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Body Composition and Energy Utilization by Steers of Diverse Genotypes Fed a High-Concentrate Diet During the Finishing Period: I. Angus, Belgian Blue, Hereford, and Piedmontese Sires

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ABSTRACT: Objectives of the study were to 1) describe body composition and composition of gain of crossbred steers sired by Angus, Hereford, Belgian Blue, or Piedmontese sires from Angus, Hereford, or MARC III dams and 2) determine the influence of sire and dam type on energy utilization during the finishing period. Beginning at 330 kg, 70 steers were adjusted to a high-corn diet and individual feeding. Steers were assigned, by sire and dam breed, to be killed as an initial slaughter group or fed either a limited amount or ad libitum for 140 d, then killed. Organ weights, carcass traits, and body composition were obtained. Effects included in the statistical model were nutritional treatment (T), sire breed (S), dam breed (D), and the S × T and D × T interactions. All traits were influenced ($P < .05$) by T. Sire influenced longissimus area, fat thickness, and quality and yield grade ($P < .01$); weight of hide, stomach complex, heart, lung, spleen, empty body fat, protein, ash, and energy; rates of fat, protein, and energy gains; and water, fat, ash, and energy content of gains ($P < .10$). Dam breed influenced ($P < .10$) DM and ME intake, fat thickness, yield grade, heart, lung, and spleen weights, and rates of water, fat, protein, and energy gains. Rates of DM or ME intake, live and empty body weights, and water, protein, ash, and energy gains were influenced ($P < .05$) by D × T. Neither S nor D influenced ($P > .10$) regressions of heat production on ME intake. Fasting heat production and maintenance were estimated to be 80.6 and 124.4 kcal ME/(kg$^{.75}$·d). The nonlinear relationship between energy gain (Y, kcal/[kg$^{.75}$·d]) and ME intake (X, kcal/[kg$^{.75}$·d]) was $Y = 74.69 \times (1 - 2.60 \times \exp(-.0159 \times (ME - 80.597)))$, and indicated energy gain approached an asymptote (74.69) as ME intake increased. This relationship also implies that efficiency of ME use for gain decreased as ME intake increased.

Key Words: Cattle, Body Composition, Organs, Maintenance, Weight Gain

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Introduction

Sire and dam breeds may have major influences on rate and composition of growth and feed efficiency (Smith et al., 1976; Gregory et al., 1994) of feedlot steers. Frequently, the observed differences in efficiency of growth have been attributed to differences in body composition. More specifically, differences in rates of water and protein accretion relative to the rate of fat accretion are thought to have a major influence on rate and efficiency of BW gain, primarily because of the lower energy content of water and protein than of fat. Conversely, higher maintenance costs have been associated with body protein than with body fat (Pullar and Webster, 1977; Ferrell et al., 1979). Variation in maintenance and efficiency of gain are frequently more highly associated with weight and metabolic activity of visceral organs such as the gut and liver than with body protein or fat or composition of gain (Ferrell and Jenkins, 1985; Ferrell, 1988). Greater visceral organ weights have been associated with increased milk production potential in mature cows and with increased feed intake in cattle, sheep, and other species. The increased milk production potential and increased feed intake have been linked to greater maintenance requirements (Ferrell and Jenkins, 1984, 1987). The objective of the present study was to evaluate the influence of sire breed (Angus, Hereford, Belgian Blue, or Piedmontese) and dam breed (Angus, Hereford, and MARC III) on weight of body components, carcass characteristics, body composition, and composition of gain. A second objective was to evaluate the influence of sire breeds differing in lean growth potential (Cundiff et al., 1995) or dam breeds differing in milk production potential (Gregory et al., 1992) on maintenance requirements and efficiency of gain of crossbred feedlot steers.

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Table 1. Diet formulation

Ingredient	Percentage of DM
Dry-rolled corn	83.80
Corn silage	13.00
Soybean meal	2.56
Limestone	.43
Urea	.14
Dicalcium phosphate	.04
Vitamin A, D, and E premix[a]	.012
Trace mineral premix[b]	.004
Sulfur	.004
Monensin premix[c]	.010
Calculated nutrient content[d]	
Metabolizable energy, Mcal/kg	3.13
NE_m Mcal/kg	2.14
NE_g, Mcal/kg	1.47
Crude protein, %	11.19
Calcium, %	.21
Phosphorus, %	.35

[a]Vitamin premix contained 8,800,000 IU vitamin A; 880,000 IU vitamin D; and 880 ppm vitamin E per kilogram.

[b]Trace mineral premix contained 13% Ca, 12% Zn, 8% Mn, 10% Fe, 1.5% Cu, .2% I, and .1% Co.

[c]Rumensin 80 (Elanco Animal Health, Indianapolis, IN).

[d]Energy and mineral concentrations in diet DM were calculated from tabular values (NRC, 1984). Crude protein was by Kjeldahl determination (N × 6.25).

Materials and Methods

Animals and Management. Steer calves (n = 70) were obtained from the Roman L. Hruska U.S. Meat Animal Research Center breeding project (Germ Plasm Evaluation Program, Cycle V). Steers were sired by Angus, Hereford, Belgian Blue, or Piedmontese bulls bred to Angus, Hereford, or MARC III (a four-breed composite consisting of ¼ Angus, Hereford, Pinzgauer, and Red Poll) dams as detailed subsequently. Steers were weaned at approximately 200 d of age and penned in two groups, and over an 8-wk period they were adjusted to a growing diet consisting of 66% corn silage, 22% rolled corn, and 12% supplement. They had ad libitum access to the growing diet until average weight was approximately 330 kg.

Steers were moved (January 6) to an individual feeding facility and assigned to initial slaughter, limit-fed, or ad libitum treatment groups by sire and dam breed. Steers were penned by sire breed, pooling Angus- and Hereford-sired steers, and treatment group in groups of eight steers per pen. Animals were fed individually by use of Calan-Broadbent headgates. Pens were in an open-fronted building and had concrete floors with no bedding provided. Steers were gradually switched to a high-concentrate diet (Table 1) over a 2-wk period and adapted to the facilities and diet. Numbers of steers assigned to the initial slaughter, limit-fed, and ad libitum groups by breed composition were as follows: Angus × Hereford (2, 2, and 2), Angus × MARC III (1, 2, and 0), Hereford × Angus (3, 3, and 3), Hereford × MARC III (2, 1, and 3), Belgian Blue × Angus (3, 2, and 4), Belgian Blue × Hereford (1, 1, and 1), Belgian Blue × MARC III (4, 5, and 3), Piedmontese × Angus (3, 3, and 2), Piedmontese × Hereford (1, 1, and 1), and Piedmontese × MARC III (4, 3, and 4), respectively. After the adaptation period, steers assigned to the initial slaughter group were killed at the MARC abattoir following approved procedures. Limit-fed steers were fed approximately 150 kcal ME/kg$^{.75}$ daily and ad libitum-fed steers were fed to appetite once daily. Steers were weighed at 2-wk intervals and feed allotments for limit-fed steers were adjusted at those times. Limit- and ad libitum-fed steers were killed at the MARC abattoir after approximately 140 d. Feed samples were taken daily, frozen, and composited over each 2-wk period for subsequent DM and nitrogen determinations. The diet formulation (Table 1) included an ionophore; additional growth stimulants were not used.

Slaughter and Body Composition. At slaughter, steers were stunned with a captive bolt gun and killed by exsanguination. Weights of the right and left halves of the warm carcass, hide (before and after cleaning), head, shanks and tail, liver, heart, lung, kidneys, spleen, and cleaned stomach complex (rumen, reticulum, omasum, and abomasum), small intestine, and large intestine (including cecum) as well as adipose tissues removed from the internal organs were recorded. Noncarcass tissues (offal) were composited for subsequent grinding and sampling. Empty BW was calculated as the sum of offal and warm carcass weights.

After a 24-h chill, carcass cooler data including longissimus muscle area, fat thickness and adjusted fat thickness (fat thickness subjectively adjusted by the grader) at the 12th rib, estimated percentage of kidney, pelvic, and heart (**KPH**) fat, marbling score, quality grade, and yield grade were obtained. The right half was subsequently weighed (cold carcass weight) and separated into lean tissue, adipose tissue, and bone. Adipose tissue was assumed to contain 13.14% water, 82.00% fat, 3.89% fat-free organic matter, .97% ash, and 7.92 Mcal/kg, and bone tissue was assumed to contain 35.79% water, 19.73% fat, 8.09% fat-free organic matter, 36.84% ash, and 2.92 Mcal/kg (based on unpublished data of C. L. Ferrell from 39 steers; the overall study was briefly described by Keele et al., 1993). Lean tissue was ground and mixed, and a sample of about 5 kg of the product was taken. Triplicate subsamples were subsequently taken, wrapped in cheesecloth, and weighed. Offal was ground through a large screw grinder through a plate with .64-cm holes and mixed by two additional passes through the grinder. Triplicate samples were taken, wrapped in cheesecloth, and weighed.

Triplicate samples of carcass lean and offal were subsequently analyzed for water (by loss in weight upon freeze drying to constant weight) and fat (by loss in weight of the dry sample upon extraction with

Table 2. Influence of sire breed on BW and composition of steers slaughtered initially

Trait	Sire breed[b]			P
	Angus/Hereford	Belgian Blue	Piedmontese	
Body weight, kg	340 ± 12.9	346 ± 12.1	323 ± 14.7	.44
Height, cm	121 ± 1.8	121 ± .8	119 ± 1.8	.67
Empty BW, kg[b]	283 ± 10.6	295 ± 10.6	274 ± 13.2	.44
Water[c]	570 ± 6.4	603 ± 6.2	603 ± 8.4	.01
Fat[c]	211 ± 8.8	168 ± 9.5	171 ± 11.1	.01
Fat-free organic matter[c]	160 ± 1.2	167 ± 2.0	168 ± 2.0	.01
Ash[c]	60 ± 2.3	62 ± 1.9	59 ± 1.4	.47
Energy, Mcal/kg	2.87 ± .08	2.51 ± .08	2.54 ± .10	.01
Feed[d]	6.35 ± .22	5.56 ± .61	5.07 ± .42	.15
n	8	8	8	

[a]Mean ± SE.
[b]Digesta-free BW.
[c]Gram per kilogram empty BW.
[d]Daily DM intake of diet (Table 1) for 2 wk before slaughter.

diethyl ether in Soxhlet apparatuses for 7 d). The dry, ether-extracted product was then ground through a Wiley mill (1-mm screen) and sampled for nitrogen (macro Kjeldahl) and ash (complete combustion in a muffle furnace at 675°C). Energy contents were calculated as weights of the ether-extracted material × 9.4 kcal/g and fat-free organic matter × 5.55 kcal/g (Garrett and Hinman, 1969; Ferrell et al., 1976).

Total carcass composition was calculated as the sum of the weight of each chemical component from lean, adipose tissue and bone, and adjusted for cooler shrinkage (weight difference between warm and cold carcass weights was assumed to be water loss), and for differences in weight of the right and left sides. Empty body composition was calculated as the sum of offal and carcass chemical component weights.

Data Analyses. General approaches were similar to classical comparative slaughter procedures (Lofgreen and Garrett, 1968). However, rather than using mean weight and composition of steers slaughtered initially to predict the composition of the remaining steers, the following procedures were used. Multiple linear regressions were developed by regressing a response variable, (empty body weight, empty body water, empty body fat, empty body fat-free organic matter [protein], empty body ash, or empty body energy) on the independent variables, (live weight, height, and daily DMI for the 2-wk period before slaughter for steers assigned to the initial slaughter group). Because of limited numbers, Angus and Hereford sire breeds were pooled for all analyses. The influence of sire breed and dam breed on the relationships were tested, but only sire breed significantly influenced the relationships. As a result, regressions developed within sire breed from steers slaughtered initially were used to predict the initial empty body weight and composition of steers assigned to the limit- or ad libitum-fed groups. Gains of body components of those steers were calculated as the difference between initial and final weights of the respective body components.

Feed intake, carcass traits, organ weights, composition, and body component gain data were analyzed with analyses of variance (SAS, 1989). The general model included treatment (**T**; initial slaughter, limit-fed, or ad libitum-fed), sire breed (**S**), dam breed (**D**), and the interactions of S × T and D × T. Linear regressions (Lofgreen and Garrett, 1968) of log heat production (**HE**) or energy gain (**RE**) on ME intake (kcal/[kg$^{.75}$·d]) were used to describe energy utilization and were tested for breed of sire and breed of dam effects to evaluate those influences on the slope and intercept. A nonlinear (exponential) regression was also used to describe the relationship between HE and ME intake (kcal/[kg$^{.75}$·d]). Additionally, a modified Brody's curve of the form

$$Y = A\ (1 - B \times \exp[C(X - D)]) \qquad [1]$$

was used to describe the relationship between RE (Y) and ME intake (X) using nonlinear procedures. The variables A, B, and C are regression coefficients, and D is the estimate of fasting heat production (**FHP**) from the nonlinear regression of heat production on ME intake. Units for Y, X, and D were kcal/(kg$^{.75}$·d).

Results and Discussion

Mean weight and composition of steers slaughtered initially are shown in Table 2. Steers of the different sire breed groups were of similar weight and height at that time. Angus/Hereford-sired steers contained less water and protein ($P < .05$) but more fat ($P < .05$) and energy ($P < .05$) than Belgian Blue- or Piedmontese-sired steers. Concentrations of ash were similar ($P > .10$). Feed intake during the adaption period did not differ ($P = .15$) among sire breeds, although intakes of Angus/Hereford-sired steers were numerically greater than intakes of Piedmontese or Belgian Blue-sired steers.

During the subsequent 140-d feeding period, feed consumption was, as designed, greater for ad libitum- than for limit-fed steers (Table 3). Feed consumption was not affected by sire breed or the S × T interaction ($P > .30$) but was influenced ($P < .04$) by the dam breed and the D × T interaction. Steers from MARC III cows consumed the most feed, those from Hereford cows the least, and those from Angus cows consumed intermediate amounts. These differences were greater for ad libitum-fed steers than for those that were limit-fed. The greater intakes of steers from MARC III dams is possibly related to the greater genetic potential for milk production.

Carcass and Body Composition. Live weight at slaughter and carcass traits differed ($P < .001$) in response to treatment (Table 4). Neither live weight nor carcass weight differed ($P > .13$) among sire or dam breeds. Sire breed significantly influenced longisissimus area, adjusted fat thickness, yield grade, and quality grade. The observed responses indicated that, in general, Belgian Blue- and Piedmontese-sired steers were leaner than Angus/Hereford-sired steers at similar carcass and live weights. These results were consistent with those of Cundiff et al. (1995). Dam breed significantly influenced only adjusted fat thickness and yield grade. Significant S × T interactions for adjusted fat thickness and estimated percentage of KPH fat suggested differential responses among sire breeds to treatment with regard to site of fat deposition. Similarly, D × T interactions for longissimus area, adjusted fat thickness, and yield grade suggested differences among steers from the different dam breeds to treatment in economically important traits.

Weights of all organs (Table 5) were influenced by treatment ($P < .001$). Hide weights were 5.4 and 9.8 kg greater in limit- and ad libitum-fed steers than in those slaughtered initially. Weights of the stomach complex, intestines, heart, lung, kidney, and spleen followed similar patterns. In contrast, weights of livers from limit-fed steers averaged 921 g less than those from steers slaughtered initially and 2,070 g less than livers from ad libitum-fed steers. Liver weight was 1.10, 1.65, and 1.30% of empty body weight in limit-fed, initial slaughter, and ad libitum-fed steers, respectively. As a percentage of BW, steers slaughtered initially consumed more feed than ad libitum-fed steers (1.68 vs 1.45%), which may account for part of the difference in liver weights; however, degree of maturity is also a potential contributor. Data previously reported (Ferrell, 1988) have demonstrated an important relationship between liver size, feed intake, and animal energy expenditures.

Sire breed influenced ($P < .02$) hide, stomach complex, heart, and spleen weights and tended ($P < .10$) to influence lung and kidney weights, whereas dam breed had a significant effect ($P < .002$) on lung weight and tended to influence ($P < .10$) heart and spleen weights. Few interactions were noted, indicating response of these organs or tissues to the imposed treatments was similar among sire or dam breeds.

Steers fed ad libitum were heavier at slaughter and contained greater amounts of water, fat, protein, ash, and energy than those fed limited amounts (Table 6). Water:protein ratios averaged approximately 5% greater ($P < .01$) in limit-fed (3.77:1) than in ad libitum-fed (3.58:1) steers. Subsequent linear regression analysis (pooled over breeds) resulted in the following relationship:

$$Y = 3.80\ (\pm\ .23) - .175(\pm\ .028)\ X,\ R^2 = .48$$

where Y was the water:protein ratio in the empty body at slaughter and X was the rate of empty BW gain. These values suggest the ratio may be altered by level of feed intake or rate of growth (Reid et al., 1955). Angus/Hereford-sired steers contained more fat ($P < .001$) and energy but tended ($P < .15$) to contain less water and protein than Belgian Blue- or Piedmontese-sired steers. These results were consistent with the carcass cooler data (Table 4) and with observations of Cundiff et al. (1995). No significant ($P > .12$) differences in weight or body composition at slaughter due to dam breed or S × T or D × T interactions were observed.

Rates of gain of all body components (Table 7) were greater ($P < .001$) in ad libitum- than in limit-fed steers. Rate of body fat, protein, and energy gain tended ($P < .10$) to differ among sire breeds and rates of gain of water, fat, and protein tended ($P < .10$) to differ among dam breeds. No S × T interactions were observed ($P > .18$), but D × T interactions accounted for significant ($P < .05$) amounts of variation in rates of live, empty body, water, protein, and ash weight gain. For those traits, rates of gain of steers from MARC III cows were, in general, less when limit-fed but greater when fed ad libitum compared with rates of gain of steers from Angus or Hereford cows. Similar patterns were observed when gains were expressed relative to metabolic body size (data not shown). These results are consistent with a dam genotype × nutritional level interaction (Jenkins and Ferrell, 1994). Empty body gains of limit-fed steers contained ($P < .05$) more water (530 vs 393 g/kg, ± 37) and ash (104 vs 36 g/kg, ± 15) but less fat (306 vs 462 g/kg, ± 51) and energy (3,221 vs 4,950 Mcal/kg, ± 445) and tended ($P = .11$) to contain less protein than gains of ad libitum-fed steers. Empty body gains of Angus/Hereford-sired steers tended to contain less water and protein but more fat and energy than those of Belgian Blue- or Piedmontese-sired steers. Composition of gain was not influenced ($P > .20$) by dam breed or the D × T interaction.

Energy Partition. Neither the slope nor intercept of the regressions (Table 8) of log HE on ME intake was influenced ($P > .10$) by sire or dam breed, indicating a common regression to be appropriate. These results indicate the relationship of HE to ME intake was

Table 3. Feed dry matter (DM) and energy (ME) intakes of steers of different sire[a] and dam[b] breeds fed limited or ad libitum

Treatment	Breed	DM intake, kg/d	ME intake, Mcal/d	DM intake, $g/(kg^{.75}\cdot d)$	ME intake, $kcal/(kg^{.75}\cdot d)$
	Sire				
Limit-fed	A,H	3.73	11.7	49.8	156
	B	3.62	11.4	47.7	149
	P	3.57	11.2	49.7	156
Ad libitum	A,H	7.25	22.7	87.0	272
	B	6.95	21.8	84.2	264
	P	7.48	23.4	92.4	289
	Dam				
Limit-fed	A	3.61	11.3	48.5	151
	H	3.53	11.0	49.2	154
	M	3.80	11.9	49.5	155
Ad libitum	A	7.36	23.0	88.5	277
	H	6.37	19.9	76.6	240
	M	7.96	24.9	98.5	308
Probability	df				
Sire breed (S)	2	.51	.51	.30	.30
Dam breed (D)	2	.002	.002	.01	.01
Treatment (T)	2	.001	.001	.001	.001
S × T	4	.42	.42	.59	.59
D × T	4	.04	.04	.02	.02
Residual standard deviation		.59	1.86	8.67	27.2

[a]Sire breed: A = Angus, H = Hereford, B = Belgian Blue, P = Piedmontese; A-sired calves were from H and M cows, H from A and M cows, and B- and P-sired calves were from A, H, and M cows.
[b]Dam breed: A = Angus, H = Hereford, M = MARC III (1/4 A, H, Red Poll, and Pinzgauer).

similar among sire or dam breeds, even though differences were observed in carcass traits and body composition. The antilog of the intercept of the pooled regression indicated the FHP of the steers in this study to be 82.4 $kcal/(kg^{.75}\cdot d)$. This value is approximately 8% greater than reported (76.2) by Garrett (1980) from 72 comparative slaughter experiments. This may result from differences in steer genotype, environmental, and(or) other experimental condition differences. Maintenance, estimated from the pooled regression as the point at which HE is equal to ME intake, was 126.4 $kcal/(kg^{.75}\cdot d)$. As an alternative to using the log transformation of HE to linearize the relationship between HE and ME, the relationships may be described by nonlinear regression (Figure 1). Estimated FHP from this model (Model II) was 80.6 ± 2.58 and maintenance was 124.4 $kcal/(kg^{.75}\cdot d)$. Both models indicated that, over the range from fasting to maintenance, efficiency of metabolizable energy use for maintenance (K_m) was .65, which compares favorably to .68 from the equations of Garrett (1980). However, if one concedes nonlinearity of the relationship between heat production and ME intake, then one must conclude K_m varies with ME intake, rather than being constant.

The slope and intercept of linear relationships between RE (energy gain and ME intake) were influenced by sire breed and dam breed (Table 9; P < .05). Results indicated that, when analyzed by sire breed, maintenance (ME intake at which RE = 0) varied from 82.1 for Piedmontese- to 130.5 for Belgian Blue-sired steers and efficiency of use of ME for empty body energy gain (K_g) varied from .27 for Piedmontese- to .44 for Belgian Blue-sired steers. Similarly, when the data were analyzed by dam breed, maintenance varied from 98.3 for steers from Angus cows to 130.7 for steers from Hereford cows, and K_g varied from .33 for steers from MARC III to .60 for steers from Hereford cows. Expected K_g for a diet having 3.13 Mcal ME/kg is .47 (NRC, 1984).

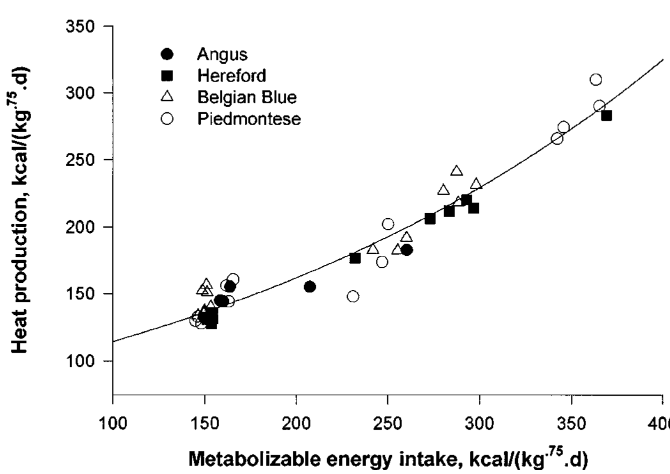

Figure 1. Relationship of head production (HP) to metabolizable energy intake (MEI) in steers of diverse genotypes. Symbols are for sire breed: Angus = ●, Hereford = ■, Belgian Blue = △, and Piedmontese = o; HP = $80.597e^{.00349 \times MEI}$.

Table 4. Influence of treatment and sire[a] or dam[b] breed on carcass characteristics

Treatment	Breed	Live weight, kg	Warm carcass weight, kg	Longissimus area, cm^2	Adjusted fat thickness, cm	KPH fat, %	Yield grade	Quality grade[c]
	Sire							
Initial slaughter	A,H	336	189	54.5	.50	.49	1.99	12.3
	B	336	200	66.5	.30	.61	1.16	11.5
	P	313	186	62.7	.31	.61	1.24	11.6
Limit-fed	A,H	395	231	55.9	.56	1.65	2.52	13.4
	B	396	242	68.9	.16	.92	1.48	12.1
	P	375	229	67.2	.32	1.35	1.58	12.3
Ad libitum	A,H	505	312	74.4	1.21	2.71	3.16	15.8
	B	491	307	83.6	.54	3.31	2.04	15.5
	P	498	316	88.8	.47	2.98	1.76	15.6
	Dam							
Initial slaughter	A	348	206	62.5	.48	.61	1.72	11.7
	H	296	170	57.8	.32	.52	1.32	11.9
	M	341	199	63.4	.31	.58	1.36	11.9
Limit-fed	A	392	238	69.4	.39	1.45	1.84	12.9
	H	374	225	60.6	.26	1.04	1.86	11.8
	M	399	239	62.0	.39	1.43	2.05	13.1
Ad libitum	A	499	313	77.8	1.09	2.91	2.88	15.9
	H	498	311	87.6	.42	3.20	1.84	15.2
	M	499	310	81.4	.71	2.90	2.26	15.3
Probability								
Sire breed (S)		.27	.67	.001	.001	.91	.001	.003
Dam breed (D)		.13	.15	.82	.001	.92	.04	.41
Treatment (T)		.001	.001	.001	.001	.001	.001	.001
S × T		.81	.69	.43	.02	.01	.40	.42
D × T		.51	.56	.02	.05	.56	.01	.04
Residual standard deviation		36	25	6.7	.25	.51	.40	.77

[a]Sire breed: A = Angus, H = Hereford, B = Belgian Blue, P = Piedmontese; A-sired calves were from H and M cows, H from A and M cows, and B- and P-sired calves were from A, H, and M cows.
[b]Dam breed: A = Angus, H = Hereford, M = MARC III (1/4 A, H, Red Poll, and Pinzgauer).
[c]Standard 0 = 11, Standard + = 12, Select − = 13, Select 0 = 14, Select + = 15, Choice − = 16.

These results conflict with earlier analyses, which indicated that neither breed of sire nor breed of dam accounted for a significant amount of variation in the relationship between HE and ME intake. Second, ME = RE + HE, as defined by NRC (1981). Thus, if the relationship between ME intake and HE is nonlinear, the relationship between ME intake and RE must also be nonlinear. As an alternative approach, a single, nonlinear relationship may be used to describe the data (Eq. 1). Results (Figure 2; Table 9, Model II) indicated that the relationship between RE and ME intake was nonlinear over the range of ME intake in this study (145 to 369 kcal/[kg$^{.75}$·d]). The regression indicated RE approached a maximum of 74.69 kcal/(kg$^{.75}$·d), ME required at maintenance (RE = 0) of 140.6 kcal/(kg$^{.75}$·d), and that efficiency of use of ME for RE was not constant, but decreased as ME intake increased.

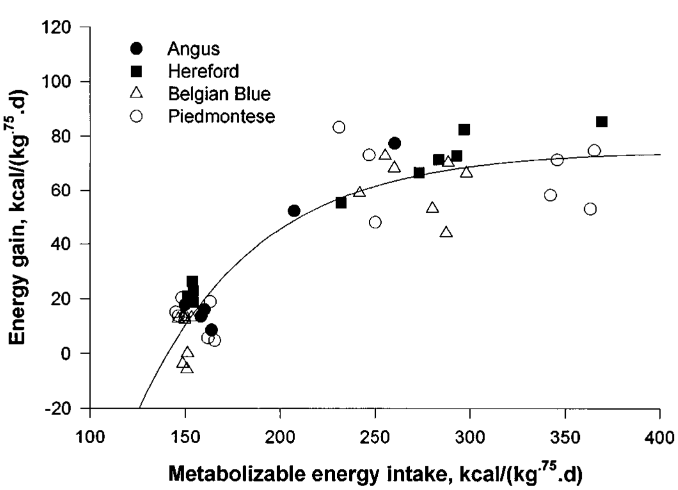

Figure 2. Relationship of energy gain (EG) to metabolizable energy intake (MEI) in steers of diverse genotypes. Symbols are for sire breed: Angus = ●, Hereford = ■, Belgian Blue = △, and Piedmontese = o; EG = 74.69 [1 − 2.60e$^{-.0159(ME\ -\ 80.597)}$].

This relationship was further tested in the following manner. Predicted energy gain was calculated by use of the regression and observed ME intake for each steer. The resulting values were subtracted from ME intake to estimate HE following the identity HE = ME − RE (NRC, 1981). The resulting predicted values (Y) were regressed on observed HE (X) with the following results:

$$Y = 7.32(\pm\ 5.94) + .961(\pm\ .032)\ X,\ R^2 = .95,\ CV = 5.96. \quad [2]$$

Table 5. Influence of treatment and sire[a] or dam breed[b] on weights of various organs and tissues at slaughter

Treatment	Breed	Weight, kg								
		Hide	Liver	Stomach complex	Small intestine	Large intestine	Heart	Lung	Kidney	Spleen
	Sire									
Initial slaughter	A,H	26.9	4.64	10.06	5.23	4.78	1.48	1.90	.73	.59
	B	24.6	4.63	9.38	5.12	4.94	1.56	1.88	.77	.63
	P	23.2	4.42	8.66	4.69	4.04	1.36	1.77	.69	.58
Limit-fed	A,H	32.4	3.96	11.52	5.29	5.55	1.76	2.14	.80	.66
	B	29.9	3.56	10.14	5.37	4.92	1.80	2.13	.73	.76
	P	28.6	3.41	9.59	5.30	5.23	1.63	1.91	.69	.67
Ad libitum	A,H	38.2	5.33	12.68	6.25	8.65	2.13	2.12	.85	.79
	B	33.3	5.81	12.18	6.13	8.26	2.04	2.43	.90	.89
	P	32.5	6.00	12.87	5.96	8.44	1.97	2.34	.84	.86
	Dam									
Initial slaughter	A	26.9	4.75	9.67	5.08	4.70	1.52	1.89	.75	.64
	H	21.5	4.25	8.96	5.04	4.53	1.30	1.69	.71	.53
	M	26.3	4.68	9.47	4.93	4.54	1.57	1.98	.74	.63
Limit-fed	A	29.2	3.62	10.76	5.40	5.27	1.75	2.03	.74	.71
	H	30.5	3.61	9.93	5.21	4.92	1.66	1.93	.68	.64
	M	31.2	3.70	10.57	5.35	5.51	1.77	2.23	.80	.74
Ad libitum	A	33.7	5.62	12.35	6.00	8.77	1.97	2.19	.88	.76
	H	34.9	5.57	12.67	6.01	8.22	2.09	2.32	.89	.83
	M	35.3	5.95	12.70	6.33	8.36	2.09	2.39	.83	.95
Probability										
Sire breed (S)		.001	.96	.01	.30	.35	.01	.06	.08	.02
Dam breed (D)		.12	.37	.58	.86	.60	.08	.002	.58	.09
Treatment (T)		.001	.001	.001	.001	.001	.001	.001	.001	.001
S × T		.70	.11	.15	.80	.49	.67	.03	.54	.62
D × T		.06	.80	.80	.76	.87	.23	.33	.28	.03
Residual standard deviation		2.8	.62	1.19	.62	1.02	.17	.20	.10	.10

[a]Sire breed: A = Angus, H = Hereford, B = Belgian Blue, P = Piedmontese; A-sired calves were from H and M cows, H from A and M cows, and B- and P-sired calves were from A, H, and M cows.
[b]Dam breed: A = Angus, H = Hereford, M = MARC III (1.4 A, H, Red Poll, and Pinzgauer).

For comparison, within-sire-breed linear regressions of RE on ME intake were used to predict HE following similar logic. The resulting equation was:

$$Y = 10.07(\pm\ 6.87) + .943(\pm\ .037)\ X,\ R^2 = .94,\ CV = 6.92. \quad [3]$$

Theoretically, these regressions should have an intercept of 0.0 and a slope of 1.0. These results indicated that the pooled nonlinear equation of RE on ME intake fit the observed data as well as linear, within-sire-breed regressions and was logically consistent with the nonlinear relationship of HE vs ME intake. These observations suggest that differences in maintenance among sire or dam breeds were removed by use of the nonlinear regression. This conclusion is consistent with results from regression of heat production on ME intake, which indicated maintenance requirements were similar.

ME intake of ad libitum-fed steers ranged from 207 to 369 kcal/(kg$^{.75}$·d) in this study (Figure 2). When RE was regressed on those data the resulting equation was as follows:

$$Y = 50.5(\pm\ 16.2) + .056(\pm\ .056)\ X,\ R^2 = .05.$$

These results indicate a positive RE (50.5) at zero ME intake and that RE did not change significantly in response to increased ME intake in ad libitum-fed steers in this study. These results are conceptually consistent with observations that rate of gain approaches an asymptote as feed intake increases in ad libitum-fed cattle (Ferrell, 1986; Meissner et al., 1995b).

It was assumed in the analyses of these data that ME content of the diet was constant. Thus, it may be argued that a portion of the nonlinearity in the relationship of RE and ME was due to depression in metabolizability of the diet at high levels of intake. Results from the use of the equation 3.3 of ARC (1980) indicate that only approximately a 2% depression in digestibility and no change in metabolizability is expected of this diet when fed at three times maintenance compared with maintenance. The ARC (1980) further noted that “energy retention of animals was not linearly related to their intake, and that not the whole of this curvilinearity was explained by changes of the metabolizability of feed with feeding level.” The ARC (1980) and subsequently the AFRC (1994) adopted the exponential equation of Blaxter and Boyne (1970) to describe the reduction in efficiency of ME use for energy retention with

Table 6. Influence of nutritional treatment and sire[a] or dam breed[b] on final live weight, empty body weight, and weight of chemical components

Treatment	Breed	Live weight, kg	Empty body component, kg: Weight	Water	Fat	Protein	Ash	Energy, Mcal
	Sire							
Limit-fed	A,H	395	336	185	81	49.0	20.8	1,037
	B	396	339	204	58	54.5	22.5	848
	P	375	322	193	58	51.0	19.4	831
Ad libitum	A,H	505	442	222	136	61.2	23.0	1,622
	B	491	432	231	114	64.7	22.5	1,435
	P	498	440	234	117	66.0	22.5	1,467
	Dam							
Limit-fed	A	392	334	193	69	51.2	20.9	937
	H	374	321	190	61	50.5	20.1	850
	M	399	340	198	68	52.9	21.7	929
Ad libitum	A	499	440	223	132	62.3	22.8	1,585
	H	498	440	230	124	63.9	22.2	1,520
	M	498	435	235	112	65.7	22.9	1,418
Probability								
Sire breed (S)		.60	.81	.15	.001	.09	.07	.002
Dam breed (D)		.72	.87	.42	.12	.39	.34	.23
Treatment (T)		.001	.001	.001	.001	.001	.004	.001
S × T		.61	.62	.62	.95	.54	.06	.89
D × T		.72	.71	.82	.17	.86	.79	.22
Residual standard deviation		36.7	33.4	20.4	15.6	5.71	1.78	155

[a]Sire breed: A = Angus, H = Hereford, B = Belgian Blue, P = Piedmontese; A-sired calves were from H and M cows, H from A and M cows, and B- and P-sired calves were from A, H, and M cows.
[b]Dam breed: A = Angus, H = Hereford, M = MARC III (1/4 A, H, Red Poll, and Pinzgauer).

Table 7. Influence of nutritional treatment and sire[a] or dam breed[b] on rate of gain of body components

Treatment	Breed	Live weight, kg/d	Empty body component: Weight, kg/d	Water, g/d	Fat, g/d	Protein, g/d	Ash, g/d	Energy, Mcal/d
	Sire							
Limit-fed	A,H	.27	.28	114	137	11	22	1.35
	B	.26	.24	140	47	24	26	.58
	P	.34	.33	192	81	34	23	.95
Ad libitum	A,H	1.18	1.15	434	556	112	43	5.85
	B	1.11	1.07	429	483	123	35	5.22
	P	1.21	1.17	485	502	140	44	5.49
	Dam							
Limit-fed	A	.34	.31	146	118	21	24	1.22
	H	.30	.33	197	70	37	25	.86
	M	.22	.21	103	78	11	21	.79
Ad libitum	A	1.10	1.08	365	573	103	38	5.96
	H	1.10	1.08	424	505	117	35	5.40
	M	1.30	1.23	560	462	157	49	5.21
Probability								
Sire breed (S)		.33	.14	.22	.08	.07	.65	.10
Dam breed (D)		.61	.83	.10	.08	.10	.33	.14
Treatment (T)		.001	.001	.001	.001	.001	.001	.001
S × T		.89	.94	.91	.97	.95	.18	.97
D × T		.008	.01	.003	.55	.004	.05	.87
Residual standard deviation		.15	.13	105	99	30	10	.88

[a]Sire breed: A = Angus, H = Hereford, B = Belgian Blue, P = Piedmontese; A-sired calves were from H and M cows, H from A and M cows, and B- and P-sired calves were from A, H, and M cows.
[b]Dam breed: A = Angus, H = Hereford, M = MARC III (1/4 A, H, Red Poll, and Pinzgauer).

Table 8. Regression equations describing relationships between heat production and ME intake for diverse breed crosses of steers fed a high-concentrate diet

Model[a] and breed	a (± SE)	b (± SE)	R^2	n	FHP[b]	Maintenance[c]
I						
Sire						
A,H	1.908 ± .016	.00146 ± .00007	.97	16	80.9	121.6
B	1.942 ± .024	.00140 ± .00011	.93	15	87.5	135.3
P	1.903 ± .028	.00153 ± .00011	.94	14	80.0	123.3
Dam						
A	1.896 ± .024	.00150 ± .00011	.93	16	78.7	118.5
H	1.974 ± .034	.00112 ± .00017	.88	8	94.2	132.6
M	1.935 ± .015	.00145 ± .00006	.97	21	86.1	135.2
All	1.916 ± .013	.00147 ± .00006	.94	45	82.4	126.4
II						
All	80.597 ± 2.58	.00349 ± .00012	.99	45	80.6	124.4

[a]Model I: log heat production = a + b × ME intake; Model II: heat production = a $e^{b \times \text{ME intake}}$, Where a and b are regression coefficients, heat production and ME intake were expressed in kcal/($kg^{.75}$·d), and e is the base of natural logs (2.71828). Neither dam breed nor sire breed significantly influenced the intercept or slope of Model I regression (*P* > .10).

[b]FHP: fasting heat production; predicted as the antilog of the intercept (a) for Model I or as the intercept (a) for Model II, kcal/($kg^{.75}$·d).

[c]Maintenance is predicted as the point on the regression at which heat production is equal to ME intake, kcal/($kg^{.75}$·d).

increasing intake. It seems likely that a portion of the curvilinearity in the observed response curve can be ascribed to higher maintenance costs or heat increment associated with the higher levels of feed intake (Ferrell, 1988). Other factors that may influence the shape of this relationship include cold stress and subsequent compensatory gain and coprophagy of limit-fed steers. Elucidation of actual contributing factors requires further investigation.

Feedlot data reported by Gill et al. (1986) demonstrated that rate of gain increased at a lower rate in response to increased feed intake than that predicted by the NRC (1984) net energy equations. That gain approaches an asymptote as feed intake increases is supported by data reported by Murphy and Loerch (1994), which indicated a decrease in the incremental increase in rate of gain with increased feed intake in ad libitum-fed steers, and by the reports of Meissner et al. (1995a,b), who reported that variation in ME intake accounted for 5.2% of the variation in rate of gain of ad libitum-fed steers. Data from ad libitum and superalimented pigs (McCracken et al., 1994) also support the present findings.

Table 9. Relationships between retained energy and ME intake for diverse breed crosses of steers fed a high-concentrate diet

Model[a] and breed	a (± SE)	b (± SE)	c (± SE)	R^2	Maintenance[b]	k_g
I						
Sire						
A,H	−38.52 ± 7.60	.383 ± .034	—	.90	100.5	.38
B	−57.54 ± 11.27	.441 ± .051	—	.84	130.5	.44
P	−22.08 ± 14.04	.269 ± .058	—	.65	82.1	.27
Dam						
A	−37.55 ± 11.94	.382 ± .053	—	.78	98.3	.38
H	−77.79 ± 11.85	.595 ± .059	—	.94	130.7	.60
M	−38.74 ± 7.56	.325 ± .031	—	.85	118.4	.33
II						
All	74.69 ± 6.37	2.60 ± .89	−.0159 ± .0049	.90	140.6	Variable

[a]Model I: retained energy = a + b × ME intake. Model II: retained energy = a (1 − b $e^{c(\text{ME intake} - 80.597)}$), where a, b, and c are regression coefficients, 80.597 is the estimate of energy loss at zero ME intake from the nonlinear regression of heat production on ME intake (Table 8). All variables are expressed as kcal/($kg^{.75}$·d).

[b]Maintenance is estimated as the ME intake (kcal/[$kg^{.75}$·d]) at which energy retention is zero.

Implications

The data reported herein documented differences among Angus/Hereford, Belgian Blue, and Piedmontese as sire breeds for several important carcass, body composition, and composition of gain traits. The observed differences indicate that the Belgian Blue or Piedmontese may be of value to the cattle industry to increase body lean content. Frequently, less emphasis is placed on the dam breed than on the sire breed. These results indicate that for many traits, dam breed (in this study, Angus, Hereford, and MARC III) and interactions between sire or dam and nutritional treatment were at least as important as sire breed effects. Data were presented that indicated the relationship between energy gain and metabolizable energy intake was not linear above maintenance, and indicated that the incremental increase in rate of gain decreased as intake increased. These findings, if substantiated by further research, indicate that maximum efficiency of growth may occur at less than maximum intakes.

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