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

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ABSTRACT: The objective of this experiment was to provide a current evaluation of the seven most prominent beef breeds in the United States and to determine the relative changes that have occurred in these breeds since they were evaluated with samples of sires born 25 to 30 yr earlier. Carcass (n = 649), yield (n = 569), and longissimus thoracis palatability (n = 569) traits from F_1 steers obtained from mating Hereford, Angus, and MARC III cows to Hereford (H), Angus (A), Red Angus (RA), Charolais (C), Limousin (L), Simmental (S), or Gelbvieh (G) sires were compared. Data were adjusted to constant age (445 d), carcass weight (363 kg), fat thickness (1.1 cm), fat trim percent (25%), and marbling ($Small^{35}$) endpoints. For Warner-Bratzler shear force and trained sensory panel traits, data were obtained on LM from steaks stored at 2°C for 14 d postmortem. The following comparisons were from the age-constant endpoint. Carcasses from L-, G-, and H-sired steers (361, 363, and 364 kg, respectively) were lighter ($P < 0.05$) than carcasses from steers from all other sire breeds. Adjusted fat thickness for carcasses from A-, RA-, and H-sired steers (1.5, 1.4, and 1.3 cm, respectively) was higher ($P < 0.05$) than for carcasses from steers from all other sire breeds (0.9 cm). Longissimus muscle areas were largest ($P < 0.05$) for carcasses from L-, C-, S-, and G-sired steers (89.9, 88.7, 87.6, and 86.5 cm^2, respectively) and smallest for carcasses from H- and RA-sired steers (79.5 and 78.4 cm^2). A greater ($P < 0.05$) percentage of carcasses from RA- and A-sired steers graded USDA Choice (90 and 88%, respectively) than from carcasses from other sire breeds (57 to 66%). Carcass yield of boneless, totally trimmed retail product was least ($P < 0.05$) for RA- and A-sired steers (59.1 and 59.2%, respectively) and greatest ($P < 0.05$) for G-, L-, C-, and S-sired steers (63.0 to 63.8%). Longissimus muscle from carcasses of A-sired steers (4.0 kg) had lower ($P < 0.05$) Warner-Bratzler shear force values than LM from carcasses of G- and C-sired steers (4.5 to 4.3 kg, respectively). Trained sensory panel tenderness and beef flavor intensity ratings for LM did not differ ($P < 0.05$) among the sire breeds. Continental European breeds (C, L, S, and G) were still leaner, more heavily muscled, and had higher-yielding carcasses than did British breeds (H, A, and RA), with less marbling than A or RA, although British breeds have caught up in growth rate.

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

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Introduction

The first six cycles of the Germplasm Evaluation (**GPE**) program at the Roman L. Hruska U.S. Meat Animal Research Center (**MARC**) characterized 33 breeds representing several biological types of cattle. 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). 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 article reports on Cycle VII of the GPE program, which characterizes cattle breeds representing diverse biological types for carcass and LM palatability

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[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

		Dam breed and number of steer progeny			
Sire breed	No. of sires	Hereford	Angus	MARC III[a]	Total
Hereford	21	20	33	44	97
Angus	22	14	33	51	98
Red Angus	21	15	31	47	93
Limousin	20	16	36	40	92
Charolais	22	12	31	47	90
Simmental	20	16	29	39	84
Gelbvieh	23	9	30	56	95
Total	149	102	223	324	649

[a]Composite consisting of ¼ each Hereford, Angus, Pinzgauer, and Red Poll.

traits that affect the quantity, quality, and value of production. This experiment includes the seven breeds with the most herd book registrations in the United States (NPLC, 2004), all of which, except Red Angus, have been evaluated in earlier cycles of the GPE program. Thus, the objective of Cycle VII was to provide a current evaluation of these prominent breeds and to determine the relative changes that have occurred in these breeds since they were evaluated with samples of sires born 25 to 30 yr earlier.

Materials and Methods

Animals

The seven most common breeds in the United States were evaluated in this experiment. Breed registrations for 2003 (NPLC, 2004) were as follows: 1) Angus (281,965); 2) Hereford (69,316); 3) Charolais (55,034); 4) Limousin (49,600 including Canadian); 5) Simmental (45,000); 6) Red Angus (42,178); and 7) Gelbvieh (31,664). Hereford, Angus, and MARC III (¼ Angus, ¼ Hereford, ¼ Pinzgauer, and ¼ Red Poll) dams were mated by AI to 22 Angus, 21 Hereford (12 polled and nine horned), 21 Red Angus, 22 Charolais, 20 Limousin, 20 Simmental, and 23 Gelbvieh bulls to produce 649 steer calves (Table 1). Matings were made to produce straightbreds and reciprocal crosses of Hereford and Angus to provide estimates of heterosis to permit adjustment of Hereford, Angus, and Red Angus data for differences in heterosis between F_1 crosses sired by Continental European and British sire breeds. All sire breeds except Red Angus had been included in either Cycles I or II of the GPE project (progeny born 1970 to 1974). In contrast to previous cycles, when only young unproven sires were sampled, approximately half of the sires sampled from each breed were among the top 50 in progeny registrations in their respective herd books, and approximately half were young, unproven sires of each breed. The young bulls unproven by progeny test were considered to be excellent herd sire prospects. In cooperation with seedstock breeders and commercial AI organizations, young sires (2 to 3 yr of age) identified as herd sire prospects, based on EPD for growth, were selected to represent the seven breeds.

Calves were born in March through mid-April of 1999 and 2000. Male calves were castrated within 24 h of birth. Calves were creep fed whole oats from mid-July or early August until weaning in mid-October at an average age of 202 d. For 26 d following weaning, a diet containing approximately 2.55 Mcal of ME/kg and 14.25% CP was fed (DM basis). Following this postweaning adjustment period, steers were assigned to replicated pens within sire breed, and fed separately by sire breed for an average of 243 d (range from 216 to 270 d). Steers were switched to a diet containing 2.62 Mcal of ME/kg of DM and 12.74% CP until early December (DM basis). Then, steers were switched to a growing diet (2.73 Mcal of ME/kg of DM and 11.8% CP) containing 66% corn silage, 22% corn, and 12% supplement (DM basis) that was fed until steers weighed approximately 320 kg. A finishing diet (3.05 Mcal of ME/kg of DM and 13.1% CP) containing 25% corn silage, 70% corn, and 5% supplement (DM basis) 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 mid-December and again in mid-March of each year.

Representative samples of the steers born in 1999 were slaughtered serially in five groups spanning 43 d (May 15, June 11, June 12, June 25, and June 27, 2000). Representative samples of steers born in 2000 were slaughtered serially in four groups spanning 53 d (May 7, May 21, June 11, and June 25, 2001). Final unshrunk live weights were obtained 1 wk before slaughter. The steers were slaughtered in a commercial beef processing facility. After a 36-h chill at 0°C, USDA yield and quality grade data (USDA, 1997) were obtained by trained MARC personnel.

Samples

Samples for rib dissection and palatability analyses were not obtained from animals slaughtered on June 12, 2000. For all other harvest dates, the wholesale rib (No. 103; NAMP, 1997) from the right side of each carcass was returned to the meat laboratory at MARC. At 3 d postmortem, the wholesale rib was dissected into the ribeye roll (NAMP No. 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. Ribeye rolls were frozen at 14 d postmortem at –30°C, and steaks were cut on a band saw. 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, and then vacuum-packaged and stored at –30°C for later chemical analysis of the raw LM. Then, four 2.54-cm-thick LM steaks were cut from the posterior end of the ribeye roll. The first steak was not used in this experiment, whereas the second and third steaks 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 were stored frozen at –30°C for 3 to 5 mo before thawing for evaluation.

Warner-Bratzler Shear Force

Frozen steaks were thawed at 5°C for 24 h and then cooked on a conveyorized 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

Immediately after cooking as described previously, the LM was cut into 1 cm × 1 cm × steak thickness cubes. Three cubes were served warm to each panel member. An eight-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 eight-point scale (8 = extremely tender, juicy, or intense to 1 = extremely tough, dry, or bland). A warm-up sample was served first, after which four experimental steaks were served in each of two sessions per day (5 min between sessions) and three evaluation days each week. In addition, a duplicate sample to one of the experimental samples was served daily for monitoring panelist and panel performance.

Chemical Composition Analyses

Raw and cooked LM chemical 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 = 202 d) and days fed postweaning (mean = 243 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 (445 d), carcass weight (363 kg), fat thickness (1.1 cm), fat trim percent (25%; for cuts trimmed to 0 cm of fat cover), or marbling (Small^{35}), following procedures used in previous cycles of GPE (Koch et al., 1979, 1982b; Wheeler et al., 1996, 2001, 2004).

Consistent with previous reports (Koch et al., 1979, 1982b; Wheeler et al., 1996, 2001, 2004), 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 and year were sources of variation ($P < 0.05$) for most traits (Table 2). Dam breed was a source of variation ($P < 0.05$) for some traits, whereas a sire breed × dam breed interaction was a source of variation ($P < 0.05$) for HCW and adjusted fat thickness. A dam breed × dam age interaction was a source of variation ($P < 0.05$) for live and carcass weight. Linear regression of weaning age was significant ($P < 0.05$) for most carcass and yield traits, but not palatability traits. Linear regression of days fed was significant ($P < 0.05$) for most traits.

Carcass Traits

Sire breeds differed ($P < 0.05$) slightly in growth rate. Final live and carcass weights at a constant age of 445 d were greater ($P < 0.05$) for Angus- and Simmental-sired steers than for Limousin- and Gelbvieh-sired steers (Table 3). At all three fatness endpoints, steers and carcasses from British sire breeds were lighter ($P < 0.05$) than steers and carcasses from Continental European sire breeds. Sire breed differences for live weight and carcass weight were similar. Hereford-, Limousin-, and Gelbvieh-sired steers were the lightest at constant age and, thus, were the slowest growing sire breeds. Angus-, Red Angus-, and Hereford-sired steers were the earliest maturing, as they required the fewest days on feed to reach the 25% fat trim endpoint. These results highlight the primary changes among these breeds since they were evaluated in GPE Cycles I and II in

Table 2. Analysis of variance

		Mean squares					
Source	df^a	Live weight, kg	HCW, kg	Dressing percent	Adjusted fat thickness, cm	LM area, cm^2	Marbling score
Sire breed (SB)	6	11,866*	4,352*	13.0*	4.2*	1,536*	89,358*
Sire within SB	139	2,644*	931*	2.6*	0.3*	89*	6,322*
Dam breed (DB)	2	2,174	1,587	6.7*	1.6*	53	31,085*
Dam age (DA)	3	9,817*	3,490*	0.3	0.6*	37	1,818
Year (Y)	1	15,492*	11,665*	29.5*	1.2*	10	5,306
SB × DB	12	2,147	1,079*	2.5	0.3*	64	3,104
b1 (weaning age)	1	33,913*	17,047*	11.0*	1.7*	350*	37,232*
b2 (days fed)	1	180,311*	108,157*	132.7*	9.9*	45	125,714*
Residual	483	1,584	601	1.7	0.1	48	3,634

			Mean squares					
	USDA Choice, %	Yield grade	Boneless retail product yield, %	df^b	Warner-Bratzler shear force, kg	Tenderness rating	Juiciness rating	Beef flavor intensity rating
Sire breed (SB)	2.39*	13.3*	275.5*	6	1.7*	1.4	0.32*	0.11
Sire within SB	0.22*	0.8*	11.9*	139	0.7	0.7*	0.11*	0.10*
Dam breed (DB)	0.43	3.1*	22.1	2	4.7*	1.3	0.08	0.13
Dam age (DA)	0.08	1.6*	8.6	3	0.1	1.6*	0.02	0.08
Year (Y)	0.16	5.2*	47.4*	1	1.7	0.8	0.88*	3.16*
SB × DB	0.27	0.5	8.3	12	0.8	0.6	0.5	0.04
b1 (weaning age)	0.47	2.1*	72.8*	1	0.4	0.1	0.06	0.27
b2 (days fed)	0.77*	38.0*	615.9*	1	6.0*	2.5*	0.09	0.02
Residual	0.16	0.3	7.5	403	0.6	0.5	0.8	0.08

*$P < 0.05$.
^{a}Degrees of freedom for carcass traits.
^{b}Degrees of freedom for palatability traits.

the early 1970s. At that time, the Continental European breeds were faster-growing than British breeds and had age-constant HCW 10 to 20 kg greater than Hereford × Angus crosses (Koch et al., 1976, 1979). In the last 30 yr, EPD genetic trends reported by the seven breeds indicate that selection pressure for growth rate has been emphasized more in the British breeds than in the Continental European breeds. In addition, there may have been some exchange of germplasm between British and Continental European breeds when it could be accomplished without major disruption to breed characteristics, such as specific color patterns and polledness. The result has been a 27% increase in HCW for Hereford × Angus cross steers in the last 30 yr. This change has been documented throughout this time period in the results of various experiments at the Meat Animal Research Center (Gregory et al., 1994b; Wheeler et al., 1996, 2001). The 19, 22, 20, and 23% increase in HCW for Charolais-, Limousin-, Gelbvieh-, and Simmental-sired steers, respectively, in the last 30 yr is slightly less than that for Hereford and Angus. Thus, the difference in age-constant carcass weight between British and Continental European breeds has been eliminated.

Dressing percent was higher ($P < 0.05$) at 445 d of age for carcasses from Limousin-sired steers than for carcasses from all other sire breeds except Charolais, and was higher ($P < 0.05$) at the other endpoints than for carcasses from most other sire breeds (Table 3). The carcasses from British sire breeds tended to have lower dressing percents than Continental European sire breeds at fat thickness and fat trim percent endpoints.

At constant age or weight, adjusted fat thickness was higher ($P < 0.05$) for carcasses from British sire breeds than for Continental European sire breeds (Table 3). At constant marbling, carcasses from Hereford-sired steers had the highest ($P < 0.05$) adjusted fat thickness except for Limousin-sired steers. At constant fat trim percent, there were no sire breed differences ($P > 0.05$) in adjusted fat thickness.

At all endpoints except constant carcass weight, Continental European sire breeds had larger ($P < 0.05$) LM areas than British sire breeds (Table 3). At constant weight, LM areas were similar for carcasses from Angus- and Gelbvieh-sired steers. Carcasses from Red Angus-sired steers had smaller ($P < 0.05$) LM areas than carcasses from Angus-sired steers at all endpoints. Carcasses from Angus-sired steers had larger ($P < 0.05$) LM areas than those from Hereford-sired steers only at constant age.

At constant age, carcasses from Hereford-sired steers had lower ($P < 0.05$) percentages of KPH fat than carcasses from all other sire breeds except Charolais and Limousin (Table 3). At constant age, carcasses from Simmental- and Angus-sired steers had higher ($P < 0.05$) percentages of KPH fat than all other sire breeds except Red Angus and Gelbvieh. At constant weight, the percentage of KPH fat was lower ($P < 0.05$) in carcasses from Hereford-sired steers than in carcasses from steers of all sire breeds except Charolais and Li-

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

		Endpoint				
Trait, μ ± SEM, b1, b2[b]	Sire breed, LSD[c]	Age (445 d)	Carcass wt (363 kg)	Fat thickness (1.1 cm)	Marbling (Small^{35})	Fat trim (25%)
Days on feed	Hereford	—	242	221	254	223
μ = 243	Angus	—	225	206	196	202
SD = 18	Red Angus	—	237	214	190	204
	Limousin	—	246	266	279	263
	Simmental	—	228	266	252	262
	Gelbvieh	—	243	273	276	276
	Charolais	—	229	277	264	272
Live wt, kg	Hereford	600	—	574	612	577
μ = 600 ± 3.0	Angus	619	—	577	566	572
b1 = 1.2417 ± 0.268	Red Angus	605	—	572	545	561
b2 = 1.1249 ± 0.105	Limousin	583	—	610	624	606
	Simmental	618	—	644	628	640
	Gelbvieh	595	—	629	633	633
	Charolais	611	—	650	636	645
	LSD	18	—	21	22	21
HCW, kg	Hereford	364	—	345	374	347
μ = 366 ± 1.8	Angus	379	—	347	338	343
b1 = 0.8415 ± 0.166	Red Angus	368	—	343	322	334
b2 = 0.8745 ± 0.065	Limousin	361	—	381	392	378
	Simmental	376	—	396	384	393
	Gelbvieh	363	—	389	392	392
	Charolais	375	—	405	393	400
	LSD	11	—	12	13	13
Dressing percent	Hereford	60.5	60.7	60.0	61.0	60.1
μ = 61.0 ± 0.08	Angus	61.1	60.7	60.1	59.8	60.0
b1 = 0.0222 ± 0.0087	Red Angus	60.7	60.6	59.9	59.2	59.6
b2 = 0.0303 ± 0.0034	Limousin	61.8	61.9	62.5	62.9	62.4
	Simmental	60.8	60.4	61.5	61.1	61.4
	Gelbvieh	61.0	61.0	61.9	62.0	62.0
	Charolais	61.3	60.9	62.3	61.9	62.2
	LSD	0.6	0.6	0.7	0.7	0.7
Adj. fat thickness, cm	Hereford	1.26	1.31	—	1.41	1.15
μ = 1.10 ± 0.029	Angus	1.46	1.37	—	1.13	1.18
b1 = 0.0088 ± 0.0026	Red Angus	1.35	1.35	—	0.97	1.08
b2 = 0.0083 ± 0.0010	Limousin	0.94	0.96	—	1.23	1.10
	Simmental	0.94	0.81	—	1.01	1.09
	Gelbvieh	0.90	0.90	—	1.17	1.17
	Charolais	0.87	0.76	—	1.05	1.11
	LSD	0.20	0.20	—	0.24	0.24
LM area, cm^2	Hereford	79.5	80.1	79.8	80.3	79.8
μ = 84.8 ± 0.5	Angus	82.9	83.2	82.9	82.7	82.8
b1 = 0.1251 ± 0.0462	Red Angus	78.4	78.9	78.5	78.0	78.3
b2 = 0.0177 ± 0.0182	Limousin	89.9	90.0	90.3	90.6	90.3
	Simmental	87.6	87.3	88.0	87.7	87.9
	Gelbvieh	86.5	86.5	87.1	87.1	87.1
	Charolais	88.7	88.4	89.3	89.0	89.2
	LSD	3.3	3.4	3.9	4.1	3.9
KPH fat, %[d]	Hereford	2.03	2.11	1.94	2.21	1.95
μ = 2.29 ± 0.03	Angus	2.45	2.39	2.23	2.15	2.20
b1 = 0.0012 ± 0.0036	Red Angus	2.36	2.39	2.21	2.01	2.12
b2 = 0.0082 ± 0.0014	Limousin	2.21	2.24	2.40	2.51	2.38
	Simmental	2.46	2.34	2.65	2.53	2.61
	Gelbvieh	2.37	2.37	2.61	2.64	2.64
	Charolais	2.19	2.07	2.46	2.36	2.42
	LSD	0.21	0.21	0.25	0.26	0.19

(Continued)

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

		Endpoint				
Trait, $\mu \pm$ SEM, b1, b2[b]	Sire breed, LSD[c]	Age (445 d)	Carcass wt (363 kg)	Fat thickness (1.1 cm)	Marbling (Small^{35})	Fat trim (25%)
Yield grade	Hereford	3.2	3.3	2.9	3.5	3.0
$\mu = 2.91 \pm 0.05$	Angus	3.4	3.2	2.9	2.8	2.9
$b1 = 0.0098 \pm 0.0039$	Red Angus	3.4	3.4	3.1	2.7	2.9
$b2 = 0.0162 \pm 0.0015$	Limousin	2.4	2.5	2.8	3.0	2.8
	Simmental	2.7	2.5	3.1	2.9	3.0
	Gelbvieh	2.6	2.6	3.1	3.1	3.1
	Charolais	2.5	2.3	3.1	2.9	3.0
	LSD	0.3	0.3	0.4	0.4	0.3
Yield grade ≥ 4.0, %	Hereford	17	19	11	23	13
$\mu = 11.3 \pm 1.6$	Angus	21	17	11	9	11
$b1 = 0.0037 \pm 0.0019$	Red Angus	21	21	15	7	11
$b2 = 0.0031 \pm 0.0008$	Limousin	1	3	9	13	9
	Simmental	7	3	15	11	13
	Gelbvieh	5	5	15	15	15
	Charolais	3	0	15	11	13
	LSD	6	6	8	8	6
Marbling[e]	Hereford	526	524	505	—	507
$\mu = 536.2 \pm 4.1$	Angus	584	566	548	—	545
$b1 = 1.291 \pm 0.403$	Red Angus	590	583	562	—	553
$b2 = 0.933 \pm 0.159$	Limousin	504	507	525	—	523
	Simmental	527	513	549	—	545
	Gelbvieh	506	506	534	—	537
	Charolais	517	503	548	—	544
	LSD	28	29	33	—	33
USDA Choice, %[f]	Hereford	65	65	57	—	58
$\mu = 69.8 \pm 0.02$	Angus	88	81	74	—	73
$b1 = 0.00457 \pm 0.003$	Red Angus	90	87	79	—	76
$b2 = 0.00230 \pm 0.001$	Limousin	57	58	65	—	64
	Simmental	66	60	74	—	73
	Gelbvieh	58	58	68	—	70
	Charolais	62	57	74	—	72
	LSD	11	11	13	—	13

[a] Endpoints 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] Least significant difference, $P < 0.05$.
[d] Estimated percentage of HCW as kidney, pelvic, and heart fat.
[e] 400 = Slight^{00}, and 500 = Small^{00}; USDA (1997).
[f] Percentage of carcasses grading USDA Choice or higher.

mousin. Carcasses from Hereford-sired steers had the lowest ($P < 0.05$) percentage of KPH fat at constant fat thickness. At constant marbling or fat trim, carcasses from Continental European sire breeds tended to have higher percentages of KPH than carcasses from British sire breeds.

Numerical USDA yield grade was not different ($P > 0.05$) among sire breeds at constant fat thickness or fat trim endpoints. Yield grade was higher ($P < 0.05$) for carcasses from British sire breeds at constant age and weight endpoints. At constant marbling, carcasses from Hereford-sired steers had similar ($P > 0.05$) yield grades as those from Gelbvieh-sired steers, but higher ($P < 0.05$) yield grades than carcasses from all other sire breeds. Sire breed differences in percentage of carcasses with yield grade of 4.0, or greater, at different endpoints were the same as for yield grade.

At constant age and weight, marbling score was higher ($P < 0.05$) in carcasses from Red Angus- and Angus-sired steers than for all other sire breeds (Table 3). At constant fat thickness, carcasses from Red Angus-sired steers had higher ($P < 0.05$) marbling scores than carcasses from Hereford- or Limousin-sired steers. At constant fat trim, carcasses from Hereford-sired steers tended to have the lowest marbling scores. Sire breed differences for the percentage of carcasses grading USDA Choice at each endpoint were the same as those for marbling differences. Only two carcasses in the experiment graded USDA Standard.

In GPE Cycles I and II, Koch et al. (1976, 1979) reported that carcasses from F_1 steers of Limousin, Charolais, Simmental, and Gelbvieh sire breeds had larger LM areas, less fat thickness, and lower yield and quality grades compared with carcasses from Hereford × Angus

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

		Endpoint				
Trait, $\mu \pm$ SEM, b1, b2[b]	Sire breed, LSD[c]	Age (445 d)	Carcass wt (363 kg)	Fat thickness (1.1 cm)	Marbling (Small^{35})	Fat trim (25%)
Retail product yield, %[d]	Hereford	60.7	60.5	61.9	59.7	61.8
$\mu = 61.9 \pm 0.18$	Angus	59.2	60.2	61.4	62.1	61.7
$b1 = -0.0631 \pm 0.0020$	Red Angus	59.1	59.2	60.8	62.4	61.5
$b2 = -0.0673 \pm 0.0074$	Limousin	63.7	63.5	62.2	61.3	62.4
	Simmental	63.0	64.0	61.4	62.4	61.7
	Gelbvieh	63.8	63.8	61.8	61.6	61.6
	Charolais	63.5	64.5	61.2	62.1	61.6
	LSD	1.3	1.3	1.5	1.6	1.5
Fat yield, %[d]	Hereford	26.0	26.3	24.8	27.2	—
$\mu = 24.9 \pm 0.23$	Angus	27.7	26.9	25.5	24.8	—
$b1 = 0.0686 \pm 0.0236$	Red Angus	27.6	27.6	25.9	24.2	—
$b2 = 0.0718 \pm 0.0087$	Limousin	23.5	23.7	25.1	26.1	—
	Simmental	23.6	22.5	25.2	24.2	—
	Gelbvieh	22.7	22.7	24.8	25.1	—
	Charolais	22.9	21.9	25.4	24.5	—
	LSD	1.5	1.6	1.8	1.9	—
Bone yield, %[d]	Hereford	14.3	14.2	14.4	14.1	14.4
$\mu = 14.2 \pm 0.06$	Angus	13.7	13.7	13.9	14.0	14.0
$b1 = -0.0162 \pm 0.0064$	Red Angus	13.8	13.7	14.0	14.2	14.1
$b2 = -0.0098 \pm 0.0023$	Limousin	14.1	14.0	13.8	13.7	13.9
	Simmental	14.3	14.5	14.1	14.2	14.1
	Gelbvieh	14.6	14.6	14.3	14.2	14.2
	Charolais	14.5	14.6	14.1	14.2	14.2
	LSD	0.6	0.4	0.5	0.5	0.5
Retail product wt, kg[e]	Hereford	218	217	211	221	212
$\mu = 226 \pm 1.0$	Angus	221	216	210	207	208
$b1 = 0.2741 \pm 0.1205$	Red Angus	215	213	206	198	203
$b2 = 0.3147 \pm 0.0442$	Limousin	229	229	236	240	235
	Simmental	237	232	244	240	243
	Gelbvieh	231	231	241	241	241
	Charolais	237	233	248	244	246
	LSD	7	7	8	9	8
Fat weight, kg[e]	Hereford	97	96	86	102	87
$\mu = 92 \pm 1.1$	Angus	107	98	89	84	87
$b1 = 0.4896 \pm 0.1083$	Red Angus	103	101	90	78	85
$b2 = 0.4747 \pm 0.0397$	Limousin	85	86	96	102	94
	Simmental	89	82	100	94	98
	Gelbvieh	83	83	97	99	99
	Charolais	86	80	103	96	100
	LSD	7	7	8	9	8
Bone weight, kg[e]	Hereford	51	51	49	52	49
$\mu = 52 \pm 0.3$	Angus	51	49	48	47	47
$b1 = 0.0589 \pm .0304$	Red Angus	50	50	47	45	46
$b2 = 0.0899 \pm .0111$	Limousin	50	51	53	54	52
	Simmental	54	53	56	55	56
	Gelbvieh	53	53	55	56	56
	Charolais	54	53	57	56	57
	LSD	2	2	2	2	2

[a] Endpoints 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] Least significant difference, $P < 0.05$.

[d] Predicted from wholesale rib dissection.

[e] Calculated from HCW and predicted yields.

crosses. Gregory et al. (1994b) found even greater differences in these traits among the carcasses of the same breeds when evaluated as purebred cattle. Results of Wheeler et al. (1996) indicated that differences in carcass traits between Charolais, Gelbvieh, Hereford, and Angus breeds were similar to those found in previous GPE cycles and to the current evaluation. Kempster et al. (1982) compared breeds at 16 mo of age after slaughter at a constant fat level, and reported that Hereford steers had heavier carcass weights than Angus steers but lighter than Charolais and Simmental. Others have reported similar differences in carcass traits between Simmental and Hereford, Red Angus, or Angus (Urick et al., 1991; Mandell et al., 1998; Laborde et al., 2001), as did the current evaluation. Differences in carcass traits between Charolais and Angus (Baker and Lunt, 1990) and between Hereford and Limousin (MacNeil et al., 2001) similar to the current evaluation have been reported. A serial slaughter at different fat levels resulted in similar findings (Kempster et al., 1988). Despite the changes in growth rate and size over the last 30 yr, relative differences in carcass traits among Limousin, Charolais, Simmental, Gelbvieh, Hereford, and Angus have not changed significantly.

Carcass Yield

At a constant age of 445 d, carcasses from Continental European sire breeds had the highest ($P < 0.05$), carcasses from Hereford-sired steers intermediate ($P < 0.05$), and carcasses from Angus- and Red Angus-sired steers had the lowest ($P < 0.05$) percentage of retail product yield (Table 4). At constant weight, carcasses from steers from Continental European sire breeds had the highest ($P < 0.05$), and carcasses from steers from British sire breeds had the lowest ($P < 0.05$) percentage of retail product yield. At constant fat thickness and fat trim, sire breed did not affect ($P > 0.05$) percentage of retail product yield. At constant marbling, carcasses from Hereford-sired steers had lower ($P < 0.05$) percentages of retail product yield than did carcasses from all sire breeds except Limousin. Differences among sire breeds in fat yield were similar to differences in retail product yield for all endpoints.

At constant age or weight, carcasses from Angus- and Red Angus-sired steers had lower ($P < 0.05$) percentages of bone than carcasses from Gelbvieh- and Charolais-sired steers (Table 4). At constant fat thickness, carcasses from Limousin-sired steers had a lower ($P < 0.05$) percentage of bone than carcasses from Hereford-sired steers. Sire breed did not affect ($P > 0.05$) percentage of bone at marbling or fat trim endpoints.

Carcasses from Continental European sire breeds had heavier weights of retail product for all endpoints than carcasses from British sire breeds. Among Continental European sire breeds, carcasses from Limousin-sired steers had lighter ($P < 0.05$) weights of retail product than carcasses from Charolais-sired steers at age, fat thickness, and fat trim endpoints. Among British sire breeds, carcasses from Hereford-sired steers had heavier ($P < 0.05$) weights of retail product than carcasses from Red Angus-sired steers at marbling and fat trim endpoints.

At constant age and weight, carcasses from British sire breeds had heavier ($P < 0.05$) fat weights than carcasses from Continental European sire breeds (Table 4). At constant fat thickness, this difference was reversed, so that carcasses from Continental European sire breeds had heavier ($P < 0.05$) fat weights. At constant marbling, carcasses from Red Angus- and Angus-sired steers had the lighter ($P < 0.05$) fat weight than carcasses of all other sire breeds. At constant fat trim, carcasses from Hereford-, Angus-, and Red Angus-sired steers had lighter ($P < 0.05$) fat weights than carcasses from Charolais-, Gelbvieh-, and Simmental-sired steers. Regardless of endpoint, carcasses from Angus- and Red Angus-sired steers tended to have the lightest ($P < 0.05$) bone weights.

As with other fatness and composition related traits, differences in yield of saleable product have not changed significantly between British and Continental European sire breeds over the last 30 yr. Koch et al., (1976, 1979) and Wheeler et al. (1997) have reported that Hereford × Angus crosses have about 4 to 5% lower yield of saleable product than F_1 Limousin, Charolais, Simmental, and Gelbvieh carcasses. Others have found similar differences among these sire breeds in carcass yield of saleable product (Mandell et al., 1998; Laborde et al., 2001). Kempster et al. (1982) compared breeds at 16 mo of age after slaughter at a constant fat level, and reported that carcasses from Hereford steers had a lower saleable meat yield than Angus, Charolais, or Simmental steers. Gregory et al. (1994b) reported differences in the percentage of saleable product of 6 to 10% in purebreds of the same breeds.

Palatability Traits

Differences among sire breeds for LM palatability traits were generally small. At constant age, LM from Gelbvieh-sired steers had higher ($P < 0.05$) 14-d postmortem Warner-Bratzler shear force values than did the LM from carcasses of steers of all three British sire breeds, and the LM from carcasses of Charolais-sired steers had higher ($P < 0.05$) 14-d postmortem Warner-Bratzler shear force values than did LM from carcasses of Angus-sired steers (Table 5). At constant weight, shear force differences were similar to those for constant age, except that LM from Angus-sired steers also had lower ($P < 0.05$) shear force values than LM from Limousin-sired steers. At constant fat thickness and constant fat trim percent, LM from carcasses of British sire breeds had lower ($P < 0.05$) shear force than Continental European sire breeds. At constant marbling, 14-d LM Warner-Bratzler shear force values were lower ($P < 0.05$) for Angus- and Red Angus-sired steers than for the LM from all other sire breeds. The LM from carcasses of steers from Angus dams had slightly lower ($P < 0.05$) shear force (4.03 kg) compared to LM from carcasses from Hereford or MARC III dams (4.37 and 4.35 kg, respectively).

For trained sensory panel traits of LM, the F-test for sire breed in the ANOVA was not significant for tenderness ($P = 0.09$) or beef flavor intensity ($P = 0.39$) ratings, and, therefore, sire breed did not affect these traits (Table 5). However, the same trend for tenderness

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

		Endpoint				
Trait, μ ± SEM, b1, b2[b]	Sire breed, LSD[c]	Age (445 d)	Carcass wt (363 kg)	Fat thickness (1.1 cm)	Marbling (Small^{35})	Fat trim (25%)
Warner-Bratzler shear	Hereford	4.12	4.12	3.98	4.20	3.99
force, kg	Angus	4.02	3.91	3.78	3.72	3.76
μ = 4.25 ± 0.04	Red Angus	4.15	4.12	3.97	3.81	3.90
b1 = –0.0046 ± 0.0056	Limousin	4.31	4.33	4.46	4.55	4.44
b2 = 0.0066 ± 0.0021	Simmental	4.30	4.20	4.45	4.36	4.42
	Gelbvieh	4.51	4.51	4.71	4.73	4.73
	Charolais	4.34	4.25	4.57	4.48	4.53
	LSD	0.31	0.32	0.27	0.38	0.36
Tenderness[d]	Hereford	5.63	5.65	5.74	5.59	5.73
μ = 5.59 ± 0.05	Angus	5.77	5.85	5.94	5.98	5.95
b1 = –0.0024 ± 0.0053	Red Angus	5.68	5.72	5.82	5.92	5.86
b2 = –0.0043 ± 0.0020	Limousin	5.65	5.64	5.55	5.49	5.56
	Simmental	5.63	5.70	5.53	5.59	5.55
	Gelbvieh	5.32	5.32	5.19	5.18	5.18
	Charolais	5.47	5.53	5.32	5.38	5.35
	LSD	0.32	0.33	0.34	0.39	0.37
Juiciness[e]	Hereford	5.32	5.31	5.30	5.32	5.30
μ = 5.29 ± 0.02	Angus	5.39	5.37	5.35	5.34	5.35
b1 = 0.0018 ± 0.0021	Red Angus	5.38	5.37	5.35	5.33	5.34
b2 = 0.0008 ± 0.0008	Limousin	5.27	5.27	5.28	5.29	5.28
	Simmental	5.28	5.26	5.30	5.28	5.29
	Gelbvieh	5.21	5.21	5.24	5.24	5.24
	Charolais	5.21	5.20	5.24	5.23	5.23
	LSD	0.12	0.13	0.16	0.15	0.14
Beef flavor intensity[f]	Hereford	4.91	4.91	4.92	4.91	4.92
μ = 4.89 ± 0.02	Angus	4.93	4.94	4.95	4.95	4.95
b1 = 0.0038 ± 0.0021	Red Angus	4.94	4.95	4.96	4.97	4.96
b2 = –0.0004 ± 0.0008	Limousin	4.88	4.88	4.87	4.87	4.87
	Simmental	4.86	4.87	4.85	4.86	4.85
	Gelbvieh	4.83	4.83	4.82	4.82	4.82
	Charolais	4.87	4.88	4.85	4.86	4.86
	LSD	0.12	0.12	0.14	0.15	0.14

[a] Endpoints 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] Least significant difference, $P < 0.05$.

[d] 1 = extremely tough; 4 = slightly tough; 5 = slightly tender; and 8 = extremely tender.

[e] 1 = extremely dry; 4 = slightly dry; 5 = slightly juicy; and 8 = extremely juicy.

[f] 1 = extremely bland; 4 = slightly bland; 5 = slightly intense; and 8 = extremely intense.

rating differences occurred as was detected for Warner-Bratzler shear force. At constant age and constant weight, the LM of carcasses from Angus- and Red Angus-sired steers received higher ($P < 0.05$) trained sensory panel juiciness ratings than the LM from carcasses of Gelbvieh- and Charolais-sired steers; however, the magnitude of the differences indicated they were of little practical importance. At constant fat thickness, marbling, and fat trim percent, LM juiciness ratings did not ($P > 0.05$) vary among sire breeds.

Consistent with the current evaluation, previous comparisons of these sire breeds have indicated small, but generally nonsignificant, differences in LM tenderness between British and Continental European breeds (Koch et al., 1976, 1979; Wheeler et al., 1996). Others have reported similar results (Mandell et al., 1998; Laborde et al., 2001). Results from purebred steers have shown that the LM from Angus was tenderer than LM from Limousin, Gelbvieh, Simmental, and Charolais (Gregory et al., 1994b). Results from previous cycles of GPE (Koch et al., 1976, 1979, 1982b; Wheeler et al., 1996, 2001, 2004) have indicated similar mean LM tenderness among most breeds. Perhaps more important than breed averages is to consider that after 14 d postmortem, the range in breed mean differences was about equal to the range in breeding value within breed, indicating that among breed variation in LM tenderness is approximately the same as variation within breeds (Wheeler et al., 1996, 2001, 2004).

Longissimus Chemical Composition

Chemical composition of raw and cooked LM adjusted to 445 d of age indicated that the LM from carcasses

Table 6. Effect of sire breed on least squares means for chemical composition of raw and cooked longissimus muscle at 445 d of age[a]

	Raw			Cooked		
Sire breed	Lipid, %	Moisture, %	Protein, %[b]	Lipid, %	Moisture, %	Protein, %[b]
μ ± SEM	5.3 ± 0.09	71.7 ± 0.08	23.0 ± 0.03	5.8 ± 0.10	64.4 ± 0.08	29.8 ± 0.06
Hereford	5.1	71.8	23.1	5.6	64.7	29.7
Angus	6.7	70.8	22.5	7.2	63.5	29.3
Red Angus	6.4	70.8	22.8	7.0	63.6	29.4
Limousin	4.5	72.4	23.1	4.9	65.0	30.1
Simmental	4.8	72.1	23.1	5.5	64.6	29.9
Gelbvieh	4.8	72.2	23.0	5.3	64.7	30.0
Charolais	4.8	72.1	23.1	5.5	64.6	29.9
LSD[c]	0.6	0.6	0.4	0.7	0.5	0.4

[a] Wet-weight basis.
[b] Calculated by difference.
[c] Least significant difference, $P < 0.05$.

from Angus- and Red Angus-sired steers had higher ($P < 0.05$) percentages of lipid and lower ($P < 0.05$) percentages of moisture than the LM from carcasses from all other sire breeds (Table 6). Differences among sire breeds for percentage of protein in the raw and cooked LM were small in magnitude and seemed to be of little practical importance. Differences among sire breeds in percentage of LM lipid were similar to differences in marbling score and were consistent with previous results (Koch et al., 1976; Wheeler et al., 2001).

Heritability Estimates and Correlation Coefficients

The range of differences among sire breed means (**R**) from topcross progeny estimates half of the breed differences (Table 7). Thus, R was doubled to assess purebred genetic variation relative to within sire breed genetic ($\boldsymbol{\sigma_g}$) and phenotypic ($\boldsymbol{\sigma_p}$) variation. However, phenotypic variation was expressed without doubling R, thereby representing F_1 progeny phenotypic variation. Heritability estimates for various carcass, yield, and palatability traits ranged from low ($h^2 = 0.20$ for Warner-Bratzler shear force) to high ($h^2 = 0.88$ for USDA yield grade). Heritability estimates of carcass traits ranged from moderate to high, and were similar to those reported by Wheeler et al. (1996, 2001) and Koch et al. (1982a), but higher for many carcass traits than those reported by others (Arnold et al., 1991; Wulf et al., 1996; Wheeler et al., 2004).

Heritability estimates of marbling and measures of LM chemical lipid were moderate and similar to one another (Table 7). Tenderness, as measured by Warner-Bratzler shear force and trained 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). Some estimates of the heritability of LM

Table 7. Variation among sire breeds for carcass and palatability traits at 445 d of age

Trait	R[a]	h^2 ± SE[b]	σ_g[c]	$2R/\sigma_g$	σ_p[d]	R/σ_p
Live weight, kg	36	0.48 ± 0.15	29.88	2.41	43.01	0.84
HCW, kg	18	0.41 ± 0.15	16.68	2.16	26.15	0.69
Dressing percent	0.8	0.46 ± 0.15	0.93	1.72	1.37	0.58
Adj. fat thickness, cm	0.59	0.86 ± 0.17	0.40	2.95	0.43	1.37
LM area, cm^2	11.5	0.67 ± 0.16	6.17	3.73	7.56	1.52
KPH fat, %	0.43	0.23 ± 0.14	0.26	3.31	0.55	0.78
Yield grade	0.9	0.88 ± 0.17	0.62	2.90	0.67	1.34
Marbling	84	0.59 ± 0.16	50.08	3.35	65.28	1.29
Retail product yield, %	4.7	0.54 ± 0.17	2.16	4.35	2.94	1.60
Retail product weight, kg	22	0.38 ± 0.17	10.57	4.16	17.13	1.28
Raw LM lipid, %	1.9	0.38 ± 0.17	0.91	4.18	1.47	1.29
Cooked LM lipid, %	2.3	0.55 ± 0.17	1.22	3.77	1.65	1.39
Warner-Bratzler shear force, kg	0.49	0.20 ± 0.16	0.35	2.80	0.78	0.63
Tenderness rating	0.45	0.39 ± 0.17	0.47	1.91	0.76	0.59
Juiciness rating	0.18	0.32 ± 0.16	0.17	2.12	0.30	0.60
Beef flavor intensity rating	0.08	0.26 ± 0.16	0.15	1.07	0.30	0.27

[a] R = range in sire breed means.
[b] h^2 = heritability.
[c] σ_g = genetic standard deviation.
[d] σ_p = phenotypic standard deviation.

Table 8. Genetic and phenotypic correlation coefficients among carcass and palatability traits at 445 d of age[a]

	Trait						
Trait	LWT	HCWT	AFT	LMA	YG	MARB	RPY
Live weight (LWT)		0.95	0.21	0.34	0.27	0.14	−0.23
Hot carcass weight (HCWT)	0.95 ± 0.03		0.26	0.38	0.30	0.14	−0.25
Adj. fat thickness (AFT)	0.14 ± 0.21	0.24 ± 0.22		−0.17	0.85	0.17	−0.62
Longissimus area (LMA)	0.18 ± 0.24	0.27 ± 0.25	−0.43 ± 0.21		−0.54	−0.10	0.28
Yield grade (YG)	0.21 ± 0.20	0.25 ± 0.22	0.93 ± 0.03	−0.69 ± 0.28		0.22	−0.67
Marbling score (MARB)	0.10 ± 0.24	0.18 ± 0.26	0.46 ± 0.17	−0.50 ± 0.23	0.58 ± 0.16		−0.41
Retail product yield (RPY)	−0.20 ± 0.29	−0.30 ± 0.33	−0.99 ± 0.35	0.44 ± 0.21	−0.94 ± 0.35	−0.67 ± 0.32	
Raw lipid (RLIPID)[b]	0.01 ± 0.32	0.02 ± 0.35	0.62 ± 0.22	−0.72 ± 0.34	0.74 ± 0.21	0.80 ± 0.13	−0.60 ± 0.41
Cooked lipid (CLIPID)[b]	−0.09 ± 0.26	−0.18 ± 0.28	0.41 ± 0.19	−0.60 ± 0.25	0.50 ± 0.18	0.82 ± 0.10	−0.55 ± 0.32
Warner-Bratzler shear force (WBS)	0.55 ± 0.46	0.88 ± 0.57	0.31 ± 0.32	0.88 ± 0.46	−0.01 ± 0.31	−0.46 ± 0.45	0.05 ± 0.38
Tenderness (TEND)	−0.63 ± 0.33	−0.78 ± 0.38	−0.34 ± 0.25	−0.37 ± 0.28	−0.21 ± 0.24	0.47 ± 0.23	0.08 ± 0.28
Juiciness (JUICY)	−0.33 ± 0.35	−0.39 ± 0.40	−0.05 ± 0.26	−0.70 ± 0.34	0.16 ± 0.25	0.71 ± 0.24	−0.11 ± 0.31
Beef flavor intensity (FLAV)	−0.57 ± 0.41	−0.53 ± 0.44	0.39 ± 0.30	−0.67 ± 0.37	0.43 ± 0.29	0.55 ± 0.30	−0.39 ± 0.36

	Trait					
	RLIPID	CLIPID	WBS	TEND	JUICY	FLAV
Live weight (LWT)	0.16	0.15	−0.03	−0.04	−0.10	−0.09
Hot carcass weight (HCWT)	0.13	0.14	−0.04	−0.03	−0.11	−0.08
Adj. fat thickness (AFT)	0.24	0.18	0.06	−0.11	−0.06	−0.02
Longissimus area (LMA)	−0.11	−0.07	0.01	−0.04	−0.06	−0.03
Yield grade (YG)	0.27	0.21	0.02	−0.06	−0.04	−0.01
Marbling score (MARB)	0.67	0.68	−0.28	0.26	0.31	0.17
Retail product yield (RPY)	−0.37	−0.34	0.02	0.00	−0.06	−0.04
Raw lipid (RLIPID)[b]		0.77	−0.20	0.19	0.28	0.17
Cooked lipid (CLIPID)[b]	1.00 ± 0.09		−0.30	0.22	0.32	0.20
Warner-Bratzler shear force (WBS)	−0.97 ± 0.70	−0.32 ± 0.46		−0.70	−0.36	−0.15
Tenderness (TEND)	0.87 ± 0.32	0.43 ± 0.25	−1.00[c] ± 1.00		0.52	0.22
Juiciness (JUICY)	0.87 ± 0.32	0.72 ± 0.25	−0.89 ± 0.78	0.82 ± 0.21		0.44
Beef flavor intensity (FLAV)	0.75 ± 0.39	0.75 ± 0.32	−0.56 ± 0.63	0.69 ± 0.35	0.44 ± 0.34	

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

[b] Chemical analysis of the LM (wet-weight basis).

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

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., 1994a; $h^2 = 0.08$, Wulf et al., 1996). Heritability estimates for LM juiciness and beef flavor intensity ratings were similar to those reported by Wheeler et al. (2004), and higher than estimates reported by others (Wheeler et al., 1996, 2001; Gregory et al., 1994a).

Estimates of the amount of variation between the two extreme breeds for a given trait in standard deviation units ($2R/\sigma_g$) from the present experiment (Table 7) were lower for most traits when compared with values reported by Wheeler et al. (1996, 2001, 2004). All traits had more variation within breeds than among breeds. These results are consistent with previous data indicating there is as much or more variation in LM tenderness within breeds as among the most extreme breeds for that trait (Wheeler et al., 1996, 2001, 2004). Phenotypic variation in carcass and palatability traits was similar or slightly less than that reported by Wheeler et al. (1996, 2001, 2004). As was observed in Cycles I to VI of GPE, little inherent genetic variation in juiciness and beef flavor intensity was detected in Cycle VII. Phenotypic variation in tenderness rating was approximately twice that of variation in ratings of juiciness and beef flavor intensity (CV = 13.6, 5.7, and 6.1%, respectively). This occurred despite a wide range of marbling scores. Thus, when variation in LM juiciness and beef flavor intensity occurs at the consumer level, it may be mostly induced by cooking practices and the level and kind of flavor enhancers added.

The genetic correlation between fat thickness and marbling was moderately high, suggesting that it would be difficult, but not impossible, to decrease s.c. fat thickness without lowering marbling level (Table 8). Marbling had relatively high genetic correlations to all carcass traits except weight. The genetic correlation between marbling and palatability traits was higher than reported by Wheeler et al. (2004), but similar to those reported by Wheeler et al. (2001). Tenderness traits and retail product yield had high genetic correlations to most carcass traits. Shear force and tenderness rating had high genetic correlations to all carcass and palatability traits except for yield traits. Juiciness rating had high genetic correlations to all traits except adjusted fat thickness, yield grade, and retail product yield. Beef flavor intensity rating had moderate to high genetic correlations to all traits.

Phenotypic correlations were not as high as genetic correlations (Table 8). Weight traits had low phenotypic correlations to most traits. Marbling had high phenotypic correlations to measures of LM lipid and retail product yield. Yield traits had moderate to high phenotypic correlations to most carcass traits. Phenotypically, LM shear force and tenderness rating were strongly correlated only to each other, although measures of tenderness were lowly related to beef flavor intensity ratings. Phenotypic correlations between measures of tenderness and juiciness ratings were moderate to high.

Implications

These results provide a current evaluation of the most commonly used sire breeds in the United States and show the amount of change in these breeds over the last 25 to 30 yr. Continental European breeds were still leaner, more heavily muscled, and had higher-yielding carcasses than British breeds with less marbling than Angus or Red Angus, but British breeds have caught up in growth rate. These results provide producers with greater information when deciding which sire breeds will maximize profit potential in their production situation.

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