of cattle. Carcass and longissimus palatability traits from these studies have been reported by Koch et al. (1976, 1979, 1982b) and Wheeler et al. (1996). Breed differences in production traits are important genetic resources for improving beef production efficiency and meat composition and quality. No single breed excels in all traits that are important to beef production. 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. This paper reports on Cycle V of the GPE program that characterizes cattle breeds representing diverse biological types, including two new tropically adapted breeds compared to Brahman and two breeds with high frequencies of double muscling, for carcass and longissimus palatability traits that affect the quantity, quality, and value of production.

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

Sire breed	Number sires	Dam breed and number of steer progeny			
		Hereford	Angus	MARC III[a]	Total
Hereford[b]	31	—	45	70	115
Angus[c]	43	21	—	106	127
Boran	8	18	48	85	151
Tuli	9	20	56	86	162
Brahman[d]	47	9	53	57	119
Piedmontese[e]	17	5	14	16	35
Belgian Blue	25	14	53	78	145
Total	180	87	269	498	854

[a]Composite consisting of 1/4 each Hereford, Angus, Pinzgauer, and Red Poll.
[b]Twenty of the Hereford sires were born 1982 to 1984 and 11 were born since 1988.
[c]Twenty-seven of the Angus sires were born 1982 to 1984 and 16 were born since 1988.
[d]Semen from a broad sample of 21 Brahman sires (born 1984 to 1989) and 26 sires (born 1964 to 1975) used in Cycle III was used in this experiment.
[e]Seventeen sires used in Cycle IV were used in this experiment to produce one calf crop (1992) for comparison to Belgian Blue.

Materials and Methods

Animals

Hereford, Angus, and MARC III (¼ Angus, ¼ Hereford, ¼ Pinzgauer, and ¼ Red Poll) dams of mature age (4 to 11 yr) were mated by AI to 43 Angus, 31 Hereford (20 polled and 11 horned), 9 Tuli, 8 Boran, 47 Brahman (Grey and Red), 17 Piedmontese, and 25 Belgian Blue bulls to produce 854 steer calves (Table 1). No purebred Hereford or purebred Angus matings were made to avoid confounding sire breed effects with heterosis effects. Semen from 20 of the Hereford (polled) and 27 of the Angus sires (born 1982 to 1984) also was used in Cycle IV. Semen from 11 of the Hereford (horned) and 16 of the Angus sires (born since 1988) was used for the first time in this experiment. Semen from a broad sample of 21 Brahman sires (born 1984 to 1989) and 26 sires (born 1964 to 1975) used in Cycle III also was used in this experiment. 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, were selected to represent the Hereford, Angus, and Brahman breeds.

Tuli, a Sanga type of cattle (cervical-humped, non-Zebu), was developed relatively recently in a research program initiated in the 1940s using foundation cattle selected as the most productive type from indigenous Tswana cattle in Zimbabwe. Australian scientists at the Commonwealth Scientific Industrial Research Organization (CSIRO), Tropical Agricultural Research Station, Rockhampton, Queensland and a consortium of private breeders in Australia imported frozen Tuli embryos from Zimbabwe into Australia in 1990. Semen from nine Tuli bulls was imported from Australia for use in this experiment. Boran, a pure Zebu breed (*Bos indicus*, humped), evolved in southern Ethiopia and is believed to have been developed for milk and meat production under stressful tropical conditions. They were imported into Australia from East Africa (Zambia). Semen from eight Boran sires was imported from Australia for use in this experiment. Belgian Blue have been selected for extreme muscling by breeders in Belgium for at least 40 yr. Sires (< 2 yr old) used to represent the Belgian Blue breed were identified in cooperation with seedstock breeders in the United States and Canada and commercial AI organizations, but without the benefit of EPD. Seventeen Piedmontese sires included in Cycle IV were used to produce one calf crop (1992) in this experiment for comparison to Belgian Blue. All Piedmontese and Belgian Blue sires used in this experiment were confirmed by MARC personnel to be homozygous for the inactive myostatin allele responsible for double muscling.

Calves were born in the spring, beginning in March each year (1992 to 1994). Male calves were castrated within 24 h of birth. Calves were creep-fed whole oats from mid-July or early August until weaning in early October. Calves averaged approximately 184 d of age at weaning. Steers were fed separately by sire breed in replicated pens for approximately 260 d (range from 225 to 293 d). A growing diet (2.7 Mcal ME/kg dry matter and 12.9% crude protein) containing 66% corn silage, 22% corn, and 12% supplement (dry matter basis) was fed until steers weighed approximately 320 kg. A finishing diet (3.04 Mcal ME/kg dry matter and 10.9% crude protein) containing 25% corn silage, 70% corn, and 5% supplement was fed from approximately 320 kg to slaughter. Steers were implanted with Synovex S (200 mg of progesterone and 20 mg of estradiol benzoate) in early December and again in mid-March of each year. The steers were slaughtered serially each year, in three slaughter groups spanning 56 d (1993), in four slaughter groups spanning 63 d (1994), or in five slaughter groups spanning 63 d (1995). In 1995, more animals were produced than could be processed for palatability evaluation; thus, for slaughter group three (n = 44) only carcass data were obtained. In addition, eight carcasses could not be sampled for palatability, and thus palatability data include 802 observations.

Final unshrunk live weights 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 with the following four-step sequence: 68 V (3 s on, 3 s off), followed by 3 times 70 V (2 s on, 3 s off). Carcasses were spray-chilled with a mist of 2°C water for 30 s every 5 min during the first 12 h of chilling. After a 24-h chill at 0°C, USDA yield and quality grade data were obtained by trained MARC personnel (USDA, 1997). The right side of each carcass was returned to the meat laboratory at MARC.

Five 2.54-cm-thick ribeye steaks were cut from the IMPS #112 ribeye roll (longissimus thoracis) between the 8th and 12th ribs and vacuum-packaged. The first steak from the 12th rib end was trimmed of all fat, epimysium, and non-longissimus muscles then frozen immediately at –30°C for later proximate analysis of the raw longissimus thoracis. The second steak was aged until 7 d postmortem at 3°C then frozen at –30°C for subsequent determination of Warner-Bratzler shear force. The third and fourth steaks were aged until 7 d postmortem at 3°C then frozen at –30°C for subsequent trained sensory evaluation. The d-7 shear force steak was used for cooked proximate analysis of the longissimus. The fifth steak was aged until 14 d postmortem at 3°C then frozen at –30°C for later determination of Warner-Bratzler shear force. Steaks were stored frozen for 3 to 5 mo before thawing for evaluation. Frozen steaks were thawed at 5°C for 24 h, broiled on Farberware Open Hearth electric boilers (Farberware, Bronx, NY) to 40°C internal temperature, then turned and broiled to a final internal temperature of 70°C. The d-7 shear force steak was trimmed before cooking so that only the longissimus thoracis was cooked. The sensory steaks were cooked as ribeye steaks and trimmed after cooking so that only the longissimus thoracis was evaluated.

Warner-Bratzler Shear Force

After cooking, longissimus thoracis steaks were chilled for 24 h at 3°C, and then six 1.27-cm-diameter cores were removed parallel to the muscle fiber orientation and sheared once each on a model 1132 Instron Universal Testing Machine (Instron, Canton, MA) with a Warner-Bratzler shear attachment, 50-kg load cell, full-scale load setting 10, and crosshead speed of 50 mm/min.

Trained Sensory Evaluation

Sensory panel steaks were cooked as described above and may have been held between cooking and serving for up to 30 min in a covered Pyrex baking dish in a 70°C oven, depending on when steaks finished cooking relative to their predetermined serving order. Cooked longissimus thoracis was cut into 1 cm × 1 cm × steak thickness cubes. Three cubes were served warm to each panel member. An eight-member 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; 1 = extremely tough, dry, or bland). A warm-up sample was served first, then four experimental steaks were served in each of two sessions (15 min between sessions) per day, 3 d per week. In addition, duplicate steaks (one in each session) were served daily for monitoring panelist and panel performance.

Proximate Composition Analyses

Raw and cooked longissimus thoracis were ground through a 0.48-cm plate. Duplicate 100-g random samples were taken, wrapped in cheesecloth, and frozen at –30°C. Moisture content was determined after samples were thawed and subjected to oven drying at 100°C for 24 h (AOAC, 1985). Total lipids were obtained on dried samples by diethyl ether extraction. Protein content was calculated by difference.

Statistical Analyses

Data were analyzed by least squares, mixed-model procedures (Harvey, 1985) considering appropriate fixed effects (sire breed, dam breed, sire breed × dam breed, birth year); random effects (sire nested within sire breed) to test sire breed; and residual variance to test other fixed effects. Estimates of heritability and genetic and phenotypic correlations were derived following procedures outlined by Harvey (1985).

In addition, linear regression of traits on differences in weaning age (due to differences in birth date) and differences in days fed (due to serial slaughter design) were fitted simultaneously with the main effects. The regressions of traits on days fed provides a method of adjusting the age-constant sire breed means to alternative end points. The regression equations 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 end point (the mean for this experiment) with regard to age (444 d), carcass weight (333 kg), fat thickness (1.0 cm), fat trim percentage (21%; when cuts were 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). Each end point has merit for specific applications, but no one basis of comparison is suitable for answering all questions related to differences among sire breeds. Age-constant contrasts measure the impact of overall growth rates to selected ages. Weight-constant contrasts accentuate the differential growth rates of lean, fat, and bone in relation to differences in maturity. Fatness end points are useful for comparisons at similar physiological maturities. The percentage fat trim end point should be a more accurate comparison at a constant degree of fatness than fat thickness; however, fat thickness provides for comparisons to other experiments and other industry applications when fat thickness, but not fat trim percentage, is available. Comparisons at marbling end points are important because of the current emphasis on USDA Choice quality grade as a marketing end point.

Consistent with previous reports (Koch et al., 1979, 1982b; Wheeler et al., 1996), the average regression over all sire breeds was modified by a proportionate adjustment of the sire breed mean to the general mean (μ) as follows:

$$y_i = \frac{y_i}{y_\mu}\left[y_\mu + b_\mu\,(D - \overline{d})\right],$$

where y_i is the adjusted mean of the i^{th} sire breed, y_i is the age-constant least squares mean of the i^{th} sire breed, y_μ is the least squares mean for all sire breeds, b_μ is the average regression coefficient over all sire breeds, D is the number of days on feed required to reach a given end point, and $\overline{d}$ is the average number of days fed (260).

The number of days fed required to reach a given end point can be derived by substituting the end point (e.g., 333 kg in the case of constant carcass weight) in the equation for y_i and solving for D. The derived D then is used in the equation for all traits other than that end point (carcass weight in this case).

Data from all Hereford- and Angus-sired progeny were pooled and used to compare Hereford and Angus crosses to other sire breeds, rather than comparing Hereford crosses and Angus crosses to other sire breeds separately, due to differences in dam breeds. However, as described in the table footnotes, these separate comparisons can be made by taking one-half of the difference between the Angus mean and the Hereford mean and adding or subtracting it from the Hx, Ax mean as appropriate (depending on which one is greater). Hereford was compared to Angus using Hereford × MARC III and Angus × MARC III cross progeny. Separate least significant differences (**LSD**) for Piedmontese progeny were calculated because of the difference in the number of observations. Sire breeds were compared using LSD for $\alpha = 0.05$ computed for all possible pairwise contrasts using the sire within breed of sire mean square as the error term in the linear contrast procedure of Harvey (1985).

Results and Discussion

The analysis of variance indicated that sire breed, dam breed, and year were significant ($P < 0.05$) sources of variation for most traits (Table 2). Sire breed × dam breed interaction was not a significant source of variation for any trait. Linear regressions of weaning age and days fed were significant for most carcass traits, but not for palatability traits.

Table 2. Analysis of variance

		Mean squares													
Source	Carcass df[a]	Live weight, kg	Hot carcass weight, kg	Dressing percentage	Adjusted fat thickness, cm	Longissimus area, cm^2	Kidney, pelvic, and heart fat, %	USDA Yield grade	Marbling score	USDA Choice, %	Sensory and shear df[b]	7-d Warner-Bratzler shear force, kg	7-d Tenderness rating	7-d Juiciness rating	7-d Beef flavor intensity rating
Sire breed (SB)	6	86,991*	28,815*	41.6*	4.1*	2,044*	2.7*	15.7*	76,500*	41,304*	6	31.6*	16.48	2.92*	0.16
Sire (Sire breed)	158	2,507*	992*	4.3	0.3*	72*	0.4*	0.6*	4,779*	2,555*	155	3.2*	1.18*	0.20	0.12
Dam breed (DB)	2	7,529	6,762*	30.6*	2.0*	71	0.5	3.0*	30,802*	18,888*	2	12.4*	2.57	0.42	0.16
Year (Y)	2	3,618	10,833*	156.2*	0.0	1,111*	1.7*	0.3	7,685	4,783	2	99.7*	17.71*	1.75*	5.17*
SB × DB	10	2,903	1,214	2.5	0.1	45	0.4	0.3	4,137	2,535	10	2.1	0.49	0.23	0.06
b1 (weaning age)	1	111,985*	47,454*	5.3	1.9*	564*	5.8*	6.1*	55,894*	14,750*	1	2.8	0.66	0.35	0.07
b2 (days fed)	1	473,816*	229,393*	131.0*	4.1*	2,381*	26.4*	21.2*	61,501*	15,607*	1	8.6	3.38	0.07	0.11
Residual	670	1,674	687	5.0	0.1	35	0.3	0.3	2,640	1,821	621	2.4	0.93	0.18	0.11

[a]The number of observations for carcass traits = 854.
[b]The number of observations for sensory and shear traits = 802.
*$P < 0.05$.

Carcass Traits

Sire breeds differed significantly in growth rate. Final live and carcass weights at a constant age of 444 d were heaviest for Hereford/Angus- and Belgian Blue-sired steers, followed by Brahman- and Piedmontese-sired steers, and lightest for Boran- and Tuli-sired steers (Table 3). At a constant fat thickness, Belgian Blue- and Piedmontese-sired steers were heaviest, then Hereford/Angus- and Brahman-sired steers, followed by Tuli-sired steers, and Boran-sired steers were the lightest. Similar sire breed differences occurred at the fat trim end point. At a constant marbling degree, Belgian Blue-sired steers were heaviest, followed by Piedmontese- and Brahman-sired steers, then Hereford/Angus- and Boran-sired steers, and Tuli-sired steers were the lightest. Hereford × MARC III cross steers and their carcasses were heavier than Angus × MARC III cross steers and their carcasses when adjusted to constant marbling.

Dressing percentage was higher for carcasses from Belgian Blue- and Piedmontese-sired steers at all end points. Carcasses from Hereford/Angus-sired steers had the lowest dressing percentage at all end points except age-constant. At a constant marbling end point, carcasses from Hereford × MARC III cross steers had greater dressing percentages than carcasses from Angus × MARC III cross steers.

Adjusted fat thickness was highest for carcasses from Hereford/Angus-sired steers and lowest for carcasses from Belgian Blue- and Piedmontese-sired steers at constant age. At constant weight, carcasses from Boran-, Hereford/Angus-, and Tuli-sired steers had the highest, carcasses from Brahman-sired steers had intermediate, and carcasses from Belgian Blue- and Piedmontese-sired steers had the lowest adjusted fat thickness. At constant marbling, carcasses from Brahman- and Boran-sired steers had the highest fat thickness, followed by carcasses from Belgian Blue- and Hereford/Angus-sired steers. Carcasses from Tuli- and Piedmontese-sired steers had the lowest fat thickness at constant marbling. At constant fat trim percentage, Piedmontese- and Belgian Blue-sired steers had greater fat thickness than all other sire breeds. Adjusted fat thickness was not different between carcasses of Hereford × MARC III cross and Angus × MARC III cross steers at any end point.

Carcasses from Belgian Blue- and Piedmontese-sired steers had the largest longissimus areas at all end points. At age, fat thickness, and fat trim constant end points, carcasses from Hereford/Angus-, Brahman-, Boran-, and Tuli-sired steers had similar longissimus areas. At constant weight, carcasses from Boran- and Tuli-sired steers had larger longissimus areas than did carcasses from Hereford/Angus- and Brahman-sired steers. At constant marbling, carcasses from Brahman-sired steers had greater longissimus areas than carcasses from Boran-sired steers, which were greater than those from Hereford/Angus- and Tuli-sired steers. Carcasses of Hereford × MARC III cross steers were not different in longissimus area from carcasses of Angus × MARC III cross steers at any end point.

At constant age, percentage of kidney, pelvic, and heart (**KPH**) fat was greatest in carcasses from Tuli- and Brahman-sired steers, followed by Boran-, Hereford/Angus-, Piedmontese-, and Belgian Blue-sired steers. At constant weight, percentage of KPH fat was greatest in carcasses from Tuli-sired steers, followed by Boran- and Brahman-sired steers, and least in carcasses from Piedmontese-, Hereford/Angus-, and Belgian Blue-sired steers. At constant fat thickness and constant fat trim, Piedmontese- and Belgian Blue-sired steers had the highest percentage of KPH fat, followed by Tuli- and Brahman-sired steers, and Hereford/Angus- and Boran-sired steers had the lowest percentage of KPH fat. At constant marbling, carcasses from Brahman-, Belgian Blue-, and Piedmontese-sired steers had the highest percentage KPH fat, followed by Boran- and Tuli-sired steers, and Hereford/Angus-sired steers had the lowest percentage KPH fat. Carcasses from Hereford × MARC III cross steers had a lower percentage of KPH fat than carcasses from Angus × MARC III cross steers at constant age but had a higher percentage of KPH fat at constant marbling.

At constant age, numerical USDA yield grade was lowest for carcasses from Piedmontese- and Belgian Blue-sired steers and highest for carcasses from Hereford/Angus- and Brahman-sired steers. At constant age, the mean yield grade of 3.45 for Hereford/Angus-sired steers resulted from a relatively high percentage (23.4%) of carcasses with a yield grade 4.0 or greater. Angus × MARC III cross steers had 29.6% and Hereford × MARC III had 14.3% of carcasses with a yield grade 4.0 or greater. Brahman-, Boran-, Tuli-, Piedmontese-, and Belgian Blue-sired steers had 13.4, 10.1, 6.4, 2.9, and 0% of carcasses with yield grade 4.0 or higher, respectively. At constant weight, carcasses from Piedmontese- and Belgian Blue-sired steers had lower yield grades than all other sire breeds. At constant marbling, carcasses from Brahman-sired steers had the highest yield grades, and carcasses from Tuli-, Piedmontese-, and Hereford/Angus-sired steers had the lowest yield grades. At constant marbling, carcasses from Angus × MARC III cross steers had lower numerical yield grades than carcasses from Hereford × MARC III cross steers.

At constant age and constant weight, marbling score was highest in carcasses of Hereford/Angus- and Tuli-sired steers, followed by Boran-sired steers, and lowest in carcasses of Brahman-, Piedmontese-, and Belgian Blue-sired steers. At constant fat thickness, carcasses from Brahman- and Boran-sired steers had the lowest marbling scores. However, at constant fat trim, carcasses from Piedmontese- and Belgian Blue-sired steers had the highest marbling scores, followed by Hereford/Angus- and Tuli-sired steers, and then Brahman- and Boran-sired steers. Sire breed differences for the percentage of carcasses grading USDA Choice at each end point were similar to marbling differences. The percent-

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

Trait, μ ± SEM, b1, b2[b]	Sire breed,[c] LSD[d]	End point: Age (444 d)	Carcass wt (333 kg)	Fat thickness (1.0 cm)	Marbling ($Small^{00}$)	Fat trim (21%)
Days on feed	Hereford	—	246	219	211	204
μ = 260	Angus	—	239	211	150	197
SD = 24	Brahman	—	261	261	326	246
	Piedmontese	—	263	487	333	504
	Boran	—	289	233	252	195
	Tuli	—	293	259	208	224
	Belgian Blue	—	240	412	350	438
Live weight, kg	Hereford	582	566	532	523*	514
μ = 551 ± 2.9	Angus	591	567	532	458*	515
b1 = 1.0853 ± 0.13	Hx, Ax	587	565	532	490	514
b2 = 1.2149 ± 0.072	Brahman	549	550	550	629	532
	Piedmontese	541	544	817	629	837
	Boran	514	549	481	504	435
	Tuli	511	551	508	448	467
	Belgian Blue	573	549	758	683	789
	LSD with Pied	23	23	44	28	50
	LSD w/o Pied	14	16	22	22	26
Hot carcass weight, kg	Hereford	345	—	310	304*	298
μ = 333 ± 1.8	Angus	352	—	311	259*	299
b1 = 0.7065 ± 0.085	Hx, Ax	349	—	311	281	298
b2 = 0.8454 ± 0.046	Brahman	332	—	333	388	320
	Piedmontese	330	—	522	392	536
	Boran	310	—	287	303	255
	Tuli	308	—	306	264	277
	Belgian Blue	351	—	479	427	501
	LSD with Pied	14	—	28	18	31
	LSD w/o Pied	9	—	14	14	16
Dressing percentage	Hereford	59.2	59.0	58.4	58.2*	58.1
μ = 60.3 ± 0.11	Angus	59.5	59.1	58.5	57.3*	58.2
b1 = 0.00744 ± 0.0072	Hx, Ax	59.4	59.0	58.5	57.7	58.2
b2 = 0.02020 ± 0.0039	Brahman	60.5	60.5	60.5	61.8	60.2
	Piedmontese	61.0	61.1	65.6	62.5	66.0
	Boran	60.4	61.0	59.9	60.2	59.1
	Tuli	60.2	60.9	60.1	59.1	59.5
	Belgian Blue	61.2	60.8	64.2	63.0	64.8
	LSD with Pied	0.9	1.0	1.8	1.2	2.1
	LSD w/o Pied	0.6	0.6	0.9	0.9	1.1
Adj. fat thickness, cm	Hereford	1.18	1.14	—	1.01	0.98
μ = 0.96 ± 0.032	Angus	1.23	1.15	—	0.83	1.00
b1 = 0.00442 ± 0.0011	Hx, Ax	1.20	1.14	—	0.92	0.99
b2 = 0.0036 ± 0.0006	Brahman	1.00	1.00	—	1.23	0.95
	Piedmontese	0.54	0.55	—	0.80	1.41
	Boran	1.11	1.22	—	1.08	0.88
	Tuli	1.00	1.12	—	0.82	0.88
	Belgian Blue	0.64	0.57	—	0.96	1.27
	LSD with Pied	0.23	0.23	—	0.29	0.50
	LSD w/o Pied	0.15	0.16	—	0.23	0.26
Longissimus area, cm^2	Hereford	73.6	72.5	70.1	69.4	68.8
μ = 77.2 ± 0.5	Angus	75.8	74.0	71.6	66.3	70.4
b1 = 0.07702 ± 0.019	Hx, Ax	74.7	73.2	70.8	67.8	69.6
b2 = 0.08613 ± 0.0105	Brahman	72.9	73.0	73.0	78.6	71.7
	Piedmontese	84.8	85.1	104.4	91.1	105.8
	Boran	74.0	76.5	71.6	73.3	68.4
	Tuli	73.6	76.5	73.5	69.2	70.5
	Belgian Blue	85.9	84.1	98.9	93.6	101.2
	LSD with Pied	3.8	3.9	7.5	4.7	8.4
	LSD w/o Pied	2.4	2.6	3.8	3.8	4.4

(continued)

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

Trait, $\mu \pm$ SEM, b1, b2[b]	Sire breed,[c] LSD[d]	End point Age (444 d)	Carcass wt (333 kg)	Fat thickness (1.0 cm)	Marbling (Small[00])	Fat trim (21%)
KPH fat, %[e]	Hereford	2.68*	2.56	2.31	2.23*	2.17
$\mu = 2.85 \pm 0.03$	Angus	2.88*	2.69	2.43	1.88*	2.31
b1 = 0.00782 ± 0.0016	Hx, Ax	2.78	2.61	2.37	2.05	2.23
b2 = 0.0091 ± 0.0009	Brahman	3.01	3.02	3.02	3.61	2.89
	Piedmontese	2.71	2.73	4.77	3.37	4.92
	Boran	2.86	3.12	2.62	2.79	2.27
	Tuli	3.15	3.45	3.13	2.67	2.82
	Belgian Blue	2.69	2.51	4.07	3.51	4.30
	LSD with Pied	0.27	0.27	0.52	0.33	0.59
	LSD w/o Pied	0.17	0.18	0.26	0.26	0.30
Yield grade	Hereford	3.44	3.33	3.10	3.04*	2.98
$\mu = 2.97 \pm 0.05$	Angus	3.47	3.30	3.07	2.58*	2.96
b1 = 0.00801 ± 0.0017	Hx, Ax	3.45	3.31	3.09	2.80	2.97
b2 = 0.0081 ± 0.0009	Brahman	3.25	3.26	3.26	3.79	3.14
	Piedmontese	2.13	2.16	3.98	2.73	4.12
	Boran	3.10	3.33	2.88	3.03	2.57
	Tuli	3.04	3.31	3.02	2.62	2.75
	Belgian Blue	2.35	2.18	3.58	3.08	3.79
	LSD with Pied	0.36	0.37	0.71	0.45	0.79
	LSD w/o Pied	0.23	0.25	0.36	0.36	0.41
Marbling[f]	Hereford	522.5*	516.8*	504.6*	—	498.0*
$\mu = 501.3 \pm 4.2$	Angus	553.0*	543.8*	531.6*	—	525.4*
b1 = 0.767 ± 0.17	Hx, Ax	537.8	529.9	518.1	—	511.5
b2 = 0.438 ± 0.091	Brahman	472.9	473.3	473.3	—	466.7
	Piedmontese	470.1	471.4	569.5	—	576.9
	Boran	503.3	516.0	491.5	—	474.9
	Tuli	523.6	538.1	522.7	—	507.9
	Belgian Blue	463.7	455.0	530.3	—	541.7
	LSD with Pied	31.2	31.7	61.3	—	68.4
	LSD w/o Pied	19.9	21.5	30.9	—	35.5
USDA Choice, %[g]	Hereford	72	69	63	—	59
$\mu = 49 \pm 3$	Angus	84	79	73	—	70
b1 = 0.3939 ± 0.14	Hx, Ax	78	74	68	—	65
b2 = 0.2205 ± 0.075	Brahman	30	30	30	—	27
	Piedmontese	29	29	79	—	83
	Boran	47	53	41	—	32
	Tuli	63	70	62	—	55
	Belgian Blue	22	18	56	—	61
	LSD with Pied	23	23	45	—	50
	LSD w/o Pied	15	16	23	—	26
USDA Standard, %[h]	Hereford	0.1	1.1	3.3	—	4.4
$\mu = 1.1 \pm 0.84$	Angus	0.1	1.7	3.8	—	4.9
b1 = –0.1415 ± 0.057	Hx, Ax	0.1	1.5	3.6	—	4.7
b2 = –0.0732 ± 0.030	Brahman	1.9	1.9	1.9	—	3.1
	Piedmontese	2.1	1.9	0.0	—	0.0
	Boran	1.4	0.0	3.3	—	6.3
	Tuli	0.9	0.0	0.0	—	2.0
	Belgian Blue	2.8	4.3	0.0	—	0.0
	LSD with Pied	7.2	7.3	14.2	—	15.9
	LSD w/o Pied	4.6	5.0	7.2	—	8.2

[a]End points represent the overall mean for that trait in this experiment.
[b]b1 = regression coefficient for weaning age, b2 = regression coefficient for days on feed.
[c]Piedmontese (Pied)-sired steers were only produced 1 yr; thus, the error variance associated with their data is inflated and comparisons of their means should be made with the Pied LSD. The number of Hereford-sired and Angus-sired steers was less than for the other sire breeds (except Piedmontese); thus, their error variances are slightly inflated and dam breed effects are biased between Hereford or Angus sired steers and other steers. Thus, data from Hereford- or Angus-sired steers should be compared only to each other. Data from all Hereford- and Angus-sired progeny were pooled and used to compare Hereford and Angus crosses to other sire breeds (using the LSD w/o Pied), rather than comparing Hereford crosses and Angus crosses to other sire breeds separately, due to differences in dam breeds. However, these separate comparisons can be made by taking one-half of the difference between the Angus mean and the Hereford mean and adding or subtracting it from the Hx, Ax mean as appropriate (depending on which one is greater).
[d]LSD = least significant difference among means ($P < 0.05$).
[e]Estimated percentage of hot carcass weight as kidney, pelvic, and heart fat.
[f]400 = Slight[00], 500 = Small[00].
[g]Percentage of carcasses grading USDA Choice or higher.
[h]Percentage of carcasses grading USDA Standard.
*Means for Hereford and Angus sire breeds are different from each other ($P < 0.05$).

age of carcasses grading USDA Standard was relatively low for all sire breeds, regardless of end point, and did not differ among sire breeds. Marbling score was higher in carcasses from Angus × MARC III steers than in Hereford × MARC III steers at all end points, but percentage USDA Choice quality grade was not different between carcasses from Angus × MARC III and Hereford × MARC III cross steers at any end point.

The adjustment of data from Piedmontese and Belgian Blue progeny to 21% fat trim or 1.0 cm fat thickness required extrapolation beyond the available data; thus, those numbers should be interpreted with caution. The time on feed and weight required for those progeny to reach these end points resulted in potentially unreasonable values for some traits.

Hereford/Angus- and Belgian Blue-sired steers were the heaviest at constant age and, thus, were the fastest growing sire breeds. Boran- and Tuli-sired steers had the slowest growth rates. Piedmontese- and Belgian Blue-sired steers were the leanest and most muscular at a constant carcass weight. Boran-, Angus-, and Hereford-sired breeds were the earliest maturing; they required the fewest days on feed to reach the 21% fat trim end point. Adjusting data to fatness end points (fat thickness, marbling, or fat trim percentage) had a greater impact on breed rankings than adjusting data to the weight-constant end point, particularly for fatness traits.

Similar results have been reported comparing F_1 Piedmontese or Belgian Blue to progeny of other sire breeds (Arthur, 1995; Wheeler et al., 1996). Carcass traits of Piedmontese- and Belgian Blue-sired steers differed only in carcass weight. This is consistent with the finding that breed source of the double muscling allele was not significant (Casas et al., 1998). It was recently shown that an inactivated myostatin gene is responsible for the double muscling phenotype in cattle (Kambadur et al., 1997; Smith et al., 1997), but the inactivating mutation is not the same in all breeds (Grobet et al., 1997, 1998; McPherron and Lee, 1997).

Sire breed differences among Boran, Brahman, and Tuli progeny for carcass traits were similar to those reported by Herring et al. (1996). Koch et al. (1982b) reported that Brahman- and Sahiwal-cross steers had lower marbling scores, but similar carcass weights, longissimus areas, and fat thicknesses, compared to HA-cross steers. Crouse et al. (1989) found Brahman-sired steers produced carcasses with higher dressing percentage than did HA-cross steers. Paschal et al. (1995) reported that Gray and Red Brahman-sired steers had heavier carcasses, similar longissimus areas and adjusted fat thicknesses, slightly higher numerical yield grades and less marbling compared to carcasses from Angus-sired steers. Wheeler et al. (1990) reported that Hereford and Brahman reciprocal cross steers had heavier carcass weights but were similar in other carcass traits to Hereford steers.

Days on Feed. Based on the regressions of days fed, each 30 d of additional time on feed (from 184 to 444 d of age) resulted in an additional 25 kg of hot carcass weight, 0.11 cm of adjusted fat thickness, 0.24 increased USDA yield grade (0.5% lower yield), and 6.6% more USDA Choice carcasses. Thus, each additional 30 d on feed resulted in a few more USDA Choice carcasses that were slightly heavier but yielded less saleable product that was not different in tenderness, juiciness, or flavor.

Longissimus Proximate Composition

Chemical composition of raw longissimus thoracis adjusted to 444 d of age indicated that longissimus from carcasses of Hereford/Angus- and Tuli-sired steers had the highest percentages of lipid, followed by Boran-, Brahman-, Piedmontese-, and Belgian Blue-sired steers (Table 4). Raw longissimus from carcasses of Hereford/Angus- and Tuli-sired steers had the lowest percentage of moisture. Raw longissimus from carcasses of Belgian Blue- and Piedmontese-sired steers had the highest percentage of protein. Chemical composition of the cooked longissimus thoracis indicated that the longissimus from carcasses of Hereford/Angus-sired steers had the highest percentage of lipid, followed by Boran- and Tuli-sired steers, and Brahman-, Belgian Blue-, and Piedmontese-sired steers had the lowest percentages of lipid. Cooked longissimus from carcasses of Hereford/Angus- and Tuli-sired steers had the lowest percentages of moisture, followed by Boran- and Brahman-sired steers. Cooked longissimus from carcasses of Piedmontese- and Belgian Blue-sired steers had the highest percentages of moisture. No sire breed differences in protein content were detected in cooked longissimus. Raw and cooked longissimus from carcasses of Angus × MARC III cross steers had a greater percentage of lipid than longissimus from carcasses of Hereford × MARC III cross steers. Percentage of moisture and protein did not differ between these groups in raw or cooked longissimus.

Palatability Traits

Longissimus from carcasses of Hereford/Angus- and Tuli-sired steers had the lowest 14-d postmortem Warner-Bratzler shear force values, followed by Piedmontese-, Belgian Blue-sired steers, then Boran-sired steers, and Brahman-sired steers had the highest 14-d shear force, regardless of end point (Table 5). At constant age and constant weight, longissimus from carcasses of Hereford/Angus-, Piedmontese-, Tuli-, and Belgian Blue-sired steers had the lowest 7-d postmortem Warner-Bratzler shear force, followed by carcasses of Boran-sired steers. Brahman-sired steers had longissimus with the highest 7-d shear force. At constant fat thickness, constant marbling, and constant fat trim percentage, longissimus from carcasses of Hereford/Angus- and Tuli-sired steers tended to have the lowest, longissimus from carcasses of Belgian Blue, Piedmontese-, and Boran-sired steers tended to be intermediate, and

Table 4. Effect of sire breed on least squares means for chemical composition of raw and cooked longissimus thoracis at a common age of 444 d

	Raw			Cooked		
Sire breed[a]	Lipid, %	Moisture, %	Protein, %[b]	Lipid, %	Moisture, %	Protein, %[b]
μ ± SEM	3.9 ± 0.07	73.4 ± 0.07	22.8 ± 0.03	5.3 ± 0.10	63.3 ± 0.11	31.4 ± 0.09
Hereford	4.3*	73.1	22.5	6.0*	62.8	31.1
Angus	4.8*	72.9	22.3	6.8*	62.3	30.9
Hx, Ax	4.5	73.0	22.4	6.4	62.6	31.0
Brahman	3.5	73.8	22.7	4.7	63.6	31.7
Piedmontese	3.4	73.5	23.2	4.2	64.3	31.5
Boran	3.8	73.5	22.7	5.3	63.3	31.4
Tuli	4.3	73.0	22.7	5.8	62.8	31.4
Belgian Blue	3.2	73.7	23.1	4.2	64.1	31.7
LSD with Pied[c]	0.6	0.5	0.3	0.8	0.9	0.7
LSD w/o Pied[c]	0.4	0.3	0.2	0.5	0.6	0.5

[a]Piedmontese (Pied)-sired steers were only produced 1 yr; thus, the error variance associated with their data is inflated and comparisons of their means should be made with the LSD with Pied. The number of Hereford-sired and Angus-sired steers was less than for the other sire breeds (except Piedmontese); thus, their error variances are slightly inflated and dam breed effects are biased between Hereford- or Angus-sired steers and other steers. Thus, data from Hereford- or Angus-sired steers should be compared only to each other. Data from all Hereford- and Angus-sired progeny were pooled and used to compare Hereford and Angus crosses to other sire breeds (using the LSD w/o Pied), rather than comparing Hereford crosses and Angus crosses to other sire breeds separately, due to differences in dam breeds. However, these separate comparisons can be made by taking one-half of the difference between the Angus mean and the Hereford mean and adding or subtracting it from the Hx, Ax mean as appropriate (depending on which one is greater).
[b]Calculated by difference.
[c]LSD = least significant difference among means ($P < 0.05$).
*Means for Hereford and Angus sire breeds are different from each other ($P < 0.05$).

carcasses of Brahman-sired steers tended to have the highest 7-d postmortem shear force. Longissimus from carcasses of Angus × MARC III cross steers had lower 7- and 14-d postmortem shear force than carcasses from Hereford × MARC III cross steers at all end points.

At 7 d postmortem, trained sensory panel tenderness ratings and shear force values indicated similar relative longissimus tenderness mean differences among sire breeds (r = –0.98). Longissimus from carcasses of Hereford/Angus-sired steers had the highest tenderness ratings at constant age and constant weight (Table 5). Longissimus from carcasses of Piedmontese-, Tuli-, and Belgian Blue-sired steers had the next highest tenderness ratings, followed by Boran-sired steers, and Brahman-sired steers had the lowest tenderness ratings, at constant age and constant weight. At the three fatness end points, longissimus from carcasses of Hereford/Angus- and Tuli-sired steers tended to have the highest tenderness ratings, followed by Boran-sired steers, then Belgian Blue- and Piedmontese-sired steers, and Brahman-sired steers had the lowest tenderness ratings. Longissimus from carcasses of Angus × MARC III cross steers had higher tenderness ratings than longissimus from Hereford × MARC III cross steers at constant marbling but were not different at other end points.

Longissimus steaks from Piedmontese-sired steers were less juicy than those from Hereford/Angus-sired steers at all end points and more juicy than those from Brahman-sired steers at constant age and constant weight. Longissimus from carcasses of Hereford/Angus-sired steers had the highest juiciness ratings at all end points, followed by Tuli-sired steers, then Boran-, Belgian Blue-, and Piedmontese-sired steers, and longissimus from carcasses of Brahman-sired steers had the lowest juiciness ratings. Some differences among sire breeds were detected for beef flavor intensity ratings; however, the magnitude of the differences indicates they were of little practical importance. The high correlations of juiciness and beef flavor intensity ratings to tenderness ratings may indicate a halo-effect of tenderness ratings on those traits. Adjusting the data to alternative end points had very little effect on breed differences in juiciness or beef flavor intensity ratings and only minor effects on sensory tenderness ratings.

The relatively less tender longissimus from *Bos indicus* breeds of cattle has been demonstrated previously. Numerous studies have established that the longissimus from Brahman cattle is less tender than longissimus from *Bos taurus* breeds (Ramsey et al., 1963; McKeith et al., 1985; Shackelford et al., 1991). Koch et al. (1982b) and Crouse et al. (1987) reported that meat from F_1 Brahman or Sahiwal crosses was less tender than meat from Hereford-Angus F_1 crosses. Crouse et al. (1989) reported that meat tenderness declined linearly as percentage of Brahman or Sahiwal increased from 0 to 75%. In contrast to our results, Herring et al. (1996) reported that longissimus from carcasses of Tuli-sired F_1 steers were similar in shear force value to longissimus from carcasses of Brahman-sired F_1 steers but lower in Warner-Bratzler shear force value than longissimus from carcasses of Boran-sired F_1 steers. Gaughan et al. (1999) reported that the heat tolerance of Boran and Tuli crosses was intermediate to that of Hereford and Brahman. However, Hammond et al.

Table 5. Least squares means for palatability traits adjusted to a common age, carcass weight, fat thickness, fat trim percentage, or marbling end point[a]

Trait, $\mu \pm$ SEM, b1, b2[b]	Sire breed,[c] LSD[d]	End point: Age (444 d)	Carcass wt (333 kg)	Fat thickness (1.0 cm)	Marbling (Small[00])	Fat trim (21%)
14-d Shear force, kg	Hereford	4.72*	4.70*	4.65*	4.63*	4.62*
$\mu = 4.84 \pm 0.07$	Angus	4.08*	4.04*	3.99*	3.88*	3.97*
b1 = –0.00008 ± 0.004	Hx, Ax	4.40	4.37	4.32	4.26	4.29
b2 = 0.00181 ± 0.0021	Brahman	5.95	5.95	5.95	6.07	5.92
	Piedmontese	4.59	4.59	5.00	4.72	5.03
	Boran	5.11	5.16	5.06	5.09	4.99
	Tuli	4.57	4.63	4.56	4.47	4.50
	Belgian Blue	4.89	4.86	5.17	5.05	5.21
	LSD with Pied	0.60	0.61	1.18	0.74	1.32
	LSD w/o Pied	0.38	0.41	0.60	0.59	0.69
7-d Shear force, kg	Hereford	5.73*	5.66*	5.52*	5.48*	5.44*
$\mu = 5.95 \pm 0.10$	Angus	5.07*	4.95*	4.81*	4.49*	4.73*
b1 = –0.0568 ± 0.0052	Hx, Ax	5.40	5.30	5.16	4.98	5.08
b2 = 0.00524 ± 0.0028	Brahman	7.24	7.24	7.24	7.58	7.16
	Piedmontese	5.47	5.49	6.66	5.86	6.75
	Boran	6.53	6.68	6.39	6.49	6.19
	Tuli	5.73	5.90	5.72	5.46	5.54
	Belgian Blue	5.91	5.80	6.70	6.38	6.84
	LSD with Pied	0.81	0.83	1.62	1.02	1.80
	LSD w/o Pied	0.52	0.57	0.82	0.81	0.94
7-d Tenderness[e]	Hereford	5.21	5.26	5.35	5.38*	5.40
$\mu = 4.88 \pm 0.06$	Angus	5.51	5.58	5.67	5.87*	5.72
b1 = –0.0028 ± 0.0033	Hx, Ax	5.36	5.42	5.51	5.63	5.56
b2 = –0.0033 ± 0.0017	Brahman	3.99	3.99	3.99	3.78	4.04
	Piedmontese	5.02	5.01	4.27	4.78	4.21
	Boran	4.48	4.38	4.57	4.51	4.69
	Tuli	5.02	4.91	5.03	5.19	5.14
	Belgian Blue	4.92	4.98	4.42	4.62	4.33
	LSD with Pied	0.49	0.50	0.98	0.61	1.09
	LSD w/o Pied	0.32	0.34	0.49	0.49	0.57
7-d Juiciness[f]	Hereford	5.26	5.27	5.28	5.28	5.29
$\mu = 5.09 \pm 0.02$	Angus	5.41	5.42	5.43	5.46	5.44
b1 = –0.0020 ± 0.0014	Hx, Ax	5.34	5.34	5.36	5.37	5.36
b2 = –0.0005 ± 0.0008	Brahman	4.76	4.76	4.76	4.73	4.77
	Piedmontese	4.99	4.99	4.88	4.95	4.87
	Boran	5.03	5.02	5.05	5.04	5.06
	Tuli	5.17	5.16	5.17	5.20	5.19
	Belgian Blue	5.01	5.01	4.93	4.96	4.92
	LSD with Pied	0.20	0.21	0.40	0.25	0.45
	LSD w/o Pied	0.13	0.14	0.20	0.20	0.23
7-d Beef flavor intensity[g]	Hereford	4.89	4.89	4.87	4.86	4.86
$\mu = 4.85 \pm 0.02$	Angus	4.91	4.90	4.88	4.84	4.87
b1 = 0.00089 ± 0.00110	Hx, Ax	4.90	4.89	4.87	4.85	4.86
b2 = 0.00061 ± 0.00059	Brahman	4.82	4.82	4.82	4.86	4.81
	Piedmontese	4.86	4.86	4.99	4.90	5.00
	Boran	4.78	4.80	4.76	4.78	4.74
	Tuli	4.86	4.88	4.86	4.83	4.84
	Belgian Blue	4.84	4.82	4.93	4.89	4.94
	LSD with Pied	0.15	0.16	0.30	0.19	0.34
	LSD w/o Pied	0.10	0.11	0.15	0.15	0.18

[a]End points represent the overall mean for that trait in this experiment.
[b]b1 = regression coefficient for weaning age, b2 = regression coefficient for days on feed.
[c]Piedmontese (Pied)-sired steers were only produced 1 yr; thus, the error variance associated with their data is inflated and comparisons of their means should be made with the LSD with Pied. The number of Hereford-sired and Angus-sired steers was less than for the other sire breeds (except Piedmontese); thus, their error variances are slightly inflated and dam breed effects are biased between Hereford- or Angus-sired steers and other steers. Thus, data from Hereford- or Angus-sired steers should be compared only to each other. Data from all Hereford- and Angus-sired progeny were pooled and used to compare Hereford and Angus crosses to other sire breeds (using the LSD w/o Pied), rather than comparing Hereford crosses and Angus crosses to other sire breeds separately, due to differences in dam breeds. However, these separate comparisons can be made by taking one-half of the difference between the Angus mean and the Hereford mean and adding or subtracting it from the Hx, Ax mean as appropriate (depending on which one is greater).
[d]LSD = least significant difference among means ($P < 0.05$).
[e]1 = extremely tough, 4 = slightly tough, 5 = slightly tender, 8 = extremely tender.
[f]1 = extremely dry, 4 = slightly dry, 5 = slightly juicy, 8 = extremely juicy.
[g]1 = extremely bland, 4 = slightly bland, 5 = slightly intense, 8 = extremely intense.
*Means for Hereford and Angus sire breeds are different from each other ($P < 0.05$).

Table 6. Variation among sire breeds for carcass and palatability traits at 444 d of age

Trait	R[a]	$h^2 \pm SE$[b]	σ_g[c]	$2R/\sigma_g$	σ_p[d]	R/σ_p
Live weight, kg	80	0.37 ± 0.12	26.14	6.12	42.95	1.86
Hot carcass weight, kg	44	0.33 ± 0.12	15.83	5.56	27.38	1.61
Dressing percentage	2.00	NE[e]	NE[e]	NE[e]	NE[e]	NE[e]
Adjusted fat thickness, cm	0.69	0.84 ± 0.14	0.35	3.94	0.38	1.82
Longissimus area, cm^2	13.0	0.69 ± 0.14	5.46	4.76	6.55	1.98
Kidney, pelvic, and heart fat, %	0.47	0.28 ± 0.12	0.28	3.36	0.53	0.89
Yield grade	1.34	0.85 ± 0.14	0.55	4.87	0.59	2.27
Marbling	89.3	0.57 ± 0.13	41.89	4.26	55.49	1.61
Raw longissimus lipid, %	1.6	0.55 ± 0.14	0.74	4.32	1.00	1.60
Cooked longissimus lipid, %	2.6	0.51 ± 0.14	1.06	4.91	1.48	1.76
14-d Shear force, kg	1.87	0.24 ± 0.12	0.58	6.45	1.20	1.56
7-d Shear force, kg	2.17	0.29 ± 0.12	0.86	5.05	1.60	1.36
Tenderness	0.75	0.22 ± 0.12	0.47	3.19	0.99	0.76
Juiciness	0.65	0.09 ± 0.11	0.13	10.00	0.43	1.51
Beef flavor intensity	0.13	0.07 ± 0.11	0.09	2.89	0.33	0.39

[a]R = Range in sire breed means.
[b]h^2 = Heritability.
[c]σ_g = Genetic standard deviation.
[d]σ_p = Phenotypic standard deviation.
[e]Not estimatable.

(1998) found that F_1 crosses of Tuli and Brahman had heat tolerance similar to that of purebred Brahman. Thus, Tuli may provide alternative heat-tolerant germplasm without detrimental effects on meat tenderness.

In agreement with our findings, Tatum et al. (1990) reported that steers sired by Piedmontese bulls produced more tender longissimus than steers sired by Gelbvieh bulls but longissimus tenderness similar to that from steers sired by Red Angus bulls, when adjusted to either constant age or constant marbling score. Wheeler et al. (1996) also reported similar longissimus tenderness between Piedmontese cross and Hereford/Angus cross steers using the same sources of germplasm as the present study. Although the present study found longissimus from carcasses of Belgian Blue-sired steers was slightly less tender than longissimus from carcasses of Hereford/Angus-sired steers, Arthur (1995) reported in a review that most reports on double-muscled cattle indicate they had more tender meat. However, there is some question whether heterozygotes for double muscling have been correctly identified in some of the existing literature (Arthur, 1995).

Heritabilities and Correlation Coefficients

The range of differences among sire breed means (**R**) from topcross (purebred sires mated to dams of another breed) progeny estimates half of the breed differences (Table 6). Thus, R was doubled to estimate purebred genetic variation relative to within-sire-breed genetic (σ_g) and phenotypic (σ_p) variation. However, phenotypic variation was expressed without doubling R, thus representing F_1 progeny phenotypic variation. Heritability estimates for various carcass and palatability traits ranged from very low (h^2 = 0.07; beef flavor intensity rating) to very high (h^2 = 0.85 and 0.84 for yield grade and adjusted fat thickness, respectively). Heritabilities of carcass traits were moderate to high and were higher than or similar to those reported by Wheeler et al. (1996) and Koch et al. (1982a). Heritabilities of marbling and measures of longissimus chemical lipid were moderately high and similar to one another. Tenderness, as measured by Warner-Bratzler shear force and trained sensory tenderness rating, had relatively low heritability estimates. These values are consistent with the average of heritabilities reported in the literature (reviewed by Koch et al., 1982a); however, some estimates of the heritability of tenderness (or shear force) have been higher (h^2 = 0.53, Shackelford et al., 1994; h^2 = 0.50, Wheeler et al., 1996) and others lower (h^2 = 0.12, Gregory et al., 1994).

Heritability estimates for juiciness and beef flavor intensity ratings were very low and lower than reported by Wheeler et al. (1996). In a review of results from Cycles I, II, and III of GPE, Cundiff et al. (1986) reported estimates of $2R/\sigma_g$ for a series of traits including fat thickness, kidney, pelvic, and heart fat percentage, marbling, and carcass weight. Values for $2R/\sigma_g$ from the present experiment were lower for weight traits, higher for marbling and lipid traits, and about the same for all other traits compared to values reported by Wheeler et al. (1996). Values for $2R/\sigma_g$ from the present experiment were similar for carcass weight and marbling but lower for fat thickness and percentage kidney, pelvic, and heart fat. Shear force and weight traits had a similar amount of genetic variation among and within breeds, but other traits generally had less genetic variation among breeds than within breeds. Phenotypic variation in carcass and palatability traits was similar to that reported by Wheeler et al. (1996).

As was observed in Cycles I to IV of GPE, little inherent genetic variation in juiciness and beef flavor intensity was detected in Cycle V. Phenotypic variation (Figure 1) in tenderness rating was over twice that of varia-

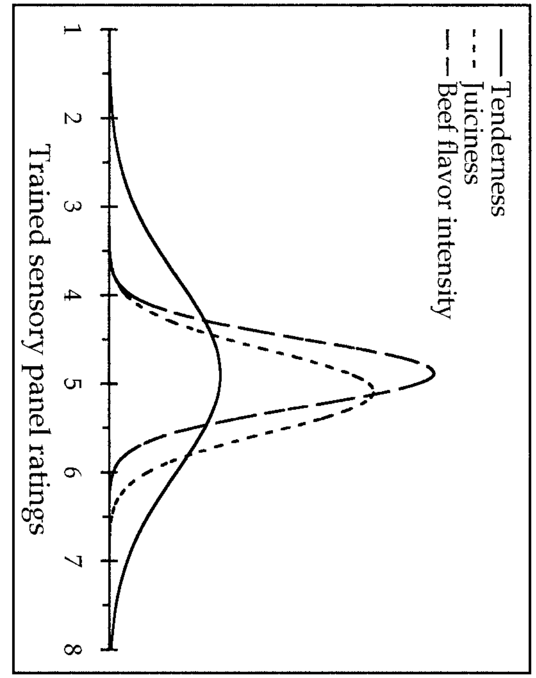

Figure 1. Phenotypic variation in longissimus sensory traits after 7 d of postmortem aging. Means ± SD for tenderness, juiciness, and beef flavor intensity ratings were 4.9 ± 1.10, 5.1 ± 0.47, and 4.9 ± 0.38, respectively.

tion in ratings of juiciness and beef flavor intensity (CV 22.6, 9.1, and 7.8%, respectively). This occurred despite a wide range in marbling scores. Thus, when variation in juiciness and beef flavor intensity occurs at the consumer level, it may be mostly induced by cooking practices and the level and kind of added flavor enhancers (e.g., spices or marinades).

The genetic correlation between fat thickness and marbling was moderate, suggesting that it would be difficult, but not impossible, to decrease s.c. fat thickness without lowering marbling level (Table 7). Juiciness rating had high genetic correlations to marbling and longissimus lipid traits. Shear force had moderate to low genetic correlations to carcass and longissimus lipid traits and a perfect genetic correlation to tenderness rating. However, tenderness rating was not as strongly related to longissimus area but was more strongly related to weight traits than was shear force. Beef flavor intensity rating had moderate to high genetic correlations to weight, fatness, and sensory traits.

Generally, phenotypic correlations were not as high as genetic correlations (Table 7). Moderate to low phenotypic correlations were detected between hot carcass weight and fat thickness, longissimus area, and yield grade. Phenotypically, marbling was strongly related only to measures of longissimus lipid. Marbling and raw longissimus lipid percentage were both highly related to phenotypic variation in cooked longissimus lipid percentage. Phenotypically, shear force and tenderness rating were strongly correlated only to each other, although measures of tenderness were moderately to lowly related to beef flavor intensity and juiciness ratings.

Table 7. Genetic and phenotypic correlation coefficients among carcass and palatability traits at 444 d of age[a]

	Trait												
Trait	LWT	HCWT	AFT	LA	YG	MARB	RLIPID	CLIPID	14-d WBS	7-d WBS	TEND	JUICY	FLAV
Live weight, LWT		0.91	0.22	0.35	0.33	0.17	0.14	0.21	–0.09	–0.09	0.11	0.06	0.07
Hot carcass weight, HCWT	0.98 ± 0.03		0.28	0.39	0.38	0.20	0.18	0.24	–0.12	–0.13	0.14	0.09	0.08
Adj. fat thickness, AFT	–0.11 ± 0.19	0.06 ± 0.20		–0.11	0.85	0.29	0.36	0.36	–0.11	–0.11	0.15	0.15	0.11
Longissimus area, LA	0.07 ± 0.20	0.11 ± 0.21	–0.42 ± 0.16		–0.46	–0.10	–0.13	–0.12	0.04	0.05	0.00	–0.05	–0.03
USDA yield grade, YG	0.12 ± 0.19	0.23 ± 0.18	0.89 ± 0.03	–0.72 ± 0.19		0.34	0.38	0.42	–0.14	–0.16	0.15	0.16	0.13
Marbling score, MARB	0.28 ± 0.20	0.44 ± 0.20	0.42 ± 0.14	–0.36 ± 0.18	0.60 ± 0.12		0.65	0.71	–0.15	–0.18	0.19	0.24	0.11
Raw lipid, RLIPID[b]	0.17 ± 0.22	0.41 ± 0.22	0.40 ± 0.15	–0.35 ± 0.19	0.57 ± 0.13	0.98 ± 0.07		0.68	–0.20	–0.23	0.24	0.28	0.17
Cooked lipid, CLIPID[b]	0.21 ± 0.22	0.35 ± 0.22	0.25 ± 0.17	–0.31 ± 0.20	0.46 ± 0.15	1.00[c] ± 0.06	0.97 ± 0.07		–0.20	–0.20	0.24	0.29	0.16
14-d Shear force, 14-d WBS	–0.09 ± 0.32	–0.03 ± 0.33	–0.42 ± 0.27	0.17 ± 0.26	–0.41 ± 0.28	–0.30 ± 0.30	–0.17 ± 0.29	–0.14 ± 0.30		0.66	–0.69	–0.32	–0.28
7-d Shear force, 7-d WBS	–0.03 ± 0.29	–0.21 ± 0.31	–0.41 ± 0.25	0.36 ± 0.23	–0.50 ± 0.26	–0.27 ± 0.27	–0.23 ± 0.27	–0.19 ± 0.28	0.88 ± 0.15		–0.74	–0.31	–0.30
Tenderness, TEND	0.45 ± 0.31	0.58 ± 0.32	0.43 ± 0.24	0.05 ± 0.26	0.42 ± 0.24	0.14 ± 0.27	0.16 ± 0.27	0.03 ± 0.29	–1.00[c] ± 0.86	–1.00[c] ± 0.80		0.57	0.25
Juiciness, JUICY	0.75 ± 0.61	0.77 ± 0.62	0.79 ± 0.52	–0.09 ± 0.40	0.78 ± 0.51	0.91 ± 0.54	0.61 ± 0.43	0.94 ± 0.54	–0.59 ± 0.87	–0.88 ± 0.94	0.50 ± 0.43		0.09
Beef flavor intensity, FLAV	0.45 ± 061	0.72 ± 0.74	0.44 ± 0.50	–0.04 ± 0.45	0.54 ± 0.53	0.45 ± 0.54	0.01 ± 0.48	0.05 ± 0.48	–1.00[c] ± 1.00	–1.00[c] ± 1.00	–1.00[c] ± 1.00	–1.00[c] ± 1.00	

[a]Genetic correlation coefficients and their standard errors are below the diagonal; phenotypic correlation coefficients are above the diagonal.

[b]Chemical analysis of the longissimus thoracis.

[c]Estimate exceeded 1.00 and thus, was set at 1.00.

Shear Force Variation

These results and those of previously published cycles of GPE (Koch et al., 1976, 1979, 1982b; Wheeler et al., 1996) indicate that there are a few breeds that on average tend to produce more tender and a few breeds that on average tend to produce less tender longissimus, but a majority of breeds are not different from one another in longissimus tenderness. Perhaps more important than breed averages is to consider the distributions of shear force illustrating the amount of variation in shear force at 14 d postmortem within a sire breed relative to the variation among sire breeds (Figure 2). These curves include the least tender (Brahman) and most tender (Angus) sire breeds from this experiment. Figure 2A indicates the amount of change that could be expected in shear force by selecting purebred Angus instead of purebred Brahman (by doubling the range in sire breed mean difference in shear force from the F_1 progeny) cattle (6.45 genetic standard deviations). Thus, variation among Cycle V breeds was about the same as the within-breed variation (6 genetic standard deviations). To the extent that *Bos indicus* × *Bos taurus* heterosis effects are more favorable than *Bos taurus* × *Bos taurus* heterosis effects for Warner-Bratzler shear force (DeRouen, et al., 1992), estimates from the present study may underestimate pure breed differences for additive direct effects between Brahman and *Bos taurus* breeds, but they are appropriate for drawing inferences to comparisons of crossbreeding systems involving *Bos indicus* × *Bos taurus* crosses vs *Bos taurus* × *Bos taurus* crosses.

For F_1 progeny this same comparison resulted in 2.34 genetic standard deviations between Angus- and Brahman-sired progeny (Figure 2B), although only 1.56 phenotypic standard deviations were realized between Angus- and Brahman-sired progeny (Figure 2C). Thus, the realized improvement in tenderness from selecting one breed over another will be small (at most 1.56 kg; 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.

The average estimate of longissimus tenderness heritability is about 0.30. Thus, within a breed, about 30% of the variation in tenderness is due to genetics (additive gene effects) and about 70% of the variation in longissimus tenderness is explained by nonadditive gene effects and nongenetic effects (Koch et al., 1982a). Among-breed variation in longissimus tenderness is about the same as variation within breeds. Thus, among cattle of all breeds, approximately 46% of the variation in longissimus tenderness is genetic and 54% is nongenetic (Koohmaraie, 1995). Given the large variation in shear force within breeds, it seems that significant genetic change could result from selection both among and within breeds. However, among-breed differences may be more easily exploited than within-breed differences because among-breed differences are more highly heritable and more easily identified and less time is required to determine them. In addition, the great impact on meat tenderness of nongenetic factors including postmortem variables must be considered and standardized as much as possible in assessing and selecting for meat tenderness (Koohmaraie, 1995).

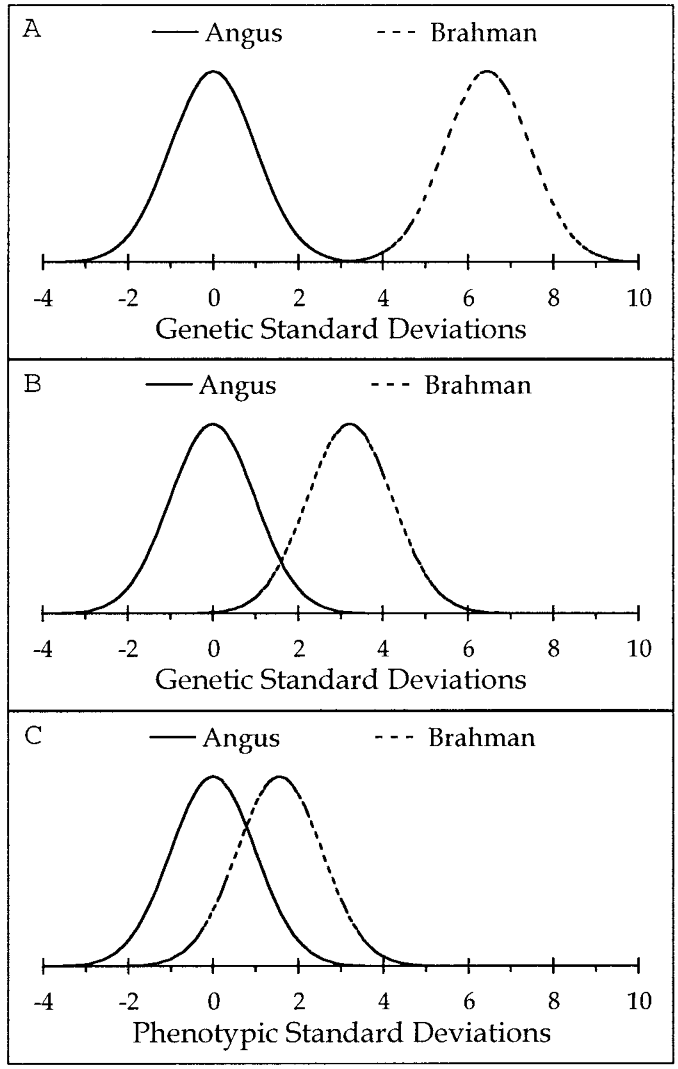

Figure 2. Genetic and phenotypic variation among and within sire breeds for Warner-Bratzler shear force at 14 d postmortem. Curves are for Angus (lowest mean shear force) and Brahman (highest mean shear force). Angus was set to zero. Differences are expressed in standard deviation units as deviations 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.

Implications

Large differences in carcass and meat palatability traits exist among and within cattle sire breeds. Selection of sire breed and end point of production are critical in order for producers to successfully target carcass and longissimus characteristics. No single sire breed excels in all economically important traits; however, of the sire breeds evaluated for production of terminal F_1 crosses out of Angus, Hereford, and MARC III cows, Belgian Blue and Piedmontese provided the most desirable combination of yield grade and longissimus palatability, but Hereford/Angus provided the most desirable combination of quality grade and longissimus palatability. Tuli seems to provide alternative heat tolerant germplasm without a detrimental effect on meat tenderness.

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