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

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**ABSTRACT:** Carcass (n = 568) and longissimus thoracis palatability (n = 460) traits from $F_1$ steers obtained from mating Hereford (H), Angus (A), and U.S. Meat Animal Research Center (MARC) III cows to H, A, Norwegian Red (NR), Swedish Red and White (RW), Friesian (F), or Wagyu (W) sires were compared. Data were adjusted to constant age (471 d), carcass weight (356 kg), fat thickness (1.0 cm), percentage of fat trim (24%), and marbling (Small$^{35}$) end points. For Warner-Bratzler shear force and trained sensory panel traits, data were obtained on longissimus thoracis steaks stored at 2°C for 14 d postmortem. The following comparisons were from the age-constant end point. Carcasses from H- and A-sired steers (377 and 374 kg, respectively) were the heaviest ($P < 0.05$) and carcasses from W-sired steers (334 kg) were the lightest ($P < 0.05$). A greater ($P < 0.05$) percentage of carcasses from A- and W-sired steers graded USDA Choice (88 and 85%, respectively) than carcasses from other sire breeds (52 to 71%). Adjusted fat thickness for carcasses from A-sired steers (1.3 cm) was highest ($P < 0.05$), followed by H-sired steers (1.1 cm) and W- and F-sired steers (0.9 cm); NR- and RW-sired steers (0.8 cm) had the lowest ($P < 0.05$) adjusted fat thickness. Longissimus thoracis area was not different ($P > 0.05$) among sire breeds (mean = 80.6 cm$^2$). Carcass yield of boneless, totally trimmed retail product was least ($P < 0.05$) for A-sired steers (60.1%), intermediate for H-sired steers (61.5%), and similar ($P > 0.05$) for all other sire breeds (62.5 to 62.8%). Longissimus thoracis steaks from carcasses of A- (3.7 kg) and W-sired (3.7 kg) steers had lower ($P < 0.05$) shear force values than longissimus thoracis steaks from other sire breeds (4.1 to 4.2 kg). Trained sensory panel tenderness, juiciness, or beef flavor intensity ratings for longissimus thoracis steaks did not differ ($P > 0.05$) among the sire breeds. Sire breed comparisons were affected by adjusting data to other end points. Heritability estimates for various carcass, yield, and palatability traits ranged from very low ($h^2 = 0.06$ for percentage of kidney, pelvic, and heart fat) to relatively high ($h^2 = 0.71$ for percentage of retail product yield). Relative to the other sire breeds, W-sired steers had the highest percentage of USDA Choice, Yield grade 1 and 2 carcasses, but their carcasses were the lightest.

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

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## Introduction

The first five 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 thoracis (**LM**) palatability traits from these studies have been reported by Koch et al. (1976, 1979, 1982b) and Wheeler et al. (1996, 2001). Breed differences in production traits are important genetic resources for improving beef production efficiency, and meat composition and quality. No one 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 VI (which includes two Scandinavian breeds and the Japanese Wagyu) of the GPE program that characterizes cattle

[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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breeds representing diverse biological types for carcass and LM palatability traits that affect the quantity, quality, and value of production.

## 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 30 Angus, 32 Hereford, 14 Norwegian Red, 16 Swedish Red and White, 24 Friesian, and 19 Wagyu bulls to produce 568 steer calves. To avoid confounding sire breed effects with heterosis effects, no purebred Hereford or purebred Angus matings were made. Semen from 11 of the Hereford and 10 of the Angus sires (born 1982 to 1984) was used for the first time in Cycle IV. Semen from 10 of the Hereford and 9 of the Angus sires (born in 1989 or 1990) was used for the first time in Cycle V. Semen from 11 of the Hereford and 11 of the Angus sires (born since 1994) was used for the first time in Cycle VI. At the time of semen purchase, the Hereford and Angus bulls used were unproven by progeny test, but were considered to be excellent young herd sire prospects in the Angus and Hereford breeds. 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, and Angus breeds. For comparison to previous GPE cycles, the simple mean of the Hereford and Angus sire least squares means has been included in the tables labeled H×, A×.

Semen from Norwegian Red bulls was imported from the Norwegian Cattle AI and Breeding Cooperative (Hamar, Norway), whereas semen from Swedish Red and White bulls was imported from the Svensk Avel Ornsro (Skara, Sweden). The Norwegian Red and the Swedish Red and White breeds could be considered the same breed because their herd books have been open to one another; however, we have presented them separately. Over the past 20 yr, each breed has introduced germplasm from North American Holsteins; however, only bulls with non-Holstein influenced pedigrees were sampled for this experiment.

Semen from Friesian bulls was obtained through the American Beef Friesian breeders. Fourteen of the bulls were full bloods originally imported into the United States from Ireland, England, The Netherlands, and Germany. Ten of the bulls were upgrades or full-blood sons of imported parents born in the United States from 1979 to 1990. Only bulls with non-Holstein-influenced pedigrees were sampled for this experiment.

Semen from Wagyu bulls was obtained through the American Wagyu Association. Four bulls were full bloods born in 1973 and 1974 and imported into the United States in the late 1970s. Eleven bulls were full bloods born in 1989 to 1994 and imported from Japan into the United States in the 1990s. Four of the bulls were upgraded purebreds (≥15/16 Wagyu) born in 1985 to 1989 in the United States.

Calves were born in the spring, beginning in March each year (1997 and 1998). 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 216 d of age at weaning. For 21 d following weaning, a diet comprising about 2.55 Mcal of ME/kg and 14.25% CP was fed. Following this postweaning adjustment period, steers were assigned to replicated pens within sire breed and fed separately by sire breed for an average of 255 d (range from 225 to 293 d). A growing diet (2.7 Mcal of ME/kg of DM and 11.8% CP) containing 66% corn silage, 22% corn, and 12% supplement (DM basis) 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 early March of each year. Steers were slaughtered serially each year, in five slaughter groups spaced about 14 d apart (spanning 56 d) in 1998 and in four slaughter groups spaced 14 to 21 d apart (spanning 56 d) in 1999.

Final unshrunk live weights were obtained 1 wk before slaughter. Steers were slaughtered in a commercial beef-processing facility. Carcass sides were electrically stimulated within 45 min postmortem with the following sequence: 68 (3 s on, 3 s off), 70 (2 s on, 3 s off), 70 (2 s on, 3 s off), and 70 V (2 s on, 3 s off). However, observation of the electrical stimulation equipment while the experimental carcasses were being processed indicated that the system was working sporadically and sometimes ineffectively, particularly in the second year. 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 36-h chill at 0°C, USDA yield and quality grade data were obtained by trained MARC personnel (USDA, 1997).

### *Samples*

The wholesale rib (#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 #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. In the first year, ribeye rolls were frozen at 14 d postmortem and steaks were cut on a band saw. In the second year, steaks were cut fresh at 7 d postmortem with a Biro slicer (model 109 PC; Marblehead, OH), vacuum packaged, stored at 2°C until 14 d postmortem, and then frozen at −30°C. 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 frozen immediately at –30°C for later proximate 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. 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 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*

A subsample of 460 LM steaks (approximately 80% of each sire breed) was evaluated by a trained descriptive attribute sensory panel. Immediately after cooking, the LM 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 eight-point scale (8 = extremely tender, juicy, or intense to 1 = extremely tough, dry, or bland). A warm-up sample was served first, and then four experimental steaks were served in each of two sessions (5 min between sessions) per day, three days per week. In addition, a duplicate sample to one of the experimental samples was served daily for monitoring panelist and panel performance.

### *Proximate Composition Analyses*

Raw and cooked LM proximate composition (wet-weight basis) was determined according to AOAC (1985) methods as described by Wheeler et al. (2001).

### *Statistical Analyses*

Data were analyzed by least squares, mixed model procedures (Harvey, 1985) using a model that included a random effect for sires nested within sire breed, and fixed effects for sire breed, dam breed, age of dam (4 to 5, 6 to 7, 8 to 9, and ≥10 yr), birth year, interaction of sire breed × dam breed, and covariates for age at weaning (mean = 216 d) and days fed postweaning (mean = 255 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).

Regressions of traits on days fed provides a method of adjusting the age-constant sire breed means to alternative end points. 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 end point (the mean for this experiment) with regard to age (471 d), carcass weight (356 kg), fat thickness (1.0 cm), fat trim percentage (24%; 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).

Consistent with previous reports (Koch et al., 1979, 1982b; Wheeler et al., 1996, 2001), 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, dam breed, and year were significant ($P < 0.05$) sources of variation for most traits (Table 2). The sire breed × dam breed interaction was a significant ($P < 0.05$) source of variation for marbling score only. Linear regression of weaning age was significant ($P < 0.05$) for live and carcass weights and linear regression of days fed was significant ($P < 0.05$) for most traits.

### *Carcass Traits*

Sire breeds differed ($P < 0.05$) in growth rate. Final live and carcass weights at a constant age of 471 d were heaviest ($P < 0.05$) for Hereford- and Angus-sired steers and lightest ($P < 0.05$) for Wagyu-sired steers (Table 3). At a constant fat thickness, Swedish Red and White- and Norwegian Red-sired steers were heaviest ($P < 0.05$), then Friesian- and Hereford-sired steers, and Wagyu- and Angus-sired steers were the lightest ($P < 0.05$). At a constant marbling degree, Hereford-sired steers were heaviest ($P < 0.05$), followed by H×, A× crosses, Swedish Red and White-, and Friesian-sired steers, then Angus- and Norwegian Red-sired steers, and Wagyu-sired steers were the lightest ($P < 0.05$). At a constant fat trim end point, Norwegian Red-sired steers were heaviest ($P < 0.05$), followed by Hereford-, Friesian-, and Swedish Red and White-sired steers, and then Angus-sired steers; Wagyu-sired steers were lightest ($P < 0.05$). Sire breed differences for live weight and carcass weight were similar ($P > 0.05$).

Dressing percentage was higher ($P < 0.05$) at 471 d of age, and tended to be higher at the other end points for carcasses from Wagyu-, Hereford-, and Angus-sired steers. Dressing percentage for carcasses from Friesian-, Swedish Red and White- and Norwegian Red-sired steers was lower ($P < 0.05$) at 471 d of age and tended to be lower at other end points.

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

| Sire breed | No. of sires | Dam breed and number of steer progeny | | | |
|---|---|---|---|---|---|
| | | Hereford | Angus | MARC III[a] | Total |
| Hereford | 32 | — | 65 | 21 | 86 |
| Angus | 30 | 29 | — | 59 | 88 |
| Norwegian Red | 14 | 11 | 34 | 18 | 63 |
| Swedish Red and White | 16 | 10 | 27 | 37 | 74 |
| Friesian | 24 | 25 | 49 | 58 | 132 |
| Wagyu | 19 | 24 | 56 | 45 | 125 |
| Total | 145 | 99 | 231 | 238 | 568 |

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

Adjusted fat thickness was highest ($P < 0.05$) for carcasses from Hereford- and Angus-sired steers and lowest ($P < 0.05$) for carcasses from Swedish Red and White- and Norwegian Red-sired steers at constant age. At constant weight, carcasses from Wagyu- and Angus-sired steers had the highest ($P < 0.05$) and carcasses from Norwegian Red- and Swedish Red and White-sired steers had the lowest ($P < 0.05$) adjusted fat thickness. At constant marbling, carcasses from Hereford-sired steers had the highest ($P < 0.05$) adjusted fat thickness followed by carcasses from Friesian-, Angus-, and Swedish Red and White-sired steers. Carcasses from Norwegian Red- and Wagyu-sired steers had the lowest ($P < 0.05$) adjusted fat thickness at constant marbling. At constant fat trim percentage, sire breed differences in adjusted fat thickness were greatly reduced with carcasses from Angus- and Hereford-sired steers tending to have the greatest and carcasses from Swedish Red and White-sired steers tending to have the least adjusted fat thickness.

Sire breed differences in LM area were relatively small. Carcasses from Hereford-sired steers had larger ($P < 0.05$) LM areas than did carcasses from Swedish Red and White- and Norwegian Red-sired steers at all end points except constant marbling, where Hereford was different ($P < 0.05$) only from Swedish Red and White. Carcasses from Hereford- and Angus-sired steers had similar ($P > 0.05$) LM areas at all endpoints and had similar ($P < 0.05$) LM areas as carcasses from Wagyu-sired steers at all end points except constant weight. It should be noted that the days on feed regression coefficient for LM area has a sign opposite (–) from

**Table 2**. Analysis of variance

| Source | df[a] | Mean squares | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Live weight, kg | Hot carcass weight, kg | Dressing percent | Adjusted fat thickness, cm | Longissimus area, cm | Marbling score | USDA Choice, % |
| Sire breed (SB) | 5 | 291,101* | 109,182* | 11.2* | 0.56* | 2.0 | 61,238* | 1.93* |
| Sire (Sire breed) | 126 | 11,100* | 4,201* | 2.5 | 0.03* | 1.5* | 6,967* | 0.24* |
| Dam breed (DB) | 2 | 39,092* | 23,311* | 9.8* | 0.26* | 0.2 | 32,600* | 0.92* |
| Dam age | 3 | 44,072* | 18,083* | 2.1 | 0.03 | 1.7 | 3,822 | 0.08 |
| Year (Y) | 1 | 186,462* | 78,175* | 1.3 | 0.13* | 0.2 | 47,045* | 1.42* |
| SB × DB | 8 | 9,368 | 2,660 | 1.3 | 0.01 | 0.8 | 9,646* | 0.26 |
| b1 (weaning age) | 1 | 56,444* | 21,331* | 0.1 | 0.01 | 3.0 | 8,350 | 0.01 |
| b2 (days fed) | 1 | 617,850* | 252,670* | 2.5 | 1.04* | 1.2 | 115,764* | 2.08* |
| Residual | 420 | 7,917 | 3,341 | 2.2 | 0.02 | 1.1 | 4,680 | 0.16 |

| Source | Mean squares | | | | | | |
|---|---|---|---|---|---|---|---|
| | USDA yield grade | Boneless retail product yield, % | df[b] | Warner-Bratzler shear force, kg | Tenderness rating | Juiciness rating | Beef flavor intensity rating |
| Sire breed (SB) | 6.9* | 88.2* | 5 | 2.54* | 1.45* | 0.21 | 0.06 |
| Sire (Sire breed) | 0.4* | 12.4* | 119 | 0.48* | 0.56 | 0.13 | 0.09* |
| Dam breed (DB) | 4.0* | 23.0* | 2 | 2.27* | 2.11* | 0.00 | 0.05 |
| Dam age | 0.3 | 6.6 | 3 | 0.15 | 0.65 | 0.00 | 0.05 |
| Year (Y) | 2.0* | 122.7* | 1 | 13.47* | 66.21* | 15.82* | 2.47* |
| SB × DB | 0.3 | 8.9 | 8 | 0.11 | 0.43 | 0.23 | 0.08 |
| b1 (weaning age) | 0.1 | 24.0 | 1 | 0.03 | 0.25 | 0.03 | 0.02 |
| b2 (days fed) | 27.9* | 483.2* | 1 | 1.50* | 0.93 | 0.47* | 0.20 |
| Residual | 0.3 | 6.6 | 319 | 0.39 | 0.46 | 0.10 | 0.07 |

[a]Degrees of freedom for carcass traits.
[b]Degrees of freedom for palatability traits.
*$P < 0.05$.

**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, $\mu \pm$ SEM, b1, b2[b] | Sire breed, LSD[c] | Age (471 d) | Carcass wt (356 kg) | Fat thickness (1.0 cm) | Marbling (Small[35]) | Fat trim (24%) |
| Days on feed | Hereford | — | 216 | 232 | 292 | 237 |
| $\mu = 255$ | Angus | — | 226 | 214 | 200 | 213 |
| SD = 24 | H×, A× | — | 221 | 223 | 246 | 225 |
| | Norwegian Red | — | 258 | 301 | 245 | 285 |
| | Swedish Red and White | — | 267 | 305 | 279 | 272 |
| | Friesian | — | 269 | 284 | 284 | 277 |
| | Wagyu | — | 304 | 272 | 224 | 265 |
| Live weight, kg | Hereford | 618 | — | 599 | 648 | 603 |
| $\mu = 585 \pm 2.7$ | Angus | 609 | — | 575 | 564 | 574 |
| b1 = 0.8037 ± 0.301 | H×, A× | 612 | — | 587 | 606 | 589 |
| b2 = 0.8223 ± 0.093 | Norwegian Red | 588 | — | 626 | 580 | 613 |
| | Swedish Red and White | 580 | — | 622 | 600 | 594 |
| | Friesian | 576 | — | 599 | 599 | 594 |
| | Wagyu | 543 | — | 557 | 517 | 551 |
| | LSD | 15 | — | 19 | 18 | 17 |
| Hot carcass weight, kg | Hereford | 380 | — | 368 | 399 | 370 |
| $\mu = 358 \pm 1.5$ | Angus | 374 | — | 352 | 345 | 352 |
| b1 = 0.4781 ± 0.198 | H×, A× | 377 | — | 360 | 372 | 361 |
| b2 = 0.5215 ± 0.061 | Norwegian Red | 357 | — | 381 | 351 | 372 |
| | Swedish Red & White | 352 | — | 378 | 365 | 361 |
| | Friesian | 351 | — | 366 | 366 | 362 |
| | Wagyu | 334 | — | 343 | 318 | 339 |
| | LSD | 9 | — | 12 | 11 | 10 |
| Dressing percent | Hereford | 61.4 | 61.3 | 61.4 | 61.5 | 61.4 |
| $\mu = 61.1 \pm 0.09$ | Angus | 61.4 | 61.3 | 61.3 | 61.3 | 61.3 |
| b1 = −0.0017 ± 0.011 | H×, A× | 61.4 | 61.3 | 61.3 | 61.4 | 61.3 |
| b2 = 0.0037 ± 0.0034 | Norwegian Red | 60.6 | 60.6 | 60.7 | 60.6 | 60.7 |
| | Swedish Red & White | 60.6 | 60.6 | 60.7 | 60.7 | 60.7 |
| | Friesian | 60.9 | 61.0 | 61.0 | 61.0 | 61.0 |
| | Wagyu | 61.5 | 61.7 | 61.6 | 61.4 | 61.5 |
| | LSD | 0.5 | 0.6 | 0.7 | 0.6 | 0.6 |
| Adj. fat thickness, cm | Hereford | 1.16 | 0.93 | — | 1.38 | 1.06 |
| $\mu = 0.96 \pm 0.024$ | Angus | 1.33 | 1.16 | — | 1.01 | 1.08 |
| b1 = 0.0018 ± 0.0024 | H×, A× | 1.25 | 1.05 | — | 1.19 | 1.07 |
| b2 = 0.0060 ± 0.0008 | Norwegian Red | 0.78 | 0.80 | — | 0.72 | 0.96 |
| | Swedish Red & White | 0.76 | 0.83 | — | 0.91 | 0.86 |
| | Friesian | 0.85 | 0.93 | — | 1.02 | 0.98 |
| | Wagyu | 0.91 | 1.20 | — | 0.72 | 0.97 |
| | LSD | 0.13 | 0.16 | — | 0.16 | 0.15 |
| Longissimus area, $cm^2$ | Hereford | 82.7 | 83.6 | 83.3 | 81.9 | 83.1 |
| $\mu = 80.8 \pm 0.4$ | Angus | 81.2 | 81.8 | 82.1 | 82.4 | 82.1 |
| b1 = 0.0830 ± 0.0495 | H×, A× | 81.9 | 82.7 | 82.7 | 82.1 | 82.6 |
| b2 = −0.0165 ± 0.0153 | Norwegian Red | 80.0 | 79.9 | 78.9 | 80.2 | 79.3 |
| | Swedish Red & White | 79.2 | 79.0 | 78.1 | 78.7 | 78.9 |
| | Friesian | 80.3 | 79.9 | 79.6 | 79.6 | 79.8 |
| | Wagyu | 80.8 | 79.7 | 80.4 | 81.5 | 80.6 |
| | LSD | 2.5 | 3.0 | 3.2 | 3.0 | 2.9 |
| KPH fat, %[d] | Hereford | 2.29 | 2.08 | 2.17 | 2.49 | 2.20 |
| $\mu = 2.55 \pm 0.03$ | Angus | 2.67 | 2.51 | 2.45 | 2.37 | 2.44 |
| b1 = −0.0011 ± 0.0036 | H×, A× | 2.48 | 2.30 | 2.31 | 2.43 | 2.32 |
| b2 = 0.0053 ± 0.0011 | Norwegian Red | 2.59 | 2.61 | 2.84 | 2.54 | 2.75 |
| | Swedish Red and White | 2.58 | 2.64 | 2.85 | 2.71 | 2.67 |
| | Friesian | 2.57 | 2.64 | 2.72 | 2.72 | 2.68 |
| | Wagyu | 2.59 | 2.85 | 2.68 | 2.42 | 2.64 |
| | LSD | 0.16 | 0.19 | 0.21 | 0.19 | 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 (471 d) | Carcass wt (356 kg) | Fat thickness (1.0 cm) | Marbling (Small$^{35}$) | Fat trim (24%) |
| Yield grade | Hereford | 3.2 | 2.7 | 2.9 | 3.6 | 3.0 |
| $\mu$ = 2.95 ± 0.04 | Angus | 3.5 | 3.1 | 2.9 | 2.8 | 2.9 |
| b1 = 0.0023 ± 0.0038 | H×, A× | 3.3 | 2.9 | 2.9 | 3.2 | 2.9 |
| b2 = 0.0122 ± 0.0012 | Norwegian Red | 2.8 | 2.8 | 3.4 | 2.7 | 3.2 |
| | Swedish Red & White | 2.8 | 2.9 | 3.4 | 3.1 | 3.0 |
| | Friesian | 2.8 | 3.0 | 3.2 | 3.2 | 3.1 |
| | Wagyu | 2.7 | 3.3 | 2.9 | 2.3 | 2.8 |
| | LSD | 0.2 | 0.2 | 0.3 | 0.2 | 0.2 |
| Marbling[e] | Hereford | 509 | 480 | 492 | — | 495 |
| $\mu$ = 536.8 ± 4.7 | Angus | 579 | 557 | 548 | — | 547 |
| b1 = 0.681 ± 0.510 | H×, A× | 544 | 518 | 520 | — | 521 |
| b2 = 0.785 ± 0.158 | Norwegian Red | 543 | 545 | 577 | — | 565 |
| | Swedish Red & White | 518 | 527 | 555 | — | 530 |
| | Friesian | 514 | 525 | 536 | — | 531 |
| | Wagyu | 559 | 595 | 572 | — | 566 |
| | LSD | 25 | 30 | 33 | — | 29 |
| USDA Choice, %[f] | Hereford | 60 | 47 | 53 | — | 54 |
| $\mu$ = 68.9 ± 0.03 | Angus | 89 | 79 | 75 | — | 75 |
| b1 = 0.00065 ± 0.003 | H×, A× | 74 | 63 | 64 | — | 65 |
| b2 = 0.00332 ± 0.001 | Norwegian Red | 71 | 72 | 86 | — | 81 |
| | Swedish Red & White | 61 | 65 | 77 | — | 66 |
| | Friesian | 52 | 57 | 62 | — | 59 |
| | Wagyu | 85 | 100 | 91 | — | 89 |
| | LSD | 15 | 18 | 20 | — | 18 |

[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]LSD = least significant difference among means, $P < 0.05$.
[d]Estimated percentage of hot carcass weight as kidney, pelvic, and heart fat.
[e]400 = Slight$^{00}$, 500 = Small$^{00}$ (USDA, 1997).
[f]Percentage of carcasses grading USDA Choice or higher.

that expected; thus, the results of adjustments to different end points should be interpreted with caution. This likely resulted from random chance that more animals with larger LM areas were assigned to earlier harvest groups than would be expected.

Carcasses from Hereford-sired steers had the lowest ($P < 0.05$) percentage of kidney, pelvic, and heart (**KPH**) fat at all end points except constant marbling. At constant weight, the percentage of KPH fat was greatest ($P < 0.05$) in carcasses from Wagyu-sired steers. Carcasses from Norwegian Red-, Swedish Red and White-, and Friesian-sired steers had similar ($P > 0.05$) percentages of KPH fat.

At constant age, numerical USDA yield grade was higher ($P < 0.05$) for carcasses from Angus- and Hereford-sired steers than for all other sire breeds. At constant age, the mean yield grade of 3.5 for Angus-sired steers resulted in a relatively high percentage (20.5%) of carcasses with a yield grade 4.0 or greater. Hereford-, Norwegian Red-, Swedish Red and White-, Wagyu-, and Friesian-sired steers at constant age had 10.0, 3.2, 2.7, 2.3, and 1.5% of carcasses with a yield grade 4.0, or higher, respectively. At constant weight, carcasses from Wagyu-sired steers had higher ($P < 0.05$) yield grades than all other sire breeds except Angus. At constant fat thickness, Norwegian Red- and Swedish Red and White-sired steers had higher ($P < 0.05$) yield grades than all other sire breeds except Friesian. At constant marbling, carcasses from Hereford-sired steers had the highest ($P < 0.05$) yield grades, followed by carcasses from Friesian- and Swedish Red and White-sired steers, and then Norwegian Red- and Angus-sired steers; Wagyu-sired steers had the lowest ($P < 0.05$) yield grades. At constant fat thickness, differences in yield grades among sire breeds were small.

At constant age, marbling score was higher ($P < 0.05$) in carcasses from Angus-sired steers than for all other sire breeds except Wagyu. At constant age, carcasses from Hereford-, Friesian-, and Swedish Red and White-sired steers had lower ($P < 0.05$) marbling scores than did all other sire breeds. At constant weight, carcasses from Wagyu-sired steers had the highest ($P < 0.05$) and carcasses from Hereford-sired steers had the lowest ($P < 0.05$) marbling scores. At constant fat thickness and constant fat trim level, carcasses from Norwegian Red- and Wagyu-sired steers tended to have the highest marbling scores, whereas carcasses from Hereford-sired steers tended to have the lowest. Sire breed differences for the percentage of carcasses grading USDA Choice at each end point were similar to marbling differences.

Only one carcass in the experiment graded USDA Standard.

Hereford- and Angus-sired steers were the heaviest ($P < 0.05$) at constant age and thus were the fastest growing sire breeds. Wagyu-sired steers had the slowest growth rate. Angus-sired steers were the earliest maturing, followed by Hereford-sired steers. The Angus-sired steers required the fewest days on feed to reach the 24% fat trim end point.

Most of the published data comparing the Wagyu breed to other breeds is based on a number of observations too small for valid conclusions. In a comparison of 12 calf-fed and 12 2-yr-old cattle in each of two breed crosses, Wertz et al. (2002) found that ½ Wagyu × ½ Angus tended to have more marbling than ¾ blood Angus, and that the 2-yr-old Wagyu crosses had smaller carcass weights and lower fat thickness. However, the calf-fed Wagyu crosses had larger carcass weights and greater fat thickness than Angus crosses. Mir et al. (1999) reported that 50 and 75% Wagyu crosses had lighter carcasses with more marbling and tended to have decreased fat thickness compared with Continental crosses. Lunt et al. (1993) compared 10 Angus and 10 American Wagyu fed according to Japanese custom for 552 d, and found no differences in any carcass traits except that Angus had heavier carcasses. Mears et al. (2001) reported marbling levels were not different between Hereford or Angus compared with Wagyu crosses with Angus or Hereford. They also found conflicting results across years for differences in fat thickness. In an experiment that was more comprehensive than most involving Wagyu, Pitchford et al. (2002) reported that carcasses from Angus-sired progeny were heavier than carcasses from Hereford-sired progeny, which were heavier than carcasses from Wagyu-sired progeny. Pitchford et al. (2002) also found that LM from carcasses of Wagyu- and Angus-sired cattle had a greater percentage of i.m. fat than LM from carcasses of Hereford-sired cattle.

A comparison of cattle selected for twinning that were 16% Swedish Friesian, 7% Norwegian Red, and 2% Swedish Red and White to a reference population that was ½ Simmental crosses indicated that twinner cattle had higher marbling scores, decreased adjusted fat thickness, and increased percentage grading USDA Choice or higher (Gregory et al., 1996). Kempster et al. (1982) compared breeds at 16 mo of age after slaughter at a constant fat level, and reported that Friesian and Hereford steers had heavier carcass weights than Angus steers (but lighter than Charolais and Simmental), and that Friesian had greater LM areas than Angus or Hereford. A serial slaughter at different fat levels resulted in similar findings (Kempster et al., 1988).

### *Carcass Yield*

At a constant age of 471 d, carcasses from Norwegian Red-, Swedish Red and White-, and Friesian-sired steers tended to have the highest and carcasses from Angus-sired steers had the lowest ($P < 0.05$) percentage retail product yield (Table 4). At constant weight, carcasses from Hereford-sired steers had a higher ($P < 0.05$) percentage of retail product yield than all other sire breeds except Norwegian Red, and carcasses from Wagyu-sired steers had the lowest ($P < 0.05$) percentage of retail product yield. At constant fat thickness, carcasses from Hereford- and Angus-sired steers tended to have the higher percentage of retail product yield. At constant marbling, carcasses from Wagyu- and Norwegian Red-sired steers tended to have the highest and carcasses from Hereford-sired steers had the lowest ($P < 0.05$) percentage of retail product yield. There were no differences ($P > 0.05$) among sire breeds for percentage of retail product yield adjusted to constant percentage of fat trim.

At constant age, carcasses from Angus-sired steers had the highest ($P < 0.05$) percentage of fat trim yield, and carcasses from Norwegian Red-, Friesian-, Swedish Red and White-, and Wagyu-sired steers had the lowest ($P < 0.05$) percentage fat yield. At constant weight, carcasses from Wagyu- and Angus-sired steers tended to have the highest and carcasses from Norwegian Red- and Hereford-sired steers tended to have the lowest percentage fat yield. At constant fat thickness, sire breed differences in fat yield were small, but carcasses from Swedish Red and White-sired steers tended to have the highest and carcasses from Hereford-sired steers tended to have the lowest percentage fat yield. At constant marbling, carcasses from Hereford-sired steers had the highest ($P < 0.05$) and carcasses from Wagyu-sired steers had the lowest ($P < 0.05$) percentage of fat yield.

Carcasses from Norwegian Red- and Friesian-sired steers tended to have the highest percentage of bone, regardless of end point. Carcasses from Angus-sired steers tended to have the lowest percentage of bone, regardless of end point.

Carcasses from Hereford-sired steers had the heaviest ($P < 0.05$) and carcasses from Wagyu-sired steers had the lightest ($P < 0.05$) weight of retail product for most end points. At constant age, carcasses from Hereford- and Angus-sired steers had heavier ($P < 0.05$) fat weight than other sire breeds. At constant weight, carcasses from Wagyu-sired steers had heavier ($P < 0.05$) fat weight than all other sire breeds except Angus. At constant fat thickness, carcasses from Swedish Red and White- and Norwegian Red-sired steers had heavier ($P < 0.05$) fat weight than carcasses from Angus- and Wagyu-sired steers. At constant marbling, carcasses from Hereford-sired steers had the heaviest ($P < 0.05$) fat weight, followed by Friesian- and Swedish Red and White-sired steers, and then Angus- and Norwegian Red-sired steers; Wagyu-sired steers had the lightest ($P < 0.05$) fat weight. At constant fat trim, carcasses from Hereford- and Norwegian Red-sired steers had heavier ($P < 0.05$) fat weights than carcasses from Wagyu-sired steers. Regardless of end point, carcasses from Hereford- and Norwegian Red-sired steers

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

| Trait, $\mu \pm$ SEM, b1, b2[b] | Sire breed, LSD[c] | Endpoint: Age (471 d) | Carcass wt (356 kg) | Fat thickness (1.0 cm) | Marbling ($Small^{35}$) | Fat trim (24%) |
|---|---|---|---|---|---|---|
| Retail product yield, %[d] | Hereford | 61.5 | 63.6 | 62.7 | 59.6 | 62.5 |
| $\mu$ = 62.1 ± 0.21 | Angus | 60.1 | 61.6 | 62.2 | 62.9 | 62.3 |
| b1 = −0.0368 ± 0.0193 | H×, A× | 60.8 | 62.6 | 62.5 | 61.3 | 62.4 |
| b2 = −0.0515 ± 0.0060 | Norwegian Red | 62.8 | 62.6 | 60.4 | 63.3 | 61.2 |
| | Swedish Red and White | 62.8 | 62.2 | 60.2 | 61.6 | 62.0 |
| | Friesian | 62.8 | 62.1 | 61.3 | 61.3 | 61.7 |
| | Wagyu | 62.5 | 59.9 | 61.6 | 64.1 | 62.0 |
| | LSD | 1.1 | 1.3 | 1.4 | 1.3 | 1.3 |
| Fat yield, %[d] | Hereford | 24.9 | 22.9 | 23.8 | 26.8 | — |
| $\mu$ = 23.9 ± 0.25 | Angus | 26.4 | 24.9 | 24.3 | 23.6 | — |
| b1 = 0.0405 ± 0.0236 | H×, A× | 25.7 | 23.9 | 24.0 | 25.2 | — |
| b2 = 0.0506 ± 0.0074 | Norwegian Red | 22.5 | 22.7 | 24.9 | 22.0 | — |
| | Swedish Red and White | 23.1 | 23.8 | 25.7 | 24.4 | — |
| | Friesian | 22.9 | 23.6 | 24.4 | 24.4 | — |
| | Wagyu | 23.5 | 26.0 | 24.4 | 21.9 | — |
| | LSD | 1.3 | 1.6 | 1.6 | 1.6 | — |
| Bone yield, %[d] | Hereford | 14.5 | 14.6 | 14.6 | 14.3 | 14.5 |
| $\mu$ = 14.6 ± 0.06 | Angus | 14.0 | 14.1 | 14.2 | 14.2 | 14.2 |
| b1 = −0.0060 ± 0.0068 | H×, A× | 14.2 | 14.4 | 14.4 | 14.3 | 14.4 |
| b2 = −0.0046 ± 0.0021 | Norwegian Red | 15.0 | 15.0 | 14.8 | 15.0 | 14.8 |
| | Swedish Red and White | 14.7 | 14.7 | 14.5 | 14.6 | 14.6 |
| | Friesian | 14.9 | 14.8 | 14.8 | 14.8 | 14.8 |
| | Wagyu | 14.4 | 14.2 | 14.4 | 14.6 | 14.4 |
| | LSD | 0.3 | 0.4 | 0.6 | 0.4 | 0.4 |
| Retail product wt, kg[e] | Hereford | 233 | 228 | 230 | 238 | 231 |
| $\mu$ = 221 ± 1.2 | Angus | 224 | 220 | 219 | 217 | 218 |
| b1 = 0.1646 ± 0.1214 | H×, A× | 229 | 224 | 224 | 228 | 225 |
| b2 = 0.1425 ± 0.0379 | Norwegian Red | 224 | 224 | 230 | 222 | 228 |
| | Swedish Red and White | 221 | 222 | 228 | 224 | 223 |
| | Friesian | 220 | 223 | 224 | 224 | 223 |
| | Wagyu | 208 | 215 | 211 | 204 | 210 |
| | LSD | 6 | 8 | 8 | 8 | 7 |
| Fat weight, kg[e] | Hereford | 95 | 83 | 88 | 107 | 90 |
| $\mu$ = 86 ± 1.0 | Angus | 99 | 90 | 86 | 82 | 86 |
| b1 = 0.2527 ± 0.1114 | H×, A× | 97 | 87 | 87 | 94 | 88 |
| b2 = 0.3046 ± 0.0348 | Norwegian Red | 81 | 82 | 95 | 78 | 90 |
| | Swedish Red and White | 82 | 86 | 97 | 89 | 87 |
| | Friesian | 81 | 85 | 90 | 90 | 88 |
| | Wagyu | 79 | 94 | 84 | 70 | 82 |
| | LSD | 6 | 7 | 7 | 7 | 7 |
| Bone weight, kg[e] | Hereford | 55 | 52 | 53 | 57 | 54 |
| $\mu$ = 52 ± 0.3 | Angus | 52 | 51 | 50 | 49 | 50 |
| b1 = 0.0489 ± 0.0309 | H×, A× | 53 | 51 | 52 | 53 | 52 |
| b2 = 0.0598 ± 0.0096 | Norwegian Red | 53 | 54 | 56 | 53 | 55 |
| | Swedish Red and White | 52 | 52 | 55 | 53 | 53 |
| | Friesian | 52 | 53 | 54 | 54 | 53 |
| | Wagyu | 48 | 51 | 49 | 46 | 49 |
| | LSD | 2 | 2 | 2 | 2 | 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. W-B = Warner-Bratzler.
[c]LSD = least significant difference among means, $P < 0.05$.
[d]Predicted from wholesale rib dissection.
[e]Calculated from hot carcass weight and predicted yields.

tended to have heavier bone weight, and carcasses from Wagyu-sired steers tended to have the lightest bone weights.

Kempster et al. (1982) compared breeds at 16 mo of age after slaughter at a constant fat level, and reported that carcasses from Friesian steers had a lower saleable meat yield than Angus, Charolais, or Simmental steers. Similar results were obtained when cattle were serially slaughtered at different fat levels (Kempster et al., 1988).

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

| Trait, $\mu$ ± SEM, b1, b2[b] | Sire breed, LSD[c] | Endpoint Age (471 d) | Carcass wt (356 kg) | Fat thickness (1.0 cm) | Marbling (Small$^{35}$) | Fat trim (24%) |
|---|---|---|---|---|---|---|
| W-B shear force, kg | Hereford | 3.79 | 3.90 | 3.85 | 3.69 | 3.84 |
| μ = 3.75 ± 0.04 | Angus | 3.55 | 3.63 | 3.67 | 3.70 | 3.67 |
| b1 = 0.0011 ± 0.0047 | H×, A× | 3.67 | 3.76 | 3.76 | 3.70 | 3.75 |
| b2 = −0.0027 ± 0.0015 | Norwegian Red | 3.77 | 3.76 | 3.65 | 3.80 | 3.69 |
| | Swedish Red and White | 3.93 | 3.90 | 3.80 | 3.87 | 3.89 |
| | Friesian | 3.94 | 3.90 | 3.86 | 3.86 | 3.88 |
| | Wagyu | 3.53 | 3.40 | 3.49 | 3.62 | 3.51 |
| | LSD | 0.21 | 0.25 | 0.27 | 0.25 | 0.25 |
| Tenderness[d] | Hereford | 6.25 | 6.15 | 6.19 | 6.35 | 6.20 |
| $\mu$ = 6.40 ± 0.04 | Angus | 6.48 | 6.40 | 6.37 | 6.33 | 6.37 |
| b1 = −0.0043 ± 0.0058 | H×, A× | 6.36 | 6.27 | 6.28 | 6.34 | 6.28 |
| b2 = 0.0026 ± 0.0018 | Norwegian Red | 6.48 | 6.49 | 6.60 | 6.45 | 6.56 |
| | Swedish Red and White | 6.32 | 6.35 | 6.45 | 6.39 | 6.37 |
| | Friesian | 6.25 | 6.29 | 6.33 | 6.33 | 6.31 |
| | Wagyu | 6.60 | 6.73 | 6.64 | 6.52 | 6.63 |
| | LSD | 0.26 | 0.31 | 0.34 | 0.31 | 0.30 |
| Juiciness[e] | Hereford | 5.29 | 5.21 | 5.24 | 5.35 | 5.25 |
| $\mu$ = 5.31 ± 0.02 | Angus | 5.29 | 5.24 | 5.21 | 5.19 | 5.21 |
| b1 = 0.0015 ± 0.0028 | H×, A× | 5.29 | 5.22 | 5.23 | 5.27 | 5.23 |
| b2 = 0.0018 ± 0.0009 | Norwegian Red | 5.34 | 5.34 | 5.42 | 5.32 | 5.39 |
| | Swedish Red and White | 5.32 | 5.34 | 5.41 | 5.36 | 5.35 |
| | Friesian | 5.24 | 5.27 | 5.30 | 5.30 | 5.28 |
| | Wagyu | 5.39 | 5.48 | 5.42 | 5.33 | 5.41 |
| | LSD | 0.12 | 0.15 | 0.16 | 0.15 | 0.14 |
| Beef flavor intensity[f] | Hereford | 4.70 | 4.65 | 4.67 | 4.74 | 4.68 |
| $\mu$ = 4.71 ± 0.02 | Angus | 4.73 | 4.69 | 4.68 | 4.66 | 4.67 |
| b1 = −0.0012 ± 0.0022 | H×, A× | 4.71 | 4.67 | 4.67 | 4.70 | 4.68 |
| b2 = 0.0012 ± 0.0007 | Norwegian Red | 4.71 | 4.71 | 4.76 | 4.70 | 4.75 |
| | Swedish Red and White | 4.70 | 4.72 | 4.76 | 4.73 | 4.72 |
| | Friesian | 4.68 | 4.70 | 4.71 | 4.71 | 4.71 |
| | Wagyu | 4.76 | 4.81 | 4.76 | 4.72 | 4.77 |
| | LSD | 0.10 | 0.13 | 0.14 | 0.13 | 0.12 |

[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. WB = Warner-Bratzler.
[c]LSD = least significant difference among means, $P < 0.05$.
[d]1 = extremely tough, 4 = slightly tough, 5 = slightly tender, 8 = extremely tender.
[e]1 = extremely dry, 4 = slightly dry, 5 = slightly juicy, 8 = extremely juicy.
[f]1 = extremely bland, 4 = slightly bland, 5 = slightly intense, 8 = extremely intense.

*Palatability Traits*

Differences among sire breeds for LM palatability traits were generally small. At constant age, LM steaks from carcasses of Wagyu- and Angus-sired steers had the lowest ($P < 0.05$) 14-d postmortem Warner-Bratzler shear force values, followed by Norwegian Red- and Hereford-sired steers; Friesian- and Swedish Red and White-sired steers had the highest ($P < 0.05$) 14-d shear force (Table 5). At constant weight, shear force differences were similar to those for constant age. At constant fat thickness and constant fat trim percentage, LM steaks from carcasses of Wagyu-, Norwegian Red-, and Angus-sired steers tended to have lower shear force than other sire breeds. At constant marbling, 14-d LM Warner-Bratzler shear force values did not vary ($P > 0.05$) among sire breeds.

At constant age and constant weight, LM steaks of carcasses from Wagyu-sired steers had higher ($P < 0.05$) trained sensory panel tenderness ratings than did other sire breeds except Norwegian Red (constant age and weight) and Angus (constant age). At constant fat thickness, LM steaks from Wagyu-sired steers had higher ($P < 0.05$) tenderness ratings than LM steaks from Hereford-sired steers. At constant percentage of fat trim, LM steaks from Wagyu-sired steers had higher ($P < 0.05$) tenderness ratings than did longissimus from Hereford- and Friesian-sired steers. At constant marbling, 14-d LM steak tenderness ratings did not vary ($P > 0.05$) among sire breeds.

Longissimus thoracis steaks from Wagyu-sired steers were juicier ($P < 0.05$) than those from Friesian-sired steers at constant age (Table 5). At constant weight, LM steaks from Wagyu-sired steers had higher ($P < 0.05$) juiciness ratings than those from all other sire breeds except Norwegian Red and Swedish Red and White. At constant fat thickness, LM steaks from Wagyu-, Norwegian Red-, and Swedish Red and White-

**Table 6**. Effect of sire breed on least squares means for chemical composition (wet-weight basis) of raw and cooked longissimus thoracis at 471 d of age

| | Raw | | | Cooked | | |
|---|---|---|---|---|---|---|
| Sire breed | Lipid, % | Moisture, % | Protein, %[a] | Lipid, % | Moisture, % | Protein, %[a] |
| $\mu$ ± SEM | 5.4 ± 0.09 | 71.8 ± 0.08 | 22.8 ± 0.03 | 6.5 ± 0.10 | 64.2 ± 0.10 | 29.3 ± 0.07 |
| Hereford | 4.9 | 72.4 | 22.7 | 6.0 | 64.6 | 29.4 |
| Angus | 6.2 | 71.1 | 22.7 | 7.4 | 63.5 | 29.1 |
| H×, A× | 5.5 | 71.8 | 22.7 | 6.7 | 64.1 | 29.2 |
| Norwegian Red | 5.5 | 71.6 | 22.9 | 6.5 | 64.2 | 29.3 |
| Swedish Red and White | 5.1 | 71.8 | 23.1 | 6.2 | 64.3 | 29.5 |
| Friesian | 4.8 | 72.3 | 22.9 | 5.9 | 64.5 | 29.6 |
| Wagyu | 5.8 | 71.4 | 22.8 | 7.0 | 63.7 | 29.3 |
| LSD[b] | 0.5 | 0.5 | 0.4 | 0.6 | 0.5 | 0.4 |

[a]Calculated by difference.
[b]LSD = least significant difference among means, $P < 0.05$.

sired steers were juicier ($P < 0.05$) than LM steaks from Hereford- and Angus-sired steers. At constant marbling, LM steaks from Swedish Red and White- and Hereford-sired steers had higher ($P < 0.05$) juiciness ratings than LM steaks from Angus-sired steers. At constant fat trim percentage, LM steaks from Wagyu-sired steers had higher ($P < 0.05$) juiciness ratings than LM steaks from Hereford- and Angus-sired steers, whereas LM steaks from Norwegian Red-sired steers was juicier ($P < 0.05$) than LM steaks from Angus-sired steers.

There were no differences ($P > 0.05$) detected among sire breeds in LM beef flavor intensity ratings at any end point except constant carcass weight (Table 5). At constant weight, LM steaks from Wagyu-sired steers had more ($P < 0.05$) intense beef flavor than did LM steaks from Hereford-sired steers; however, the magnitude of the difference indicated it was of little practical importance.

With only three or four observations per breed type, Busboom et al. (1993) reported that after feeding for 524 d, loin steaks from Japanese Wagyu received higher tenderness ratings from a trained sensory panel than did steaks from Angus or Longhorn, but received tenderness ratings similar to those for American Wagyu and USDA Choice steaks. No differences were detected in other sensory traits. Consumer evaluation of loin steaks found Japanese Wagyu to be more tender than Angus or USDA Choice, but not different from American Wagyu (Busboom et al., 1993). May et al. (1993) compared 10 Angus and 10 Wagyu crosses fed a Japanese diet for 552 d, and reported no difference in any trained sensory panel traits; however, consumer triangle tests detected differences between the breeds that were attributed to tenderness, flavor, juiciness, fatty taste, or some combination of these. Mir et al. (1999) reported that shear force values were not different among LM steaks from Continental crosses or 50 or 75% Wagyu steers.

Results from previous cycles of GPE (Koch et al., 1976, 1979, 1982b; Wheeler et al., 1996, 2001) have indicated a similar mean LM steak 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 steak tenderness is about the same as variation within breeds (Wheeler et al., 1996, 2001).

### *Longissimus Thoracis Chemical Composition*

Chemical composition of raw LM adjusted to 471 d of age indicated that LM from carcasses of Angus- and Wagyu-sired steers had the highest ($P < 0.05$) percentages of lipid, followed by Norwegian Red- and Swedish Red and White-sired steers, and that the LM from Friesian- and Hereford-sired steers tended to have the lowest percentages of lipid (Table 6). Differences among sire breeds in the percentage of cooked LM lipid were similar to those for raw LM. Sire breeds differences in LM moisture percentage were inversely related to lipid differences. Raw and cooked LM from carcasses of Angus- and Wagyu-sired steers tended to have the lowest percentages of moisture. No sire breed differences ($P > 0.05$) in protein content were detected in raw LM. Differences among sire breeds for percentage moisture in the cooked LM were statistically significant ($P < 0.05$) but were small in magnitude and appeared to be of little practical importance.

Lunt et al. (1993) reported raw LM from American Wagyu was higher in ether extract (18.9%) than was the LM from Angus (14.5%). Mir et al. (1999) reported that across 2 yr, inconsistent differences in LM fat percentage were detected among Continental crosses and 50 and 75% Wagyu steers and heifers.

### *Heritabilities 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 ($\sigma_g$) and phenotypic ($\sigma_p$) variation. However, phenotypic

**Table 7**. Variation among sire breeds for carcass and palatability traits at 471 d of age

| Trait | R[a] | $h^2 \pm SE$[b] | $\sigma_g$[c] | $2R/\sigma_g$ | $\sigma_p$[d] | $R/\sigma_p$ |
|---|---|---|---|---|---|---|
| Live weight, kg | 76 | 0.31 ± 0.16 | 23.34 | 6.51 | 42.03 | 1.88 |
| Hot carcass weight, kg | 46 | 0.17 ± 0.15 | 11.10 | 8.29 | 26.88 | 1.71 |
| Dressing percent | 0.9 | 0.15 ± 0.15 | 0.57 | 3.16 | 1.51 | 0.60 |
| Adjusted fat thickness, cm | 0.57 | 0.54 ± 0.17 | 0.26 | 4.38 | 0.35 | 1.63 |
| Longissimus area, $cm^2$ | 3.5 | 0.37 ± 0.16 | 4.26 | 1.64 | 6.99 | 0.50 |
| Kidney, pelvic, heart fat, % | 0.38 | 0.06 ± 0.14 | 0.13 | 5.85 | 0.49 | 0.78 |
| Yield grade | 0.8 | 0.49 ± 0.17 | 0.38 | 4.21 | 0.54 | 1.48 |
| Marbling | 65 | 0.35 ± 0.16 | 42.30 | 3.07 | 71.08 | 0.91 |
| Retail product yield, % | 2.3 | 0.71 ± 0.17 | 2.38 | 1.93 | 2.83 | 0.81 |
| Retail product weight, kg | 25 | 0.49 ± 0.17 | 11.98 | 4.17 | 17.21 | 1.45 |
| Raw longissimus lipid, % | 1.4 | 0.27 ± 0.16 | 0.75 | 3.73 | 1.43 | 0.98 |
| Cooked longissimus lipid, % | 1.5 | 0.32 ± 0.16 | 0.95 | 3.16 | 1.67 | 0.90 |
| Warner-Bratzler shear force, kg | 0.41 | 0.16 ± 0.15 | 0.25 | 3.28 | 0.63 | 0.65 |
| Tenderness | 0.35 | 0.25 ± 0.19 | 0.35 | 2.00 | 0.70 | 0.50 |
| Juiciness | 0.15 | 0.24 ± 0.18 | 0.16 | 1.88 | 0.33 | 0.45 |
| Beef flavor intensity | 0.08 | 0.40 ± 0.19 | 0.17 | 0.94 | 0.27 | 0.30 |

[a]R = Range in sire breed means.
[b]$h^2$ = Heritability.
[c]$\sigma_g$ = Genetic standard deviation.
[d]$\sigma_p$ = Phenotypic standard deviation.

variation was expressed without doubling R, thus representing $F_1$ progeny phenotypic variation. Heritability estimates for various carcass, yield, and palatability traits ranged from very low ($h^2 = 0.06$ for KPH percentage) to relatively high ($h^2 = 0.71$; percentage of retail product yield). Heritabilities of carcass traits ranged from low to high and were similar to those reported by Wheeler et al. (1996) and Koch et al. (1982a), but lower for many carcass traits than reported by Wheeler et al. (2001). Heritabilities of marbling and measures of LM chemical lipid were moderate and similar to one another. 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 heritabilities reported in the literature (reviewed by Koch et al., 1982a). 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 higher than those reported previously (Wheeler et al., 1996, 2001).

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 were about the same or lower for most traits compared to values reported by Wheeler et al. (1996, 2001). Hot carcass weight had more variation among breeds than within breeds. Live weight and percentage of KPH fat had about the same amount of variation within as among breeds. All other 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 steak tenderness within breeds as among the most extreme breeds for that trait. Phenotypic variation in carcass and palatability traits was similar to, or slightly less than, that reported by Wheeler et al. (1996, 2001).

As was observed in Cycles I to V of GPE, little inherent genetic variation in juiciness and beef flavor intensity was detected in Cycle VI. Phenotypic variation in tenderness rating was about twice that of variation in ratings of juiciness and beef flavor intensity (CV 14.8, 8.3, and 6.4%, 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 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, but not to all palatability traits. Tenderness traits had high genetic correlations to several carcass traits, but not to marbling. Retail product yield had high genetic correlations to most fatness traits. Juiciness rating had high genetic correlations to raw LM lipid percentage, but not marbling or cooked LM lipid percentage. Shear force had moderate to low genetic correlations to carcass and LM lipid traits and high genetic correlations to live and carcass weight. Tenderness rating was more strongly related to most carcass traits than was shear force. Beef flavor intensity rating had moderate to high genetic correlations to weight, fatness, and palatability traits.

Phenotypic correlations were not as high as genetic correlations (Table 8). Moderate phenotypic correlations were detected between hot carcass weight and fat thickness, LM area, and yield grade. Phenotypically, marbling was strongly related to measures of LM lipid and retail product yield. Yield grade had high phenotypic correlations to fat thickness and retail product

**Table 8**. Genetic and phenotypic correlation coefficients among carcass and palatability traits at 471 d of age[a]

| | Trait | | | | | | |
|---|---|---|---|---|---|---|---|
| Trait | LWT | HCWT | AFT | LA | YG | MARB | RPY |
| Live weight, LWT | | 0.95 | 0.27 | 0.44 | 0.30 | 0.06 | –0.26 |
| Hot carcass weight, HCWT | 0.99 ± 0.06 | | 0.31 | 0.51 | 0.30 | 0.05 | –0.26 |
| Adj. fat thickness, AFT | 0.08 ± 0.30 | 0.05 ± 0.40 | | –0.04 | 0.81 | 0.28 | –0.65 |
| Longissimus area, LA | 0.12 ± 0.35 | 0.37 ± 0.38 | –0.45 ± 0.30 | | –0.46 | –0.09 | 0.20 |
| USDA yield grade, YG | 0.07 ± 0.31 | –0.12 ± 0.40 | 0.90 ± 0.07 | –0.83 ± 0.46 | | 0.28 | –0.69 |
| Marbling score, MARB | –0.45 ± 0.36 | –0.98 ± 0.59 | 0.53 ± 0.25 | –0.82 ± 0.40 | 0.58 ± 0.25 | | –0.49 |
| Retail product yield, RPY | 0.11 ± 0.29 | 0.33 ± 0.43 | –0.86 ± 0.37 | 0.34 ± 0.24 | –0.66 ± 0.36 | –0.77 ± 0.40 | |
| Raw lipid, RLIPID[b] | –0.66 ± 0.40 | 1.00[c] ± 0.65 | 0.27 ± 0.30 | –0.40 ± 0.38 | 0.14 ± 0.32 | 0.98 ± 0.17 | –0.51 ± 0.40 |
| Cooked lipid, CLIPID[b] | –0.12 ± 0.37 | –0.40 ± 0.49 | 0.54 ± 0.26 | –0.12 ± 0.35 | 0.34 ± 0.28 | 0.81 ± 0.19 | –0.81 ± 0.43 |
| Warner-Bratzler shear force, WBS | 0.85 ± 0.64 | 1.00[c] ± 1.00 | 0.04 ± 0.41 | 0.57 ± 0.51 | 0.15 ± 0.43 | –0.03 ± 0.49 | 0.03 ± 0.37 |
| Tenderness, TEND | 1.00[c] ± 1.00 | NE[d] | –0.63 ± 0.50 | –0.49 ± 0.54 | –0.61 ± 0.49 | –0.08 ± 0.42 | 0.30 ± 0.34 |
| Juiciness, JUICY | 0.17 ± 0.93 | NE[d] | 0.28 ± 0.42 | –0.16 ± 0.49 | 0.19 ± 0.42 | 0.21 ± 0.41 | –0.41 ± 0.40 |
| Beef flavor intensity, FLAV | –0.73 ± 0.98 | NE[d] | 0.29 ± 0.33 | –0.43 ± 0.39 | 0.35 ± 0.34 | 0.15 ± 0.34 | –0.36 ± 0.30 |

| | Trait | | | | | |
|---|---|---|---|---|---|---|
| Trait | RLIPID | CLIPID | WBS | TEND | JUICY | FLAV |
| Live weight, LWT | 0.11 | 0.06 | –0.01 | –0.14 | –0.09 | –0.02 |
| Hot carcass weight, HCWT | 0.11 | 0.06 | –0.01 | –0.14 | –0.09 | –0.02 |
| Adj. fat thickness, AFT | 0.27 | 0.26 | 0.00 | –0.11 | 0.04 | 0.03 |
| Longissimus area, LA | 0.00 | –0.07 | 0.05 | –0.13 | –0.16 | –0.02 |
| USDA yield grade, YG | 0.23 | 0.26 | –0.03 | –0.05 | 0.08 | 0.03 |
| Marbling score, MARB | 0.64 | 0.59 | –0.15 | 0.11 | 0.23 | 0.14 |
| Retail product yield, RPY | –0.40 | –0.46 | 0.01 | 0.08 | –0.12 | –0.09 |
| Raw lipid, RLIPID[b] | | 0.57 | –0.12 | 0.10 | 0.22 | 0.17 |
| Cooked lipid, CLIPID[b] | 1.00[c] ± 0.22 | | –0.17 | 0.10 | 0.21 | 0.18 |
| Warner-Bratzler shear force, WBS | –0.04 ± 0.55 | 0.07 ± 0.52 | | –0.62 | –0.26 | –0.10 |
| Tenderness, TEND | –0.23 ± 0.50 | –0.67 ± 0.51 | –1.00[c] ± 1.00 | | 0.21 | 0.08 |
| Juiciness, JUICY | 0.92 ± 0.50 | 0.13 ± 0.49 | –0.90 ± 1.00 | 0.68 ± 0.47 | | 0.38 |
| Beef flavor intensity, FLAV | 0.41 ± 0.39 | 0.53 ± 0.38 | –0.69 ± 1.00 | 0.09 ± 0.45 | 0.77 ± 0.36 | |

[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 (wet-weight basis).
[c]Estimate exceeded 1.00 and thus was set at 1.00.
[d]NE = not estimable.

yield. Phenotypically, retail product yield was more highly correlated to fat thickness and yield grade than was marbling score. Raw LM lipid percentage had a slightly higher phenotypic correlation to marbling score than to cooked LM lipid percentage. Phenotypically, shear force and tenderness rating were strongly correlated only to each other, although measures of tenderness were not strongly related to beef flavor intensity and juiciness ratings.

## Implications

Differences exist among and within cattle sire breeds in carcass and meat palatability traits. Selection of sire breed and end point of production are critical in order for producers to successfully target carcass and longissimus characteristics. Among the sire breeds evaluated in this cycle of the Germplasm Evaluation Project, Wagyu-sired steers had the highest percentage of USDA Choice, Yield grade 1 and 2 carcasses, were among the highest in longissimus thoracis steak tenderness, had greater retail product yield than the British sire breeds, but were the smallest of all the sire breeds. The Scandinavian sire breeds had greater retail product yields, similar longissimus thoracis steak tenderness, a higher percentage of USDA Choice, Yield grade 1 and 2 carcasses, but lighter carcasses than the British sire breeds. These results provide producers with more information when deciding which sire breeds will maximize profit potential in their production situation.

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