Growth and Pubertal Development of F_1 Bulls from Hereford, Angus, Norwegian Red, Swedish Red and White, Friesian, and Wagyu Sires

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ABSTRACT: The objective of the study was to characterize body growth, testicular development, and puberty from 8 to 14 mo of age in bulls (n = 120) produced by mating sires from Hereford, Angus, Norwegian Red, Swedish Red and White, Friesian, and Wagyu breeds to MARC III (¼ Hereford, ¼ Angus, ¼ Red Poll, and ¼ Pinzgauer) cows. Traits evaluated were birth weight, weaning weight (at 215 d), yearling weight, ADG from 8 to 14 mo of age, paired testicular volume growth from 8 to 14 mo of age, age at puberty (determined by production of 50×10^6 sperm with 10% motility), age at freezable semen (determined by production of 500×10^6 sperm with 50% motility), and, at 15 mo of age, paired testicular weight and daily sperm production per testis pair. There was an effect of sire breed (P = 0.03) for age at puberty; animals with Wagyu and Swedish Red and White inheritance reached puberty at a later date (302 and 302 d of age, respectively) compared with Angus-sired bulls (268 d). Age at puberty for Hereford-, Norwegian Red-, and Friesian-sired bulls was 270, 271, and 278 d, respectively. Differences in BW were observed (P = 0.03) at birth; bulls with Hereford and Friesian were heavier at birth (43 and 41 kg, respectively) compared with those with Norwegian Red, Swedish Red and White, and Wagyu inheritance (39, 38, and 38 kg, respectively). Differences in BW were also observed at 1 yr of age (P = 0.001), where the heaviest animals were those sired by Angus (450 kg), whereas the lightest animals were those sired by Wagyu (403 kg). Bulls with Wagyu inheritance had the lowest (P = 0.04) ADG (1.12 kg/d) compared with bulls with inheritance from Hereford (1.22 kg/d), Angus (1.28 kg/d), Norwegian Red (1.24 kg/d), Swedish Red and White (1.25 kg/d), and Friesian (1.27 kg/d). Differences in scrotal growth rate were not significant (P = 0.99). They ranged from 1.95 in Angus-sired to 1.66 cm^3/d in Wagyu-sired bulls. There were no differences (P = 0.80) for age at freezable semen (335 ± 10 d). At slaughter (15 mo of age), there were no differences (P = 0.62) for paired testicular weight (603 ± 28 g) and daily sperm production ($10.6 \times 10^9 \pm 0.9 \times 10^9$ per testis pair). Growth of bulls with Wagyu inheritance was slower, and bulls with Wagyu or Scandinavian inheritance reach puberty at an older age than bulls with Angus inheritance.

Key words: beef cattle, bull, puberty, semen, testes

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INTRODUCTION

The sixth cycle of the Germplasm Evaluation Program (**GPE**), developed at the US Meat Animal Research Center, characterizes breeds representing several biological types of cattle. It included 2 Scandinavian breeds (Norwegian Red and Swedish Red and White), Friesian (European dual-purpose, with no Holstein inheritance), Wagyu (Japanese Black and Japanese Red), and 2 British breeds (Hereford and Angus). Growth, carcass composition, and meat quality traits have been evaluated in steers and heifers of this cycle (Cundiff et al., 2001; Wheeler et al., 2004; Casas and Cundiff, 2006).

The increasing use of EPD information and AI by beef cattle producers has placed greater value on early puberty, larger testis size, and increased sperm production by individual bulls. Thus, there is a need for characterization of reproductive traits in bulls representing diverse beef breeds. An evaluation of reproductive development of beef bulls in cycle V of the GPE (Lunstra and Cundiff, 2003) compared 3 heat-tolerant breeds (Brahman, Boran, and Tuli) and 1 continental breed

[1]Mention of a trade name, proprietary product, or specified equipment does not constitute a guarantee or warranty by the USDA and does not imply approval to the exclusion of other products that may be suitable.

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Table 1. Number of F_1 bulls evaluated for pubertal development in the Germplasm Evaluation Project (cycle VI) by sire breed and year of birth

	Year		
Sire breed	1997	1998	Total
Hereford	10	7	17
Angus	10	10	20
Norwegian Red	7	7	14
Swedish Red and White	5	8	13
Friesian	13	15	28
Wagyu	16	12	28
Total	61	59	120

(Belgian Blue) with 2 British breeds (Hereford and Angus).

The objective of the current study was to extend the previous evaluations conducted in GPE cycle V and characterize F_1 bulls from GPE cycle VI for growth, testicular development, and puberty.

MATERIALS AND METHODS

Animals

The US Meat Animal Research Center Animal Care and Use Committee approved these experimental procedures.

Bulls for this study were produced by MARC III (¼ Hereford, ¼ Angus, ¼ Red Poll, ¼ Pinzgauer) cows as part of cycle VI of the GPE program. Wheeler et al. (2004) described the mating scheme to produce these bulls. Briefly, cows were mated by AI to Hereford, Angus, Norwegian Red, Swedish Red and White, Friesian, or Wagyu sires. A total of 81 sires were used to produce 120 bull calves. Bull calves were born during the spring of 1997 (n = 61) and 1998 (n = 59). Table 1 shows the number of animals born by sire breed and year.

Management and Data Collection

Bull calves were weaned at 215 ± 1 d of age and were fed a diet of corn silage, rolled corn, and protein-mineral-vitamin supplement (2.69 Mcal of ME/kg of DM, 12.9% of CP of DM) for 9 mo. After a 42-d acclimation period, BW, hip height, scrotal circumference, and length of each testicle were measured at 28-d intervals for 7 mo. All testicle measurements were done by 1 technician using procedures described by Lunstra et al. (1988). Concurrent with these measurements, electroejaculated semen collections began when the bulls reached a scrotal circumference of 26 cm and continued at 28-d intervals. Ejaculate volume, sperm concentration, and progressive motility were assessed for each ejaculate, using the methods described by Lunstra and Echternkamp (1982). Briefly, semen was maintained at 37°C, and progressive motility was determined from duplicate estimates using a microscope (400× magnification). Sperm concentration was determined from spectrophotometer (550 nm) readings of duplicate semen aliquots diluted 1:200 (vol/vol) with 1% formalin in 0.9% saline (Lunstra and Coulter, 1997). Puberty was defined as the age at which a bull first produced an ejaculate containing at least 50×10^6 sperm with >10% progressive motility (Lunstra et al., 1978). Age at first freezable semen was defined as the age at which a bull first produced an ejaculate containing at least 500×10^6 sperm with >50% progressive motility (Lunstra et al., 1993). The age of freezable semen represents a threshold after which freezing of semen becomes economically feasible. Semen collection ceased for each bull when they achieved 500×10^6 sperm with at least 50% progressive motility.

Table 2. Dates of periods in which traits were measured for 1997- and 1998-born bull calves

Period	1997-born bull calves	1998-born bull calves
1	December 11, 1997	December 15, 1998
2	January 12, 1998	January 12, 1999
3	February 10, 1998	February 9, 1999
4	March 6, 1998	March 9, 1999
5	April 2, 1998	April 6, 1999
6	April 30, 1998	May 4, 1999
7	June 3, 1998	June 1, 1999

To calculate paired testicular volume, scrotal circumference was assumed to represent the connected circumference of 2 apposed circles of equal radius, using the following equation (Lunstra et al., 1988): scrotal circumference = $(4 \times \text{radius}) + (2\pi \times \text{radius})$; no adjustment for thickness of the scrotum was used. Average testicular length was calculated by averaging the lengths of the left and right testicles. Assuming each testicle was a prolate spheroid, paired testicular volume was calculated using the following formula (Lunstra et al., 1988): paired testicular volume = $0.0396 \times$ average testicular length $\times$ (scrotal circumference)^2. Approximately 30 d after collection of the final data, bulls were slaughtered (approximately15 mo of age) at a local slaughter facility. Testes obtained at slaughter were weighed, and a sample of testicular parenchyma (10 g) was snap-frozen for subsequent homogenization to determine total daily sperm production per paired testes (Amann et al., 1974).

Traits Evaluated

Several traits were obtained once. These traits were birth weight, weaning weight (215 d), yearling weight, paired testicular weight, total daily sperm production per testis pair, age at puberty, and age at freezable semen. Other traits were measured in 7 periods. The dates on which the measurements were taken are shown in Table 2. These traits included scrotal circumference and right and left testicular length, height, and weight. Paired testicular volume was calculated each period using the formula previously described.

Table 3. Levels of significance, least squares means, and SEM for birth weight (BWT), weaning weight (WWT), and yearling weight (YWT) by sire breed

Item	BWT, kg	WWT,[1] kg	YWT, kg
P-value	0.030	0.155	0.001
Sire breed			
Hereford	42.6^{x}	250	432^{x}
Angus	40.3^{xyz}	251	450^{x}
Norwegian Red	38.8^{xyz}	247	430^{x}
Swedish Red and White	38.1^{yz}	237	421^{xy}
Friesian	41.3^{xy}	248	435^{x}
Wagyu	37.8^{z}	233	403^{y}
SEM	1.3	6	10

[x-z]Means without a common superscript within trait are different ($P < 0.05$).
[1]Weaning weight was measured at an average age of 215 d.

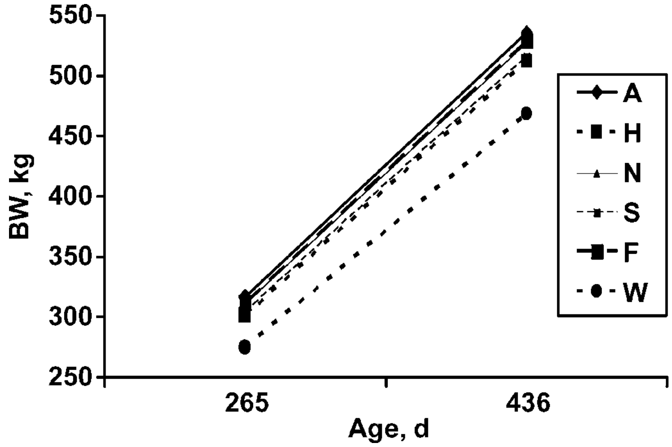

Figure 1. Linear regression of growth rate on age (from 265 to 436 d) by sire breed. Sire breeds included were Angus (A; 1.28 ± 0.04 kg/d), Hereford (H; 1.22 ± 0.04 kg/d), Norwegian Red (N; 1.24 ± 0.05 kg/d), Swedish Red and White (S; 1.25 ± 0.05 kg/d), Friesian (F; 1.27 ± 0.03 kg/d), and Wagyu (W; 1.12 ± 0.03 kg/d; differed from the other sire groups, $P < 0.039$).

Statistical Methods

For birth weight, weaning weight, yearling weight, paired testicular weight, age at puberty, and age at freezable semen, a fixed model was fitted using the GLM procedure (SAS Inst. Inc., Cary, NC). The model used included sire breed (Hereford, Angus, Norwegian Red, Swedish Red and White, Friesian, and Wagyu), 4 cow age groups (4 and 5 yr, 6 and 7 yr, 8 and 9 yr, and 10 yr and older), year of birth (1997 and 1998), the linear effect of birth date, and interactions of sire breed with cow age, sire breed with year of birth, and year of birth with cow age. Each sire produced on average 1.5 bull calves; consequently, sire was excluded as a random effect due to inaccurate variance component estimates.

Growth rate was evaluated for traits measured in several periods. Traits included were scrotal circumference, average testicular length, paired testicular volume, hip height, and BW. The GLM procedure of SAS was used to generate linear regressions. The model included similar effects as previously mentioned, with the addition of the fixed effect of age in days at each period and the interaction between sire breed and age in days. Sire was excluded as a random effect. Estimates were used to generate the slope of each sire breed and to make pairwise comparisons of sire breed slopes. A contrast was used to compare all sire breed slopes.

RESULTS

Growth

Means by sire breed of BW at birth, at weaning, and at 1 yr of age are shown in Table 3. Differences were detected ($P = 0.03$) at birth; bulls with Wagyu inheritance were the lightest, although similar to bulls from Angus and Norwegian Red sires. No differences by sire breed were detected ($P = 0.15$) for weaning weight. Sire breed influenced weight at 1 yr of age ($P = 0.001$); bulls with Wagyu inheritance were the lightest at 1 yr of age but were similar to Norwegian Red- and Swedish Red and White-sired bulls.

Growth rate from 9 to 14 mo of age is shown in Figure 1. Differences were observed ($P = 0.039$) among sire breeds; bulls with Wagyu inheritance had the slowest growth rate compared with Angus, Hereford, Norwegian Red, Swedish Red and White, and Friesian. Animals with Wagyu inheritance accrued the least BW when growing.

Pubertal Development

Table 4 shows the means by sire breed for age at puberty and at freezable semen, paired testicular weight, and total daily sperm production. Angus-sired bulls reached puberty at an earlier age compared with

Table 4. Levels of significance, least squares means, and SEM for age at puberty (AP), age at freezable semen (AFS), paired testicular weight (PTW), and total daily sperm production (TDSP) at slaughter by sire breed

Item	AP, d	AFS, d	PTW, g	TDSP[1]
P-value	0.026	0.803	0.625	0.591
Sire breed				
Hereford	270^{xy}	346	592	9,563
Angus	268^{x}	330	616	10,171
Norwegian Red	271^{xy}	327	633	10,719
Swedish Red and White	302^{yz}	331	617	12,069
Friesian	278^{xy}	337	593	10,204
Wagyu	302^{z}	341	570	11,194
SEM	10	10	28	913

[x-z]Means without a common superscript within trait are different ($P < 0.05$).
[1]Total daily sperm production is expressed as sperm production in millions.

Table 5. Levels of significance, growth rate from 9 to 14 mo of age, and SEM for scrotal circumference (SC), average testicular length (ATL), paired testicular volume (PTV), and hip height (HT) by sire breed[1]

Item	SC, cm/d	ATL, cm/d	PTV, cm^3/d	HT, cm/d
P-value	0.925	0.726	0.136	0.633
Intercept	15.02	5.58	–200.3	99.17
Sire breed				
Hereford	0.047	0.014	1.8	0.066
Angus	0.049	0.014	1.9	0.072
Norwegian Red	0.049	0.014	1.9	0.073
Swedish Red and White	0.048	0.015	1.8	0.072
Friesian	0.047	0.014	1.8	0.073
Wagyu	0.046	0.013	1.7	0.069
SEM	0.002	0.001	0.1	0.003

[1]No significant differences were found for any of the variables in this table.

bulls with Swedish Red and White and Wagyu inheritance ($P = 0.026$). Bulls produced by Hereford, Norwegian Red, and Friesian sires reached puberty at a similar age as Angus-sired bulls. The average age at freezable semen was 335 ± 4 d; this age was similar ($P = 0.80$) for all sire breeds. Average paired testicular weight and total daily sperm production were 603 ± 7 g and 10.7 ± 0.23 × 10^9 sperm/paired testes; sire breed was an unimportant factor ($P = 0.62$) affecting these 2 traits.

Rates for scrotal circumference growth ($P = 0.92$), average testicular length ($P = 0.73$), paired testicular volume ($P = 0.14$), and hip height ($P = 0.63$) were similar regardless of sire breed (Table 5). At 9 mo of age, the mean for scrotal circumference, average testicular length, paired testicular volume, and hip height were 26.9 ± 0.2 cm, 9.2 ± 0.1 cm, 270 ± 6 cm^3, and 116 ± 0.3 cm, respectively. At 14 mo of age, the mean for scrotal circumference, average testicular length, paired testicular volume, and hip height for all bulls were 35.4 ± 0.2 cm, 11.7 ± 0.1 cm, 585 ± 10 cm^3, and 129 ± 0.3 cm, respectively.

DISCUSSION

Wagyu-sired bulls in the current study reached puberty 34 d later than the Angus-sired bulls; in contrast, Tatman et al. (2001) observed that Wagyu were 53 d younger than Angus in straightbred bulls evaluated in Texas. These Angus bulls were proportionately older, 373 d, for age at puberty than the Wagyu bulls, 320 d, relative to their ages in the current study. Potential explanations for this difference include inappropriate sampling of each breed, the effect of heterosis associated with comparison of straightbred with crossbred bulls and environmental interactions. The study of Sosa et al. (2002) proposed that straightbred Wagyu bulls reach puberty at a younger age and smaller scrotal circumference than other breeds, whereas the current findings indicate that these differences are lost in crossbred Wagyu bulls. Environmental influences on age at puberty are readily apparent, because Brahman- and Tuli-sired bulls were older when reared in Florida relative to rearing in Nebraska, but scrotal circumference at puberty was similar at each location (Chase et al., 2001; Lunstra and Cundiff, 2003). Likewise, Almquist and Amann (1976) observed puberty in Holstein bulls at 273 d of age; however, in the report of Jimenez-Severiano (2002), Holstein and Brown Swiss bulls did not achieve puberty until 318 d of age. A major difference being that the Jimenez-Severiano (2002) study was conducted under tropical conditions. It is known that environment plays an important role in pubertal development (Fields et al., 1979; Godfrey et al., 1990).

Testis size of beef and dairy Bos taurus breeds evaluated in the current study were similar at 15 mo of age. Likewise, Lunstra et al. (1988) and Lunstra and Cundiff (2003) observed no differences in testicular size by 15 mo of age among *B. taurus* breeds. Jimenez-Severiano (2002) indicated that under tropical conditions, scrotal circumference of puberal Holstein and Brown Swiss bulls was similar to those of puberal bulls under temperate climate. However, differences have been observed when comparing testicular size between *B. taurus* and *Bos indicus* animals (Fields et al., 1979; Godfrey et al., 1990; Lunstra and Cundiff, 2003). Animals with *B. indicus* inheritance develop smaller testicles compared with animals with *B. taurus* inheritance.

Growth, age at puberty, and scrotal circumference have been modified in Hereford and Angus bulls during the past 40 yr. Wolf et al. (1965), using Hereford and Angus bull calves, indicated that yearling BW was 374 and 369 kg, respectively. Bulls currently being produced for these breeds are heavier at the same age (Lunstra and Cundiff, 2003; present study). Wolf et al. (1965) also indicated that age at puberty was 315 and 308 d for Hereford and Angus, respectively, whereas currently produced bulls of these breeds reach puberty by more than 40 d younger (Lunstra and Cundiff, 2003; present study). Also, scrotal circumferences at puberty reported in the current study for Hereford and Angus, 27.7 and 28.1 cm, respectively, are similar to those reported by Lunstra and Cundiff (2003); however, these are smaller than those observed by Wolf et al. (1965), who reported scrotal circumferences of 31.2 and 30.0 cm at puberty for Hereford and Angus bulls, respectively. In contrast, bulls of these 2 breeds now do not achieve scrotal circumferences greater than 30 cm until 1 yr of age or older. Lunstra et al. (1988), observed scrotal circumferences at 364 d of 30.1 and 31.9 cm for Hereford and Angus bulls, respectively, and Gregory et al. (1991) observed scrotal circumferences in yearling Hereford and Angus bulls of 33.1 and 30.3 cm, respectively. Currently used Hereford and Angus bulls are heavier and reach puberty at a younger age, with smaller scrotal circumference.

Postweaning ADG is a measure of cattle growth. Mir et al. (2002) showed that Limousin and Limousin × Wagyu animals grew faster than Wagyu animals. Myers et al. (1999) indicated that animals with ½ Wagyu, ¼ Angus, and ¼ Simmental inheritance grew slower than animals with ¾ Angus and ¼ Simmental, or animals with ¼ Angus and ¾ Simmental inheritance. Cundiff et al. (2001) evaluated contemporary steers from sires evaluated in the current study and observed that animals with Norwegian Red, Swedish Red and White, and Friesian inheritance were similar in postweaning ADG and were intermediate between animals with Hereford or Angus inheritance and animals with Wagyu inheritance. The latter group had the lowest ADG. Casas and Cundiff (2006) evaluated steers and heifers produced by sisters of the bulls included in the current study and found that animals with Wagyu inheritance had the lowest postweaning ADG, but ADG was similar to animals with Friesian and Norwegian Red inheritance. Results of the current study indicate that bulls with Wagyu inheritance have the lowest growth rate compared with bulls from Hereford, Angus, Norwegian Red, Swedish Red and White, and Friesian sires. Collectively, all studies indicate that animals with Wagyu inheritance have slower growth rate compared with other breeds.

Differences in BW at birth and at 1 yr of age were observed in the current study. Cundiff et al. (2001) indicate that animals with inheritance other than Wagyu were heavier at birth, when compared with animals with Wagyu inheritance. In the current study, animals with Wagyu inheritance had the lightest birth weight but were similar to animals with Angus, Norwegian Red, and Swedish Red and White inheritance. Cundiff et al. (2001) also indicate that at weaning, progeny of Hereford and Angus sires were heavier than progeny of other breeds. Progeny of Wagyu sires were the lightest at weaning compared with all other breeds.

Differences in the comparison of BW with other studies could be attributed to the number of individuals used. Cundiff et al. (2001) used the entire calf crop (more than 2,140 animals), and Casas and Cundiff (2006) evaluated the generation produced from the contemporary heifers of the bulls used in the current study (807 animals), compared with 120 bulls included in the current study. Another difference when comparing studies is that Cundiff et al. (2001) and Casas and Cundiff (2006) evaluated either steers or heifers for BW at different ages.

No differences were observed for scrotal circumference at puberty among all breeds. However, Sosa et al. (2002) indicated that American Wagyu have smaller scrotal circumferences than reported for other breeds. It is possible that the number of bulls evaluated in the current study hampered the ability to detect such differences. At 13 mo of age, bulls in the current study reached a scrotal circumference of 33 cm, whereas Wagyu animals used by Sosa et al. (2002), only reached a scrotal circumference of 30 cm at similar age. These differences could be attributed to heterotic effects in crossbred animals used in the current study. Regardless of sire breed, bulls reached puberty when scrotal circumference reached approximately 28 cm in diameter as previously reported (Lunstra et al., 1978, 1988, 1993). Dairy breed bulls used in beef production reach puberty at similar scrotal circumference as bulls of beef breeds.

In summary, bulls with Wagyu or Scandinavian inheritance reached puberty at an older age than Angus-sired bulls. Similar scrotal circumference and testicular volume were observed in all breeds at puberty; production of freezable sperm occurred at similar age, and their sperm production was similar at 15 mo of age. Growth rate of bulls with Wagyu inheritance was less than in bulls with inheritance from other beef and dairy breeds, indicating that producers using Wagyu would need greater emphasis on growth rate in genetic improvement programs.

LITERATURE CITED

Almquist, J. O., and R. P. Amann. 1976. Reproductive capacity of dairy bulls. XI. Puberal characteristics and postpuberal changes in production of semen and sexual activity of Holstein bulls ejaculated frequently. J. Dairy Sci. 59:986–991.

Amann, R. P., J. F. Kavanaugh, L. C. Griel Jr., and J. K. Vogelmayr. 1974. Sperm production of Holstein bulls determined from testicular spermatid reserves, after cannulation of rete testis or vas deferens, and by daily ejaculation. J. Dairy Sci. 57:93–99.

Casas, E., and L. V. Cundiff. 2006. Postweaning growth and carcass traits in crossbred cattle from Hereford, Angus, Norwegian Red, Swedish Red and White, Friesian, and Wagyu maternal grandsires. J. Anim. Sci. 84:305–310.

Chase, C. C., Jr., P. J. Chenoweth, R. E. Larsen, A. C. Hammond, T. A. Olson, R. L. West, and D. D. Johnson. 2001. Growth, puberty, and carcass characteristics of Brahman-, Senepol-, and Tuli-sired F_1 Angus bulls. J. Anim. Sci. 79:2006–2015.

Cundiff, L. V., T. L. Wheeler, S. D. Shackelford, M. Koohmaraie, R. M. Thallman, K. E. Gregory, and L. D. Van Vleck. 2001. Preliminary results from Cycle VI of the cattle Germplasm Evaluation Program at the Roman L. Hruska U. S. Meat Animal Research Center. USDA-ARS, RLHUSMARC Beef Cattle Research Program, GPE Progress Report No. 20:13. ARS/USDA, Clay Center, NE.

Fields, M. J., W. C. Burns, and A. C. Warnick. 1979. Age, season and breed effects on testicular volume and semen traits in young beef bulls. J. Anim. Sci. 48:1299–1304.

Godfrey, R. W., D. D. Lunstra, T. G. Jenkins, J. G. Berardinelli, D. A. Neuendorff, C. R. Young, and R. D. Randel. 1990. Effect of location and season on body and testicular growth in Brahman and Hereford bulls. J. Anim. Sci. 68:1520–1529.

Gregory, K. E., D. D. Lunstra, L. V. Cundiff, and R. M. Koch. 1991. Breed effects and heterosis in advanced generations of composite populations for puberty and scrotal traits of beef cattle. J. Anim. Sci. 69:2795–2807.

Jimenez-Severiano, H. 2002. Sexual development of dairy bulls in the Mexican tropics. Theriogenology 58:921–932.

Lunstra, D. D., and G. H. Coulter. 1997. Relationship between scrotal infrared temperature patterns and natural-mating fertility in beef bulls. J. Anim. Sci. 75:767–774.

Lunstra, D. D., J. D. Crouse, and L. V. Cundiff. 1993. Pages 90–92 in Puberty occurs at the same testis size in both *Bos taurus* and *Bos indicus* crossbred beef bulls. USDA ARS-71. RLHUSMARC Beef Cattle Research Program, Progress Report No. 4. ARS/USDA, Clay Center, NE.

Lunstra, D. D., and L. V. Cundiff. 2003. Growth and pubertal development in Brahman-, Boran-, Tuli-, Belgian Blue-, Hereford-, and Angus-sired F_1 bulls. J. Anim. Sci. 81:1414–1426.

Lunstra, D. D., and S. E. Echternkamp. 1982. Puberty in beef bulls: Acrosome morphology and semen quality in bulls of different breeds. J. Anim. Sci. 55:638–648.

Lunstra, D. D., J. J. Ford, and S. E. Echternkamp. 1978. Puberty in beef bulls: Hormone concentrations, growth, testicular development, sperm production and sexual aggressiveness in bulls of different breeds. J. Anim. Sci. 46:1054–1062.

Lunstra, D. D., K. E. Gregory, and L. V. Cundiff. 1988. Heritability estimates and adjustment factors for the effects of bull age and age of dam on yearling testicular size in breeds of beef bulls. Theriogenology 30:127–136.

Mir, P. S., Z. Mir, P. S. Kuber, C. T. Gaskins, E. L. Martin, M. V. Dodson, J. A. Elias Calles, K. A. Johnson, J. R. Busboom, A. J. Wood, G. J. Pittengers, and J. J. Reeves. 2002. Growth, carcass characteristics, muscle conjugated linoleic acid (CLA) content, and response to intravenous glucose challenge in high percentage Wagyu, Wagyu × Limousin, and Limousin steers fed sunflower oil-containing diets. J. Anim. Sci. 80:2996–3004.

Myers, S. E., D. B. Faulkner, T. G. Nash, L. L. Berger, D. F. Parrett, and F. K. McKeith. 1999. Performance and carcass traits of early-weaned steers receiving either a pasture growing period or a finishing diet at weaning. J. Anim. Sci. 77:311–322.

Sosa, J. M., P. L. Senger, and J. J. Reeves. 2002. Evaluation of American Wagyu sires for scrotal circumference by age and body weight. J. Anim. Sci. 80:19–22.

Tatman, S. R., C. C. Chase, T. W. Wilson, D. A. Neuendorff, A. W. Lewis, C. G. Brown, and R. D. Randel. 2001. Comparison of traits at puberty of four recently introduced breeds to Angus and Brahman bulls. J. Anim. Sci. 79(Suppl. 2):4. (Abstr.)

Wheeler, T. L., L. V. Cundiff, S. D. Shackelford, and M. Koohmaraie. 2004. Characterization of biological types of cattle (Cycle VI): Carcass, yield, and longissimus muscle palatability traits. J. Anim. Sci. 82:1177–1189.

Wolf, F. R., J. O. Almquist, and E. B. Hale. 1965. Prepuberal behavior and puberal characteristics of beef bulls on high nutrient allowance. J. Anim. Sci. 24:761–765.