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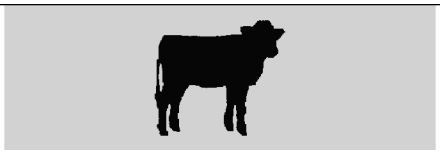

Case Study: Metabolic Hormone Profiles and Evaluation of Associations of Metabolic Hormones with Body Fat and Reproductive Characteristics of Angus, Brangus, and Brahman Heifers[1]

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Abstract

Metabolic hormone profiles and their associations with measures of body fat and reproduction were evaluated among Angus, Brangus, and Brahman heifers (n = 8/breed). Heifers of similar age from breeding programs in semi-arid environments were pen-fed for 10 wk prior to their yearling breeding season. At the beginning of this 10-wk period, heifers were 317 ± 8.6 d of age. Subsequently, heifers were exposed to breeding for 12 wk as they grazed the Chihuahuan Desert. Despite greater (P < 0.05) ADG in Angus heifers than in Brahman heifers, hip height was greater (P < 0.05) in Brahman heifers than in Angus or Brangus heifers at the end of the 10-wk period. Puberty occurred 40.5 d earlier (P < 0.05) in Angus heifers than in Brangus heifers, but was undetected in Brahman heifers of these ages. Serum concentrations of leptin were positively associated (r ≥ 0.27, P ≤ 0.05) with measures of body fat across breed groups. Concentrations of this hormone during wk 4 to 10 were greater (P < 0.05) in Angus than in Brangus, and greater in Brangus than in Brahman heifers. Conversely, serum concentrations of IGF-I were greater (P < 0.05) in Brangus and Brahman heifers than Angus heifers during the 10 wk. Serum concentrations of glucose, insulin, leptin, growth hormone, and insulin-like growth factor-I determined at the end of the 10-wk period were not significant predictors of growth or reproductive traits. Results provide evidence to suggest that growth and reproductive observations herein were typical of Angus, Brangus, and Brahman heifers. Novel results from the study suggest differences exist among these breeds in serum concentrations of leptin and insulin-like growth factor-I in similar-age comparisons.

Key words: breed, heifer, insulin-like growth factor-I, leptin, puberty

Introduction

Puberty in heifers is influenced by age, growth rate, mature size, and ge-

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netics (Patterson et al., 1992). If calving by 24 mo of age is a management criterion within a beef production system, heifers must be pubertal by 15 mo of age. This is a challenge for production systems that use *Bos indicus*-influenced breeds. These cattle are older at puberty and have many behavioral and physiological differences relative to *Bos taurus* cattle, particularly in breeds of British ancestry (Chenoweth, 1994; Rodrigues et al., 2002; Bo et al., 2003). Hormones and metabolites involved in lipogenesis, lypolysis, or both are considered modulators of reproduction (Chandrashekar et al., 2004; Schneider, 2004). Relationships between metabolic hormones and puberty were observed in studies that evaluated associations of hormones relative to day of puberty (Garcia et al., 2002; 2003). However, endocrine profiles expressed on a similar-age basis may not parallel these findings, particularly among breeds of cattle known to have differing rates of sexual maturity. These were the findings suggested by Thomas et al. (2002) involving the hormones leptin and insulin-like growth factor-I (**IGF-I**) in Angus, Brangus (i.e., 3/8 Brahman and 5/8 Angus), and Brahman bulls. These bulls were derived from breeding programs of 2 semi-arid rangeland experiment stations in New Mexico, Chihuahuan Desert Rangeland Research Center, and the Corona Range and Livestock Research Center. Similar results involving metabolic hormones were also observed in Angus and Brahman cows from these experiment stations (Obeidat et al., 2002). However, relationships of metabolic hormones with reproductive traits have not been evaluated in heifers from these breeding programs.

The first objective of this case study was to compare metabolic hormone profiles among Angus, Brangus, and Brahman heifers of similar age as they advanced to their yearling breeding season. Hormones and metabolites included in these profiles were glucose, insulin, leptin, growth hormone (**GH**), and IGF-I. A second objective was to evaluate associations of serum concentrations of metabolites and metabolic hormones to measures of body fat and reproduction. Growth and reproductive performance were also compared among these breed groups to validate observations in this breeding program relative to published literature.

Materials and Methods

Description of Animals and Experimental Procedures. Procedures and protocols were approved by the Institutional Animal Care and Use Committee of New Mexico State University. Twenty-four Angus, Brangus, and Brahman heifers (n = 8/breed) were born between February 14 to April 16, 1999 from cows averaging 5.2 ± 2.6 yr. These animals were selected from a group of 85 heifers weaned from 3 locations in New Mexico and Arizona. No more than 2 heifers in each breed group were from a common sire. With this exception, heifers selected from each breed group did not share common ancestry based on a 3-generation pedigree. Once it was determined that a group of heifers existed in each breed group that fit these familial criteria, heifers were randomly selected from each breed group and managed as a single contemporary group. Angus heifers were selected from 20 heifer calves derived from 5 sires; Brangus heifers were selected from 50 heifer calves derived from 8 sires; and Brahman heifers were randomly selected from 15 heifer calves that were the progeny of 5 sires. Three of these Brahman heifers were derived from 10 heifers purchased from Pratt farms, Maricopa, AZ. These heifers were weaned from a registered Brahman herd managed for production in a desert rangeland system supported with irrigated forage. These heifers were weaned on September 1 and brought to the New Mexico State University campus farm on October 21. The other Angus, Brangus, and Brahman heifers were weaned and managed as described by Thomas et al. (2002) and Obeidat et al. (2002). Once all heifers were received on the New Mexico State University campus farm, they were pen-fed as a single group with ad libitum access to alfalfa, water, and mineral.

Beginning January 28, 2000, heifers were separated from the group of 85 weanlings and placed in a 1,984 m^2 pen with bunk space available for feeding 48 cattle. Heifers were pen-fed while being adapted to a corn-alfalfa-based diet of 14.9% CP and 75% TDN described by Thomas et al. (2002). Objective of the feeding regimen was to promote a rate of gain of = 1 kg/d. Heifers were adapted to the diet by replacing alfalfa with the diet at a rate of 20% every other day for 10 d. Heifers were pen-fed the ration ad libitum until estrous synchronized with a target AI date of April 16.

Data were collected for 10 wk from January 28 to April 16. Data included BW collected every 2 wk pre-feeding at 0800 h. Heifers were bled twice weekly via jugular venipuncture (Corvac serum separator tubes, Sherwood, St. Louis, MO) on Tuesday and Friday at 0800 h pre-feeding. Samples were allowed to clot at room temperature for 1 h; serum was separated by centrifugation at 1,000 × g for 20 min at 4°C, transferred to plastic vials, and stored at –20°C. Samples were later analyzed for concentrations of glucose, insulin, leptin, GH, IGF-I, and progesterone

Heifers were also implanted with 6 mg of norgestomet and given an i.m. injection of 5 mg estradiol valerate and 3 mg of norgestomet to synchronize estrous (Syncro-Mate B, Sanofi Animal Health, Overland Park, KS) 11 d before the end of the 10-wk data collection period. This regimen yielded AI dates of April 16 and 17. The implant was removed 9 d after implantation and heifers were observed for estrus for 48 h. Any heifer observed in estrus was artificially inseminated 12 h later. Blood and fecal samples were also collected from each heifer on the last 3 d of the 10-wk data collection period. Serum was assayed for concentrations of glucose, insulin, leptin, GH, IGF-I and proges-

terone. Data from these samples were used in prediction analyses. Fecal samples were assayed to estimate level of fecal output.

Estrous behavior was monitored using the HeatWatch system (DDx Inc., Denver, CO) and the procedures described by Flores et al. (2004). This system was used to evaluate estrous behavior during the 10-wk period and during the 48-h observation period following implant removal. Additionally, 48 h after norgestomet implant removal, a transrectal ultrasound unit (7 mHz probe; Aloka USA, Wallingford, CT) was used to count the number and measure the size of ovarian follicles. Large- (> 10 mm) and medium-sized (4 to 9.99 mm) follicles were counted. Length and width of each ovary was measured for estimation of ovarian area.

After the 10-wk data collection period (i.e., April 16), hip height was measured and body condition score (**BCS**) estimated for each heifer using a scale of 1 (i.e., emaciated) to 9 (i.e., obese; Beef Improvement Federation, 1996). Fat thickness and longissimus area per 100 kg of BW were also measured using an Aloka SSD-500-V diagnostic ultrasound unit equipped with a 3.5 MHz linear array transducer using procedures described by Perkins et al. (1992). Two wk after AI, heifers were transported 37 km to the Chihuahuan Desert Rangeland Research Center. Heifers were then separated by breed and managed with a bull of the corresponding breed for 12 wk from May 1 to August 1. Heifers grazed native desert rangeland during the forage growth period of the Chihuahuan Desert, which is typically May to September (Holechek et al., 2003). Bulls were greater than 27 mo of age and had passed a breeding soundness exam 45 d before the start of the breeding season. The bull to heifer ratio was 1:8. Pregnancy rate was determined via ultrasound and rectal palpation 60 d after the breeding season. Body weight and BCS were also determined at this time. Regarding age, heifers were 317 ± 8.6 d of age at the initiation of the 10-wk data collection period. Heifers averaged 396 d of age when synchronized and observed for estrus for AI, and averaged 502 d of age when natural service breeding ended August 1.

Fecal Output Estimates and Quality of Diet. Eleven days before the end of the 10-wk data collection period, heifers were orally administered boluses containing chromium sesquioxide (Captec Chrome, Captec NZ Ltd., Aukland, NZ) to evaluate fecal output. Boluses were designed to release 1.43 g of chromic oxide/d. After 7 d, fecal samples were collected per rectum from all heifers for 3 consecutive d at 0700 h to estimate fecal output. The 3 samples/animal were composited to account for daily variability and then frozen at –20°C. Feed samples were also collected and frozen on these days to assist in estimating fecal output by utilizing chemical composition and digestibility of diet as previously described by Obeidat et al. (2002) and Thomas et al. (2002).

Serum Hormone and Glucose Analyses and Puberty. Serum samples were thawed and randomized, and concentrations of hormones were determined in duplicate aliquots using RIA. Serum concentrations of leptin were determined in a single assay by the procedures of Delavaud et al. (2000) with an intraassay CV of 4.4%. Serum concentrations of GH were determined by procedures of Hoefler and Hallford (1987) in a single assay with an intraassay CV of 13%. Concentrations of serum insulin were determined in 2 assays using Coat-A-Count (Diagnostic Products Corp., Los Angeles, CA) according to manufacturer instructions and procedures of Reimers et al. (1982). Intra- and interassays CV for these assays were 6.5 and 6.3%, respectively. Serum concentrations of IGF-I were determined after extracting the sample with an acid-ethanol procedure and then assaying concentrations of IGF-I within the extracts using the methodologies of Berrie et al. (1995). Concentrations were determined in 2 assays with intra- and interassay CV of 6 and 12%, respectively. Serum concentrations of progesterone were determined in 2 assays using Coat-A-Count (Diagnostic Products Corp.) and manufacturer instructions and procedures of Schneider and Hallford (1996). Intra- and interassay CV were 5 and 6%, respectively. Age at puberty was determined using birth date and the day when 2 consecutive samples of progesterone were detected to be greater than 1.0 ng/mL during the 10-wk evaluation period. All serum samples were analyzed to verify that progesterone profiles were indicative of normal luteal activity and not a short cycle described by Dodson et al. (1988) and Zoellers et al. (1993). If an estrus event was recorded via the HeatWatch system and a subsequent rise in luteal progesterone was not detected, then the event was recorded and defined as non-puberal estrus as described by Nelsen et al. (1985) and Rutter and Randel (1986).

Serum concentrations of glucose were determined with enzymatic reagents and procedures from the Sigma-Aldrich Company (St. Louis, MO). Samples were randomized and then 10 assays were performed in 96-well microtiter plates. Assays were evaluated at 340 nm wavelength using MRX Microtiter Plate Reader (Dynatec Laboratories, Chantilly, VA). Each assay included standards and a set of high and low samples. If a CV for a duplicate was greater than 15%, analysis of the sample was repeated. Intra- and interassays CV were 6% and 7%, respectively.

Age Adjustments, ADG, and Statistical Analyses. Adjusted 205-d and yearling 365-d BW were determined according to guidelines of the Beef Improvement Federation (1996) using standard age of dam adjustments. Adjusted 365-d BW was estimated using BW collected at the end of the 10-wk data collection period. Average daily gain was estimated by regressing BW against time and using the slope as an estimate of ADG. These estimations and statistical analyses were conducted using the procedures of SAS (version 8.1; SAS Inst. Inc., Cary, NC).

Homogeneity of variance for each variable was tested using PROC UNIVARIATE and Levene's hovtest (Littell et al., 2002). Variances among breed groups were determined to be homogeneous with normal distribution. Thus, means were tabled as mean for each breed group subsequently followed by pooled standard error. Probability values less than 0.05 were considered significant in the analyses and values less than 0.10 were considered tendencies. Except for 205- and 365-d adjusted BW, age of heifer and age of dam were tested in each statistical model as a covariate; however; due to insignificance, these covariates were eliminated from the models.

Serum concentrations of glucose, insulin, leptin, GH, and IGF-I and BW collected during the 10-wk evaluation period were analyzed using a mixed procedure for a repeated measures split-plot design (Littell et al., 1996). The model included breed, day, and the interaction of breed × day with heifer nested within breed as the repeated term. Serum concentration of progesterone was also tested in each model as a covariate. However, it was not detected as significant source of variation, so it was eliminated from the models. The most appropriate covariance structure was selected for each analysis from the structures of compound symmetric, autoregressive order one, autoregressive heterogeneous, and unstructured using Akaike's Criterion and Swartz' Bayesian Criterion. The covariance structure of compound symmetric was determined as the most appropriate. When a breed, day, or breed × day interaction ($P < 0.05$) was observed, means were separated using preplanned pair-wise comparisons within this ANOVA of least squares means generated with PDIFF.

Hip height, BCS, longissimus area per 100 kg of BW, fat thickness, fecal output per 100 kg of BW, age at puberty, number of large- (≥10 mm) and medium-sized (4 to 9.99 mm) follicles, ovarian area, and variables output from the HeatWatch system were analyzed using a one-way ANOVA within a GLM procedure (Littell et al., 2002). Breed was the independent variable in the model. When an effect of breed ($P < 0.05$) was observed, means were separated using preplanned pair-wise comparisons of least squares means generated with PDIFF. Chi-square analyses using the PROC FREQ procedure were used to compare the percentage of heifers among breeds for which measures of puberty, non-puberal estrus, presence of large follicles, and pregnancy were detected (Littell et al., 2002).

Data collected from the last 3 d of the 10-wk evaluation period were used to assess associations of serum concentrations of metabolites and metabolic hormones to measures of heifer performance. Metabolite and hormone data used in these analyses were from a 3 d average. Metabolite and hormones used in these analyses were glucose, insulin, leptin, GH, and IGF-I. Measures of heifer performance were BW, hip height, BCS, longissimus area per 100 kg of BW, fat thickness, and fecal output per 100 kg of BW. These hormone data were also used to evaluate associations with age at puberty. These associations were evaluated with residual correlation analyses with effect of breed removed using the PROC CORR procedure described by Cody and Smith (1997). These types of residual correlations among concentrations of hormones and glucose were also estimated.

Age at puberty as well as measures of body fat, variables collected with HeathWatch, and measures of ovarian structure were predicted using a GLM multivariate analysis (Littell et al., 2002). Breed served as a fixed effect in these analyses with age, weight, and serum concentrations of glucose, insulin, leptin, GH, and IGF-I serving as covariates. Covariates were tested for colinearity before model application. This model was also used within PROC GENMOD in prediction of the categorical traits of percent detected in estrus and percent pregnant from AI using the procedures described by Stokes et al. (2000).

Results and Discussion

Measures of growth and reproductive performance were evaluated among breed groups to validate observations in these breeding programs for semi-arid environments relative to published literature. In brief, heifers had similar Julian day of birth, BW at birth, and 205-d adjusted BW; however, Angus and Brangus heifers had greater ($P < 0.05$) adjusted 365-d BW than did Brahman heifers (Table 1). According to breeding values published in sire summaries of American Angus Association (St. Joseph, MO), American Brahman Breeders Association (Houston, TX), and International Brangus Breeders Association (San Antonio, TX) in 2000, the trait levels of these heifers appeared slightly below breed averages. This was not a surprising finding, as moderate-performing cattle have previously been suggested to be most suitable for semi-arid rangeland production systems (Winder et al., 1992; Kattnig et al., 1993; Winder et al., 2000).

Angus heifers had greater ($P < 0.05$) initial and final BW during the 10-wk growth evaluation period than did Brangus heifers, which had greater ($P < 0.05$) BW than Brahman heifers did on these days (Table 2). Angus heifers also had greater ($P < 0.05$) ADG than did Brahman heifers (Table 2). The interaction of BW and day was significant ($P < 0.05$) during the 10-wk evaluation period, as Angus heifers weighed more ($P<0.05$) than Brangus, which weighed more ($P<0.05$) than Brahman at each measurement. Heifers from these breeds had similar hip height at the beginning of the 10-wk data collection period, but Brahman heifers had greater ($P<0.05$) hip height than Angus or Brangus heifers at the end of the 10-wk data collection period (Table 2). Performance trends of these heifers paralleled their herd contemporary bulls and concurred with previous descriptions of growth in Brahman heifers (Vargas et al., 1998; Thomas et al., 2002).

Differences among breed groups were not detected in categorical repro-

TABLE 1. Least squares means of Julian day of birth, BW at birth, and adjusted 205- and 365-d BW in Angus, Brangus, and Brahman heifers.

Item	Angus	Brangus	Brahman	Pooled SE
n	8	8	8	—
Julian day of birth, d	73.9	75.5	77.1	7.7
BW at birth, kg	35.2	35.5	31.5	2.2
205-d adjusted BW, kg	238.3	231.0	232.5	11.6
365-d adjusted BW, kg	382.1[a]	367.0[a]	333.8[b]	16.7

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

ductive traits listed in Tables 2, 3, and 4. This result would be expected in analyses with n = 8 in each group; however, for traits of numerical measures, age at puberty, in the heifers that achieved puberty, was 40.5 d earlier ($P < 0.05$) in Angus heifers than in Brangus heifers (Table 2). Area of each ovary was similar among breed groups and averaged 72.3 ± 4.6 mm^2 48 h after norgestomet implant removal at 396 days of age. Numbers and area of large-sized follicles were similar among breed groups (Table 3), but Angus heifers had greater ($P < 0.05$) number of medium-sized follicles than Brangus or Brahman heifers at this age (Table 3). These findings parallel results of other studies reviewed by Bo et al. (2003), which evaluated medium-sized follicle populations among *Bos taurus* and *Bos indicus* cattle.

There are many other documented differences in reproductive characteristics between *Bos taurus* and *Bos indicus* cattle. Specifically, standing-estrus is usually more difficult to detect in *Bos indicus* cattle relative to *Bos taurus* cattle and occurs more frequently during the evening in *Bos indicus* cattle (Chenoweth et al., 1994; Bo et al., 2003). No differences were detected in measures of estrous characteristics among breed groups in this study. These results may have been a consequence of the fewer observations in later maturing Brahman and Brangus heifers monitored at this age. These results could have also been a consequence of additional variation attributed to non-puberal estrus, which was observed in 25% of the Angus heifers and 37.5% of the Brangus heifers. Non-puberal estrus would be de-

TABLE 2. Least squares means of growth and reproductive measures during a 10-wk data collection period in Angus, Brangus, and Brahman heifers.[a]

Item	Angus	Brangus	Brahman	Pooled SE
n	8	8	8	—
Growth and body measures				
Initial BW, kg	313.1[b]	287.2[c]	247.3[d]	9.0
Final BW, kg	421.2[b]	392.2[c]	332.2[d]	8.8
ADG, kg/d	1.6[b]	1.4[bc]	1.2[c]	0.1
Initial hip height, cm	114.6	115.1	117.6	2.1
Final hip height, cm	121.6[b]	123.0[b]	125.6[c]	1.1
Reproductive measures via serum concentration of progesterone				
Pubertal, %	87.5	62.5	0	—
Age at puberty, d	334.2[b]	374.5[c]	—	16.0
Estrous characteristics measured with HeatWatch(r)				
Detected in estrus,	87.5	50.0	0	—
Estrus events/heifer per 10-wk[e]	2.9	2.3	—	11.8
Number of standing events[e]	19.1	15.7	—	4.6
Duration of estrus, h[e]	11.6	7.5	—	4.0
Quiescent period, h[e]	3.8	3.7	—	1.4
Estrus onset, time of day, h[e]	1,344.4	1,482.5	—	250.9

[a]The 10-wk period was initiated when heifers were 317 ± 8.6 d of age.

[b–d]Within a row, means without a common superscript differ ($P < 0.05$).

[e]Means represent only heifers determined as pubertal via progesterone sampling or estrous characteristics observed with HeatWatch (DDx Inc., Denver, CO).

TABLE 3. Least squares means of measures of behavioral estrous, ovarian follicles, and body characteristics in Angus, Brangus, and Brahman heifers 396 ± 8.6 d of age.

Item	Angus	Brangus	Brahman	Pooled SE
n	8	8	8	—
Estrous characteristics measured with HeatWatch				
Detected in estrus, %	87.5	62.5	12.5	—
Number of standing events[a]	22.1	14.7	6.5	10.3
Duration of estrus, h[a]	12.3	8.6	6.2	3.5
Quiescent period, h[a]	3.6	3.8	4.9	1.1
Estrus onset, time of day, h[a]	1,256.1	1,383.3	345.4	75.3
Pregnancy and ovarian measures				
Pregnant from AI,%	62.5	50.0	0.0	—
With large-sized follicles (≥10 mm), %	62.5	62.5	12.5	—
Number of large-sized follicles (≥10 mm)[b]	1.2	1.0	1.0	0.1
Large follicle area (mm)[b]	12.4	14.1	15.0	1.8
Number of medium-sized follicles (4 to 9.9 mm) 5.3[c]	3.6[d]	3.3[d]	1.0	
Measures of body characteristics				
Longissimus area, cm^2/100 kg of BW	1.0	1.0	0.9	0.1
BCS[f]	6.1[c]	5.6[d]	5.1[e]	0.02
Fat thickness, cm	0.8[c]	0.6[d]	0.4[e]	0.02

[a]Means represent only heifers that estrous characteristics were observed with HeatWatch (DDx Inc., Denver, CO).

[b]Means represent only heifers with large-sized follicles (≥10 mm).

[c–e]Within a row, means without a common superscript differ ($P < 0.05$).

[f]BCS = body condition score.

fined as the occurrence of standing-estrus without a subsequent luteal-phase increase in serum concentration of progesterone during an estrous cycle (Nelsen et al., 1985; Rutter and Randel, 1986). Conversely, these results also could have been from the failure to detect standing-estrus that coincided with a luteal-phase increase in progesterone. Detection of standing-estrus followed by a luteal phase rise in serum concentration of progesterone occurred in 66.7% of the Angus heifers and 60% of the Brangus heifers. In both the Angus and Brangus heifers, 25% of the initial estrous cycles were short (i.e., <11 d).

Only 12.5% of Brahman heifers exhibited standing-estrus from synchronization and became pregnant from exposure to bulls by 502 d of age. Pubertal characteristics of these Brahman heifers are consistent with evaluations of developing Brahman bulls from these herds (Thomas et al., 2002) and other evaluations of Brahman heifers (Vargas et al., 1998). Also, results presented in Tables 2 through 4 appear similar to observations in Angus, Brangus, and Brahman heifers described by Martin et al. (1992) and Thallman et al. (1999). It is important to note that even though observations of this study were among breeds, it is probable to suggest similar results could occur within a breed if a great amount of variance exists in growth rate and hip height. This concept has been documented in studies evaluating breeds of similar ancestry, such as the various British *Bos taurus* breeds (Lamb et al., 1993; Rodriquez-Almeida et al., 1995; Bennett and Gregory, 2001).

In other evaluations of body growth and performance, no differences were detected among breed groups in longissimus area (Table 3).

TABLE 4. Pregnancy percent, BW, and body condition score (BCS) in Angus, Brangus and Brahman heifers 562 ± 8.6 d of age.

	Breed Group			Pooled
Item	Angus	Brangus	Brahman	SE
n	8	8	8	—
% pregnant	100.0	75.0	12.5	—
BW, kg	488.3[a]	411.5[b]	409.6[b]	13.7
BCS	6.0[a]	5.6[b]	5.5[b]	0.1

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

However, BCS and measures of fat thickness were greater ($P < 0.05$) in Angus heifers than in Brangus heifers, and Brangus heifers had greater ($P < 0.05$) fat thickness and BCS than did Brahman heifers (Table 3). Heifers were 396 ± 8.6 d of age when these data were collected. Angus heifers also had greater ($P < 0.05$) BW and BCS than Brangus or Brahman heifers in the fall of the year when heifers averaged 562 ± 8.6 d of age (Table 4).

Fecal output can be used to estimate feed intake, even though the technique yields varying magnitudes of error (Macoon et al., 2003). Fecal output averaged 0.6 ± 0.2 kg/100 kg of BW and was similar among breed groups at the end of the 10-wk data collection period. This is an interesting finding because Hunter and Seibert (1986) reported differences in rumen characteristics and feed intake levels among Hereford and Brahman cattle fed energy-dense diets. In another case study using heifers from the Brangus breeding program evaluated herein, Brangus heifers in a sire group experiencing early puberty were also the most feed efficient (Shirley et al., 2006). Feed intake is a complex trait with a primary sight of regulation being the hypothalamus. This regulation center is also influenced by metabolic hormones such as leptin, which is secreted by adipose tissue (Kalra et al., 1999).

The first objective and novelty of this study was evaluation of metabolic hormone profiles among Angus, Brangus, and Brahman heifers as they progressed to their yearling breeding season. Serum concentrations of leptin were greater (breed × day; $P < 0.05$) in Angus heifers than in Brangus heifers, which had greater serum leptin concentrations than did Brahman heifers during wk 4 through 10 of the 10-wk evaluation period. These data parallel measures of body fat (Tables 3 and 4). Concomitantly, serum concentrations of IGF-I were greater (breed × day; $P<0.05$) in Brangus and Brahman heifers relative to Angus heifers during wk 4 through 10 (Figure 1). No differences were detected among breed groups in serum concentrations of glucose, insulin, or GH during the 10-wk data collection period. However, serum concentrations of glucose declined ($P<0.05$) with time.

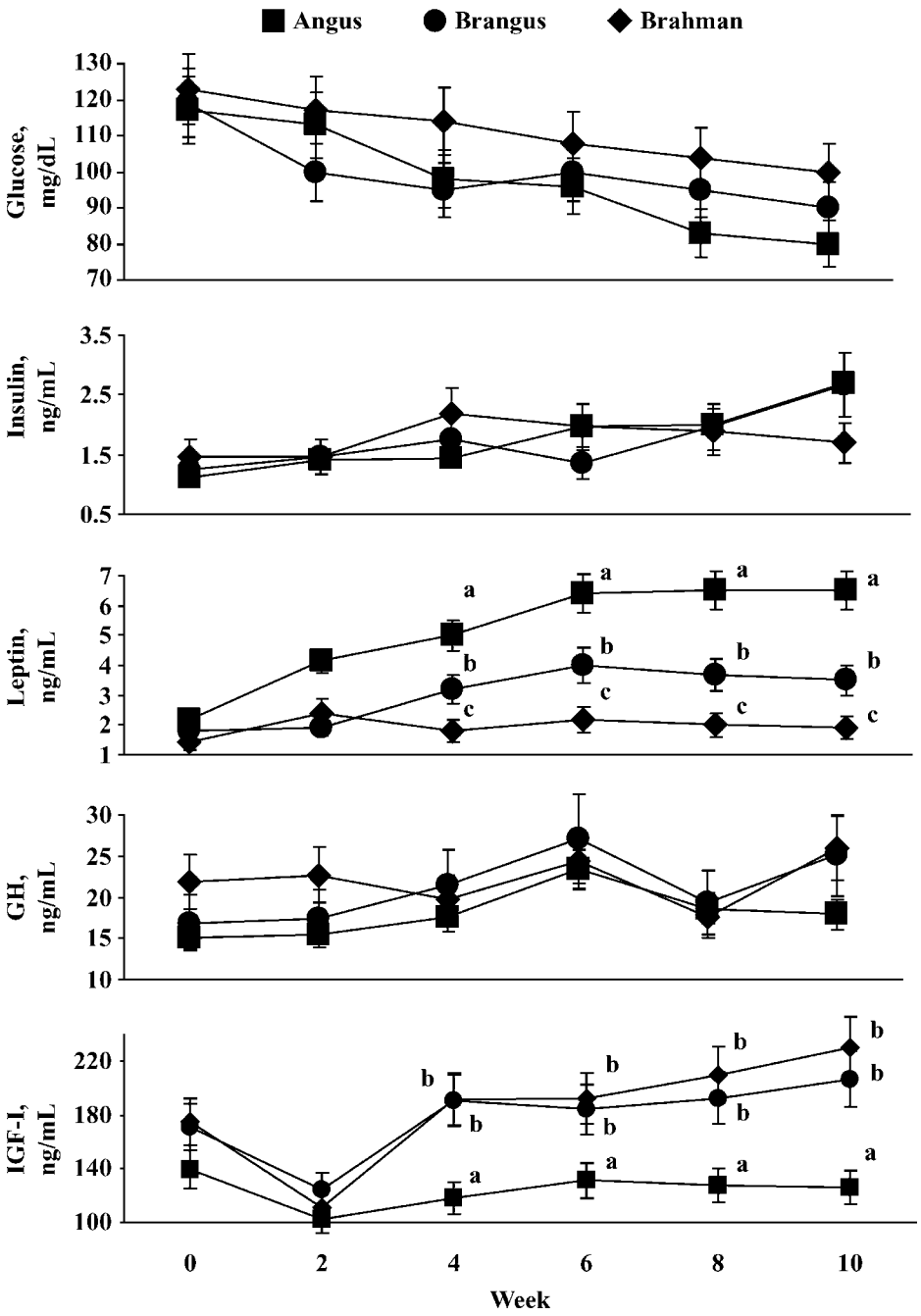

Figure 1. Serum concentrations of glucose, insulin, leptin, GH, and IGF-I in Angus, Brangus, and Brahman heifers (n = 8 heifers/breed group). Sample collection initiated when heifers were 317 ± 8.6 d of age. [a–c]Means within a panel differ (P < 0.05).

In growing bulls that were herd-contemporaries to the heifers in this study, Angus bulls had greater serum concentrations of leptin and IGF-I than Brangus or Brahman bulls (Thomas et al., 2002). Angus bulls also had greater scrotal circumference and serum concentrations of testosterone than Brahman bulls. This result could provide evidence to suggest that greater levels of circulating leptin and IGF-I are positively associated

with earlier testicular function in growing Angus bulls relative to growing Brahman bulls. Garcia et al. (2002; 2003) reported linear increases in circulating leptin and leptin gene expression as puberty approached in heifers. However, in the current study, differences among breed groups in serum concentrations of leptin occurred after many of the Angus heifers had achieved puberty. These results appear to conflict with the concept of a positive association of leptin with puberty. Several review articles have described a positive relationship between body fat and fecundity (Farooqi, 2002; Schneider, 2004). However, Yelich et al. (1995) suggested body fat may not be the sole regulator of puberty in beef heifers. These citations, the results involving Angus and Brangus bulls reported by Thomas et al. (2002), and observations herein suggest additional research is needed to fully understand the role of body fat and leptin in puberty of cattle.

Differences in tonic secretion patterns of GH have been observed among Holstein cows with normal fertility vs. infertility (Taylor et al., 2004). In the animal model utilized herein, studies involving intensive blood sampling procedures are needed to further characterize the episodic secretion patterns of GH and possibly pre- and post-prandial glucose and insulin levels before strong conclusions can be stated about their role in reproductive development. These studies are also needed to provide understanding as to why concentrations of these hormones and metabolites were similar in these breed groups of heifers in the current study, but differed among these breed groups in primiparous cows (Alvarez et al., 2000; Obeidat et al., 2002; Spicer et al., 2002). The liver synthesizes and secretes IGF-I in response to GH, and IGF-I is a known regulator of reproductive function (Giudice, 1992; Chandrashekar et al., 2004). It is unknown why concentrations of metabolic hormones such as IGF-I differ among breed groups and gender in animals from this breeding program. Therefore, these results warrant further studies comparing the animals on both an age- vs. maturity-constant basis.

The second objective of this study was to evaluate associations of serum concentrations of metabolites and metabolic hormones with measures of reproduction and with traits indicating growth and body fat levels. Residual Pearson's correlation coefficients, with the effect of breed removed, indicated serum concentrations of leptin were positively correlated ($P < 0.05$) with fat thickness (r = 0.30) and BCS (r = 0.27) collected at the end of the 10-wk data collection period. These results support observations of Buchanan et al. (2002), Delavaud et al. (2002), and Geary et al. (2003). However, leptin was not a significant source of variation in prediction of these traits or other measures of reproduction even though the model explained a large proportion of the variation ($R^2 \geq 0.74$). In prediction analyses of the endocrine variables of insulin, leptin, GH, and IGF-I, breed was a significant predictor ($P < 0.05$) of IGF-I, as was the covariate serum concentration of glucose. This prediction accounted for a moderate proportion of the variation ($R^2 = 0.59$); however, these types of predictions for serum concentrations of glucose, insulin, leptin, and GH were weak ($R^2 \leq 0.32$), as were predictions of growth and categorical traits reproductive traits. These weak predictions of reproductive traits were probably because most of the Angus heifers were pubertal at the age of 396 d, whereas only a few of the *Bos indicus* influenced-heifers had achieved puberty. These types of predictions for endocrine variables were more effective using the numerical trait data from bulls that were herd contemporaries to these heifers (Thomas et al., 2002) and in the studies of Garcia et al. (2002; 2003), which analyzed and presented endocrine data relative to day of puberty.

In summary, when compared on a similar-age basis, Angus heifers had greater growth rate and earlier age at puberty relative to Brangus heifers. Brahman heifers had the greatest hip height, but limited reproductive activity at these ages. Novelty of this case study was that Angus heifers had greater serum concentrations of leptin and levels of body fat relative to Brangus and Brahman heifers of these ages, but lesser serum concentrations of IGF-I. Brangus heifers had serum concentrations of leptin and IGF-I similar to Brahman heifers, but measures of reproductive parameters more similar to Angus than Brahman. Metabolic hormones such as leptin and IGF-I were not strong predictors of fecundity or other endocrine measures in heifers of these breeds at 396 d of age.

Implications

A heifer must become pregnant by 15 mo of age if she is to calve by 24 mo of age. In beef production systems utilizing *Bos indicus*-influenced heifers, achieving this management goal is challenging due to later sexual maturity of *Bos indicus* cattle. It appears that differing rate of reproductive maturity among Angus, Brangus, and Brahman heifers may be associated with differing concentrations of metabolic hormones such as IGF-I and leptin. However, these types of associations are difficult to interpret in studies comparing animals on a similar-age basis rather than days-relative-to puberty. Further knowledge of the relationships of metabolic hormones to reproductive development, particularly if comparisons are made on an age-constant basis, may be important for determining the most suitable management for breeding programs using *Bos indicus*-influenced germplasm.

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