Early-weaning and postweaning nutritional management affect feedlot performance, carcass merit, and the relationship of 12th-rib fat, marbling score, and feed efficiency among Angus and Wagyu heifers[1]

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ABSTRACT: Twelve ¾ Angus (Angus) and 12 Wagyu-cross (½ Wagyu × ½ Angus) (Wagyu) heifers were weaned at 180 d of age and grazed on endophyte-infected tall fescue for 16 mo before entering the feedlot as 2-yr-olds. Twelve ¾ Angus heifer calves and 12 Wagyu-cross heifer calves from the following year's calf crop were weaned at 142 ± 4.1 d of age, immediately adjusted to an 80% concentrate diet, and finished as calves. All heifers were fed a common finishing diet until an estimated 50% of their respective group would grade USDA low Prime or better based on ultrasound predictions. Ultrasound measurements of s.c. and i.m. fat depots were recorded at 60-d intervals throughout the finishing period. Heifers finished as calves had higher (P = 0.02) marbling scores at any given fat thickness and gained more efficiently ($P \le 0.01$) at any given marbling score than heifers finished as 2-yr-olds. Gain:feed decreased quadratically ($P \le 0.05$) as 12th-rib fat thickness increased for Angus and Wagyu heifers. Gain:feed decreased linearly ($P \le 0.01$) for Wagyu calves and quadratically ($P \le 0.01$) for Angus calves as 12th-rib fat thickness increased. However, these differences in slope were not different (P = 0.34) as a result of breed among heifers finished as calves. Marbling score increased linearly ($P \le 0.01$) as 12th-rib fat thickness increased for Angus and Wagyu heifers finished as 2-yr-olds or as calves. However, Wagyu heifers, regardless of age at feedlot entry, had a higher marbling score ($P \le$ 0.05) at any given 12th-rib fat thickness than Angus heifers. Finishing early-weaned heifers as calves as opposed to 2-yr-olds results in i.m. fat deposition during a period of more efficient growth. Additionally, including Wagyu genetics into the breeding of early-weaned heifers finished as calves or as 2-yr-olds results in higher marbling scores at any 12th-rib fat thickness.

Key Words: Early Weaning, Ultrasound

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Introduction

Intramuscular fat closely correlates to the juiciness and the characteristic flavor of beef (Hornstein and Wasserman, 1987). Cianzio et al. (1985) reported that marbling score correlates more closely to the number of adipocytes/gram of tissue than to diameter of the adipocytes. Additionally, the research of Prior (1983) indicated that grain-fed cattle have smaller but more numerous adipocytes than forage-fed cattle. Smith and Crouse (1984) reported that the primary substrate for i.m. fat deposition is glucose, which differs from the use of acetate to synthesize s.c. fat. As a result, it is hypothesized that feeding grain to young cattle may stimulate the onset of marbling. In support of this, data indicate that early-weaned steers fed high-concentrate diets from weaning to slaughter have a greater percentage of carcasses that grade USDA average Choice or higher than steers grazed on pasture before entering the feedlot (Myers et al., 1999a,b,c). Loy et al. (1999) demonstrated that decreasing weaning age from 147 d to 67 d and feeding high-concentrate diets until slaughter results in a greater percentage of carcasses that grade USDA Choice or Prime. Lunt et al. (1993) reported Wagyu-cross steers to have a greater potential to marble than their Angus contemporaries.

The objectives of this trial were 1) to evaluate the feedlot performance of Angus and Wagyu heifers managed differently from weaning to slaughter and 2) to establish, through the use of ultrasound technology, the relationships of marbling score, 12th-rib fat thick-

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Table 1. Ingredient and calculated nutrient composition of the finishing diet fed to heifers finished as 2-yr-olds or early-weaned heifers

Item	%, DM basis
Ingredient	
Coarsely ground corn	63.48
Soybean meal	13.11
Ground corn cobs	10.03
Trace mineralized salt[a]	0.56
Calcium carbonate	1.05
Dehydrated molasses	5.08
Rumensin[b]	1.63
Soybean oil	5.03
Calculated nutrient composition	
NE_m, Mcal/kg	2.12
NE_g, Mcal/kg	1.42
CP, %	13.49
Ca, %	0.53
P, %	0.30

[a]Trace mineralized salt composition was: NaCl 94 to 98.5%, Na 37.0 to 38.75%, Zn 3,500 mg/kg, Fe 2,000 mg/kg, Mg 2,000 mg/kg, Cu 3,000 mg/kg, I 70 mg/kg, Co 50 mg/kg.

[b]Monensin concentration was 33 g/t diet DM; Elanco Animal Health, Indianapolis, IN.

ness, and feed efficiency between breeds and over a range of ages and body compositions.

Materials and Methods

Growing Period Management. Animals used in this trial were managed according to guidelines recommended in the *Guide for the Care and Use of Agricultural Animals in Agriculture Research and Teaching* (Consortium, 1988). Twenty-four heifers, twelve ¾ Angus (Angus) and twelve ½ Wagyu × ½ Angus (Wagyu) were weaned (180 d) and grazed on endophyte-infected tall fescue for 16 mo. Following the 16-mo growing period, heifers were transported to the Illinois State University research farm, where they were adjusted to a finishing diet (Table 1). These heifers were 22 mo of age upon entering the feedlot and are referred to as 2-yr-old heifers throughout. An additional 12 ¾ Angus and 12 ½ Wagyu × ½ Angus heifer calves were early-weaned at 142 ± 4.1 d of age and immediately adjusted to an 80% concentrate, 20% corn silage diet supplemented with soybean meal to contain 16% CP and to meet NRC (1996) mineral and vitamin requirements for growing heifers. Heifer calves were of the same genetics as the 2-yr-old heifers but from the following year's calf crop. Heifer calves were maintained on this diet for 119 d and then transported to Illinois State University and immediately adjusted to a finishing diet (Table 1). These heifers were 9 mo of age upon entering the feedlot and are referred to as heifer calves throughout. Two-year-old heifers were implanted with Finaplix-H (200 mg trenbolone acetate; Intervet/Hoechst Roussel, Millsboro, DE) and heifer calves were implanted with Synovex-C (10 mg estradiol benzoate and 100 mg testosterone; Fort Dodge Animal Health, Fort Dodge, IA) at initiation of the finishing trial. Heifers were implanted only once during the finishing period and fed the 90% concentrate finishing diet for greater than 200 d to produce high-quality carcasses.

Finishing Period Management. Two Angus and two Wagyu heifers of similar age were assigned to 12 pens. Heifers were individually fed using Calan (American Calan, Northwood, NH) gate-equipped bunks and weighed at 21-d intervals. Dry matter intakes and feed refusals were recorded on a daily basis and individual animal feed efficiency (gain:feed) was calculated using these data. Two-year-old heifers were individually fed for 125 d and pen-fed from d 126 to slaughter at 218 d on feed. Dry matter intakes for individual heifers during the pen-fed period were estimated by calculating the percentage each animal consumed relative to its penmates during the last individual feeding period (d 105 to 125). This percentage was multiplied by total pen consumption to yield an estimated intake for each animal in the pen. Heifer calves were individually fed through 216 d of the feeding trial and pen-fed from d 217 to 238, during which time an ultrasound measurement was recorded. Individual DMI from d 217 to 238 was estimated for heifer calves by calculating the percentage each animal consumed relative to its penmates during the last individual feeding period (d 190 to 216). Pen DMI at the time of ultrasound measurement was multiplied by this percentage to estimate individual DMI for the final period.

Collection of Ultrasound Data. Real-time (linear array) ultrasound was used to monitor i.m. and s.c. fat deposition over the course of the feedlot-finishing period. Aloka 500V ultrasound equipment (Aloka, Wallingford, CT) with an Aloka UST-5049-3.5 transducer was used to record an image of the longissimus thoracis and its i.m. and surrounding s.c. fat. Images were interpreted using the CVI Scan Session Reporting Version 6.2b in combination with Rib-O-Matic Version 3.1 software (Critical Vision, Atlanta, GA). Ultrasound measurements recorded at four times during the finishing period were used to develop regression equations for 12th-rib fat thickness and marbling score. Ultrasound measurements for the 2-yr-old heifers were recorded at 44, 101, 155, and 211 d in the feedlot and actual carcass measurements were recorded at slaughter (218 d in the feedlot). Ultrasound measurements for the heifer calves were recorded on 44, 101, 187, and 230 d in the feedlot and actual carcass measurements were recorded at slaughter (238 d on final finishing diet). Regression equations were established using the four ultrasound measurements. Ultrasound-predicted marbling scores and 12th-rib fat thickness were compared to the carcass measurements collected at slaughter.

Collection of Carcass Data. Heifer calves and 2-yr-old heifers were shipped to a commercial packing plant 8 d following the final ultrasound session for slaughter and collection of carcass data. Heifers were stunned via captive bolt pistol and exsanguinated. Hot carcass weights were collected on the day of slaughter, whereas

12th-rib fat thickness; longissimus thoracis area; percentage of kidney, pelvic and heart fat; marbling scores; and bone maturity scores were collected after carcasses had hung at –4°C for 24 h. Chromatography paper was used to make an image of the longissimus thoracis and grid measurements were made of the image. Quality grades were recorded based on the USDA grid of marbling and bone maturity scores. Yield grades were calculated using the formula reported by Taylor (1994).

Collection of Extractable Lipid Data. Carcasses were ribbed between the 12th and 13th rib and a rib section 7 to 8 cm thick was removed from each carcass. Rib steak sections were vacuum-packaged and aged for 7 d at 4°C. The longissimus thoracis muscle was removed from the rib steak section. External fat surrounding the muscle was trimmed and the muscle was homogenized for fat extraction. Duplicate 5-g samples were dried and repeatedly washed with chloroform:methanol in accordance with the procedures of Riss et al. (1983). Chloroform:methanol lipid extraction values were used to verify grader-called marbling scores according to the methods of Brackebusch et al. (1991).

Statistical Analysis. Heifers were slaughtered when it was estimated that 50% of each age group would grade low Prime or better. As a result, heifers were not fed for a common time or to a common fat end point. Therefore, calf and 2-yr-old heifer feedlot performance data were statistically analyzed separately using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC) with individual animal as the experimental unit. The model for feedlot performance included the fixed effect of breed. Carcass variables collected at slaughter were analyzed using the GLM procedure of SAS with individual animal as the experimental unit. The model included the fixed effects of breed, age at feedlot entry, and the interaction of the two main effects. The residual mean square was used as the error term. Treatment effects on percentage of USDA Choice or Prime carcasses were analyzed using chi-squared analysis.

Ultrasound measurements of i.m. and s.c. fat deposition and feed efficiency were analyzed as repeated measures over time using the Mixed models procedure of SAS (SAS Inst. Inc.). Individual animal served as the experimental unit when analyzing ultrasound data. Data sets were established so that comparisons could be made between heifers finished as calves or as 2-yr-olds, regardless of breed or between breeds (Angus vs Wagyu) within age group. The effects of age on the relationships of feed efficiency (gain:feed) to s.c. fat deposition and feed efficiency to i.m. fat deposition were evaluated using a model with the fixed effects of age at feedlot entry, the linear and quadratic terms of the regresser (s.c. or i.m. fat), the interaction of age and the regresser, and random effects of animal. The effects of age at feedlot entry on the relationship of i.m. fat deposition regressed over s.c. fat deposition was evaluated using a model that included the fixed effects of age at feedlot entry, the linear and quadratic terms for the regresser (s.c. fat), the interaction of age and the regresser, and the random effects of animal. The residual mean square was used as the error term.

Feed efficiency was regressed over s.c. and i.m. fat among Angus and Wagyu heifers within their respective age group to evaluate the effects of breed on these relationships. The model included the fixed term of breed, the linear and quadratic terms of the regresser (s.c. or i.m. fat), the interaction of breed and the regresser, and the random effects of animal. Additionally, i.m. fat was regressed over s.c. fat among Angus and Wagyu heifers within an age group. The model included breed, the linear and quadratic terms of the regresser (s.c. fat), the interaction of breed and the regresser, and the random effects of animal. In each case the quadratic and interaction terms were dropped from the model if they were not significant ($P > 0.05$). Differences in the intercepts of the regression lines of cattle from different age or breed groups were established based on significance ($P \leq 0.05$) of the regresser. Differences in slope of the regression lines that resulted from age or breed were established based on a significant ($P \leq 0.05$) interaction between breed or age and the regresser. The residual mean square was used as the error term.

Intramuscular fat and s.c. fat were regressed over time for Angus and Wagyu heifers within each age group to predict s.c. and i.m. fat at slaughter. The model included the fixed terms of breed, the linear and quadratic terms of the regressor (days on the finishing diet), the interaction of breed and the regressor, and the random effects of animal. These equations were used to predict 12th-rib fat thickness and marbling score at the time of slaughter and to compare these predicted values with the actual carcass measurements collected at slaughter. The residual mean square was used as the error term.

Results and Discussion

Feedlot Performance. Feedlot performance for 2-yr-old heifers and heifer calves is presented in Table 2. Two-year-old Angus heifers were an average 23 d younger ($P \leq 0.01$) than Wagyu heifers at the initiation of the finishing phase. Angus 2-yr-olds weighed more initially ($P \leq 0.01$) and gained 0.18 kg/d faster throughout the finishing period ($P \leq 0.01$) than Wagyu heifers. Lunt et al. (1993) reported a similar difference in ADG between purebred Angus and ¾ Wagyu steers fed a corn/barley diet for 552 d. As a result of faster ADG and heavier initial BW, Angus heifers weighed an average of 60 kg more ($P \leq 0.01$) than Wagyu heifers at the trial's termination. Two-year-old Wagyu heifers consumed less ($P \leq 0.01$) DM on a daily basis than their Angus counterparts. As a result of slower ADG, but lower DMI, Wagyu heifers were more efficient ($P \leq 0.01$) than their Angus contemporaries. Wagyu 2-yr-olds were slaughtered with less ($P \leq 0.01$) 12th-rib fat thickness than Angus heifers. Had both groups of 2-yr-olds been fed to a common s.c. fat cover, feed efficiency for the Wagyu

Table 2. Feedlot performance of Angus and Wagyu heifers finished as 2-yr-olds or early-weaned and immediately finished as calves

Item	2-Yr-old heifers				Heifer calves			
	Angus	Wagyu	SE	Breed $P <$	Angus	Wagyu	SE	Breed $P <$
n	12	12	—	—	11	9	—	—
Weaning age, d	—	—	—	—	133	150	4.1	0.01
Initial age, d[a]	704	727	4.6	0.01	285	302	4.1	0.01
Individual intake, d	217	217	—	—	216	216	—	—
Days on high-concentrate diet at slaughter	217	217	—	—	368	368	—	—
Initial BW, kg	410.7	371.9	6.76	0.01	243.5	274.1	7.41	0.02
Final BW, kg	568.0	507.6	9.86	0.01	474.9	489.0	16.32	0.55
ADG, kg/d	1.28	1.10	0.046	0.01	1.07	0.99	0.053	0.31
DMI, kg/d	9.87	8.04	0.333	0.01	6.24	6.33	0.312	0.84
Gain:feed, kg/kg	0.130	0.138	0.0034	0.09	0.173	0.157	0.0052	0.05

[a]Initial age is the age at which the individual feed intake period was initiated.

heifers would likely have been equal to or less than that of their Angus counterparts.

Individual feedlot performance for heifer calves was recorded for 216 d on the 90% concentrate diet. However, heifer calves had been on an 80% concentrate diet since weaning and were therefore fed high-concentrate diets for a total of 368 d at slaughter. Four early-weaned heifer calves were removed from trial because of rectal prolapse. This trend was not observed for 2-yr-old heifers despite their higher degree of s.c. fat cover. Wagyu-cross calves were heavier ($P = 0.02$) than Angus calves at the trial's initiation. Differences in initial BW were likely a reflection of differences in age at weaning. Wagyu heifer calves were an average of 17 d older ($P \leq 0.01$) at weaning. Although not significant ($P > 0.05$), Angus calves gained numerically faster than Wagyu calves. As a result, final live BW between heifer calves of the two breeds were similar. The combination of numerically slower ADG and numerically higher DMI resulted in ($P = 0.05$) less efficient gains for Wagyu calves than for Angus calves. Myers et al. (1999c) indicated that among early-weaned, concentrate-fed steers, Wagyu-cross steers tended to be less efficient than British crossbred steers. One must consider also that Wagyu calves had numerically more s.c. fat cover at slaughter than did Angus calves (Table 3), which could account for a portion of the difference in feed efficiency.

Carcass Characteristics. Carcass characteristics of 2-yr-old heifers and heifer calves are presented in Table 3. Heifers finished as 2-yr-olds had heavier carcasses ($P \leq 0.01$) than heifers finished as calves. However, within age group, breed affected ($P \leq 0.01$) hot carcass weight. As 2-yr-olds, Angus heifers had heavier carcasses ($P \leq 0.01$) than Wagyu heifers, whereas Wagyu calves had heavier carcasses ($P \leq 0.01$) than Angus calves. This interaction was the result of heavier initial BW for Angus 2-yr-olds and Wagyu calves than for their respective counterparts. Heifers finished as 2-yr-olds had larger ($P \leq 0.01$) longissimus thoracis muscle area than heifers finished as calves. However, when longissimus thoracis muscle area was expressed as square centimeters per 100 kg of hot carcass weight there was no difference ($P > 0.05$) in longissimus thoracis muscle area as a result of age at entry into the feedlot.

Carcasses from heifers finished as calves had less advanced ($P \leq 0.01$) skeletal maturities than carcasses from heifers finished as 2-yr-olds. No significant differences in grader-called marbling scores as a result of breed or age at feedlot entry were detected. However, Wagyu heifers averaged a slightly abundant marbling score, whereas Angus heifers averaged a moderate marbling score. Lunt et al. (1993) reported similar numerically greater marbling scores for Wagyu steers compared with Angus steers. Numerically higher extractable lipid values for Wagyu longissimus thoracis muscle supported the numerically higher marbling score called by the grader. Angus 2-yr-old heifers had a mean extractable lipid value of 10.9%. Brackebusch et al. (1991) reported that longissimus thoracis muscle with this percentage of extractable lipid had a USDA marbling score of moderate. Extractable lipid values for Wagyu heifers averaged 11.9%, which was equivalent to a slightly abundant degree of marbling (Brackebusch et al., 1991). Grader-called and extractable lipid-predicted marbling scores were similar for Angus and Wagyu heifers. These differences in marbling scores, although only numeric, resulted in 60.0% more Wagyu heifers than Angus heifers grading USDA Prime. Heifers finished as calves had a similar, nonsignificant difference in marbling scores. Wagyu calves averaged a grader-called marbling score of slightly abundant, whereas Angus calves averaged a grader-called marbling score of moderate. Extractable lipid values indicated a similar difference in marbling score between Angus and Wagyu calves. However, for both breed groups, extractable lipid values indicated marbling scores were higher than those called by the grader (Brackebusch et al., 1991). Average extractable lipid values were 14.4% (moderately abundant) for Wagyu calves and 13.2% (slightly abundant) for Angus calves. The small number of observations may have

Table 3. Carcass characteristics of Angus and Wagyu heifers finished as 2-yr-olds or early-weaned and immediately finished as calves

Item	2-Yr-old heifers Angus	2-Yr-old heifers Wagyu	Heifer calves Angus	Heifer calves Wagyu	SE	Age $P \leq$	Breed $P \leq$	Age × breed $P \leq$
n	12	12	11	9	—	—	—	—
Days on high-concentrate diet at harvest	218	218	368	368	—	—	—	—
Hot carcass weight, kg	396.1	351.5	285.3	313.8	11.66	0.01	0.50	0.01
Longissimus thoracis area, cm^2	92.5	93.0	77.0	82.5	2.74	0.01	0.28	0.38
Longissimus thoracis area, cm^2/100 kg hot carcass wt	23.7	26.6	27.4	26.4	1.17	0.15	0.39	0.11
Bone maturity[a]	232	228	144	151	10.8	0.01	0.29	0.66
Kidney, pelvic, and heart fat, %	2.1	2.6	2.1	2.6	0.16	0.99	0.01	0.95
12th-Rib fat thickness, cm	2.71	1.90	1.53	2.29	0.265	0.15	0.91	0.01
Yield grade[b]	4.6	3.1	3.1	3.6	0.32	0.11	0.13	0.01
Marbling score[c]	1,298	1,349	1,219	1,323	49.4	0.29	0.13	0.60
Longissimus ether extract, %	10.9	11.9	13.2	14.4	1.16	0.05	0.36	0.89
USDA Choice, %	50.0	33.33	45.45	42.86			0.57[d]	
USDA Prime, %	41.67	66.67	54.54	57.14			—	

[a]Based on the following scale: 100 to 199 = A, 200 to 299 = B, 300 to 399 = C.
[b]Yield grade calculated using the formula reported by Taylor (1994).
[c]Marbling score: 900 = slight, 1,000 = small, 1,100 = modest, 1,200 = moderate, 1,300 = slightly abundant, 1,400 = moderately abundant, 1,500 = abundant.
[d]Determined by chi-squared analysis.

limited statistical power to detect breed differences in marbling score. Although no differences in grader-called marbling scores were detected between heifers finished as calves and those finished as 2-yr-olds, heifer calves had more extractable fat ($P \leq 0.05$) in the longissimus thoracis than did heifers finished as 2-yr-olds. These data suggested that heifers finished as calves were capable of depositing i.m. fat equal to or greater than that of 2-yr-olds provided they were fed a high-concentrate diet for an adequate length of time. Early-weaned heifers finished as calves were fed high-concentrate diets for 150 d longer than heifers finished as 2-yr-olds. The increased length of time on a high-concentrate diet likely accounted for the higher extractable lipid values. Lunt and Orme (1987) reported that feeding a high-concentrate diet from weaning (8 mo) to slaughter resulted in higher marbling scores and thicker s.c. fat cover than feeding a high-concentrate diet from 12 mo of age to a common carcass weight. Additionally, Sindt et al. (1993) demonstrated that weanlings immediately fed a high-concentrate diet had higher marbling scores than yearlings grazed on corn stalks before entering the feedlot when fed to the same compositional end point (1.2 cm 12th-rib fat cover). In both situations, heifers finished as weanlings were more efficient. These data suggest that i.m. fat can be deposited in cattle finished as calves provided they receive a high-grain diet for an adequate length of time.

Wagyu heifers had more ($P \leq 0.05$) kidney, pelvic, and heart fat than Angus heifers, regardless of age (Table 3). However, age at feedlot entry did not significantly affect percentage of kidney, pelvic, and heart fat. Within age group, breed affected ($P \leq 0.01$) s.c. fat cover and USDA yield grade. Wagyu heifers finished as 2-yr-olds had less s.c. fat cover ($P \leq 0.01$) and lower yield grades ($P \leq 0.01$) than Angus heifers. In contrast, Wagyu calves had more s.c. fat cover ($P \leq 0.01$) and higher yield grades ($P \leq 0.01$) than Angus calves.

Relationship Among Intramuscular Fat, Subcutaneous Fat, and Feed Efficiency as Affected by Age. Comparing feed efficiency (gain:feed) at physiological benchmarks such as common s.c. fat thickness or i.m. fat content provides a critical evaluation of differences in the relationships of s.c. and i.m. fat deposition relative to feed efficiency that result from breed and age at feedlot entry. Gain:feed decreased quadratically ($P \leq 0.01$) as 12th-rib fat thickness increased among heifers finished as calves and heifers finished as 2-yr-olds (Figure 1,

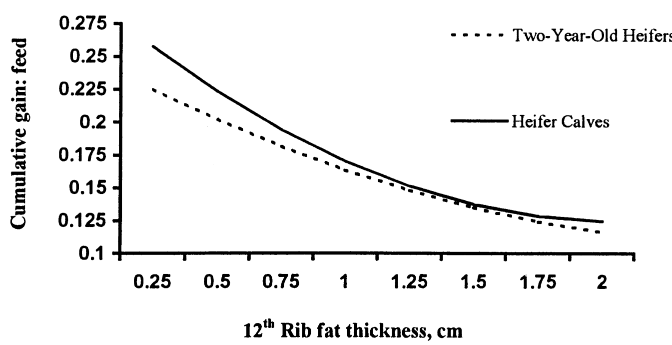

Figure 1. Regression of gain:feed (kg/kg) on 12th-rib fat thickness (based on ultrasound) for early-weaned heifers finished as 2-yr-olds or finished as calves. Gain:feed decreased quadratically ($P \leq 0.01$) as 12th-rib fat thickness increased for heifers finished as 2-yr-old and those finished as calves. The slopes ($P = 0.63$) and intercepts ($P = 0.22$) of these lines did not differ as a result of age at feedlot entry.

Table 4. Regression coefficients for feed efficiency regressed over 12th-rib fat thickness and marbling score and for marbling score regressed over 12th-rib fat thickness for heifers finished as 2-yr-olds or early-weaned and immediately finished as calves

Item	Intercept ± SE	b_1 ± SE	b_2 ± SE	RSE[a]
Gain:feed regressed on 12th-rib fat (Figure 1)				
Heifer calves[b]	0.297 ± 0.0221	–0.168 ± 0.03569	4.14×10^{-2} ± 1.32×10^{-2}	6.10×10^{-4}
Two-year-olds[c]	0.250 ± 0.0168	–0.107 ± 0.0206	2.03×10^{-2} ± 6.05×10^{-3}	3.12×10^{-4}
Feed efficiency regressed on marbling score (Figure 2)				
Heifer calves	0.481 ± 0.0373	-2.85×10^{-4} ± 3.46×10^{-5}	NA[d]	5.69×10^{-4}
Two-year-olds	0.378 ± 0.0304	-2.19×10^{-4} ± 2.81×10^{-5}	NA	3.77×10^{-4}
Marbling score regressed on 12th rib fat (Figure 3)				
Heifer calves	955.5 ± 26.29	113.6 ± 23.14	NA	4,692.2
Two-year-olds	839.1 ± 47.35	215.7 ± 55.35	–32.4 ± 15.61	2,579.6

[a]Residual standard error.
[b]Early-weaned (174 d) heifers immediately adjusted to a high-concentrate diet and finished as calves.
[c]Early-weaned (180 d) heifers grazed on endophyte-infected tall fescue 16 mo before being finished on a high-concentrate diet.
[d]NA = not applicable.

Table 4). The slope and intercept of gain:feed relative to 12th-rib fat thickness were not significantly affected by age. Gain:feed decreased linearly ($P \leq 0.01$) as marbling score increased for heifers finished as calves and heifers finished as 2-yr-olds. Additionally, the slope of the regression line was similar for heifers of the two age groups (Figure 2, Table 4). However, at any given marbling score heifers finished as calves were more efficient than heifers finished as 2-yr-olds ($P \leq 0.01$). Heifers finished as calves had a higher marbling score at any given 12th-rib fat thickness ($P = 0.02$) than heifers finished as 2-yr-olds (Figure 3, Table 4). The relationship between s.c. and i.m. fat increased quadratically ($P = 0.04$) for heifers finished as 2-yr-olds, whereas the relationship increased linearly ($P \leq 0.01$) for heifers finished as calves. However, the differences in slope that resulted from age at entry into the feedlot were not significant ($P = 0.80$).

These data illustrated that gain:feed decreased ($P \leq 0.01$) as marbling score and 12th-rib fat thickness increased for heifers finished as calves and those finished as 2-yr-olds. However, heifers finished as calves deposited i.m. fat while gaining more efficiently ($P \leq 0.01$) than heifers finished as 2-yr-olds. Additionally, heifers finished as calves deposited more ($P \leq 0.01$) i.m. fat relative to s.c. fat compared with heifers finished as 2-yr-olds. These data suggest that heifers finished as calves are capable of accumulating sufficient i.m. fat to grade USDA average Choice or better without attaining

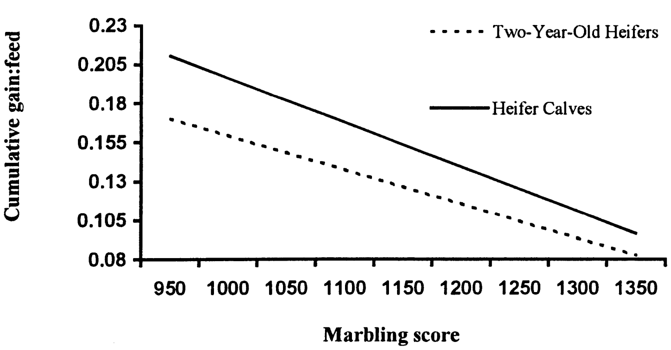

Figure 2. Regression of gain:feed (kg/kg) on marbling score (based on ultrasound) for early-weaned heifers finished as 2-yr-olds or finished as calves. Marbling scores were based on the following scale: 900 = slight, 1,000 = small, 1,100 modest, 1,200 = moderate, 1,300 = slightly abundant, 1,400 = moderately abundant, 1,500 = abundant. Gain:feed decreased linearly ($P \leq 0.01$) as marbling score increased for heifers finished as 2-yr-olds and finished as calves. The slope at which gain:feed decreased relative to increasing marbling score was not different ($P = 0.20$) as a result of age at feedlot entry.

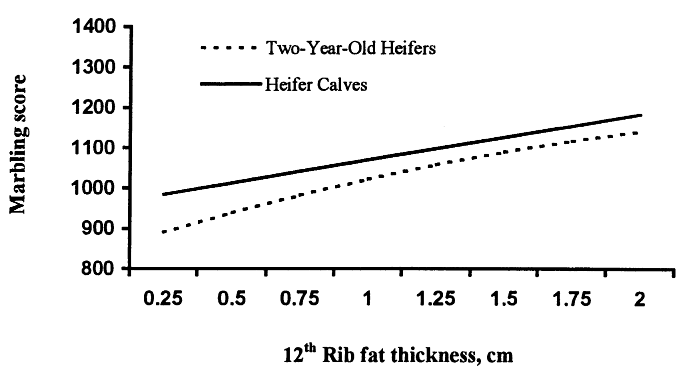

Figure 3. Regression of marbling score on 12th-rib fat thickness (both based on ultrasound) for early-weaned heifers finished as 2-yr-olds or finished as calves. Marbling score was based on the following scale: 900 = slight, 1,000 = small, 1,100 modest, 1,200 = moderate, 1,300 = slightly abundant, 1,400 = moderately abundant, 1,500 = abundant. Marbling score increased quadratically ($P = 0.04$) as 12th-rib fat thickness increased for heifers finished as 2-yr-olds. Marbling score increased linearly ($P \leq 0.01$) as 12th-rib fat thickness increased for heifers finished as calves. The slope of these lines did not differ ($P = 0.80$).

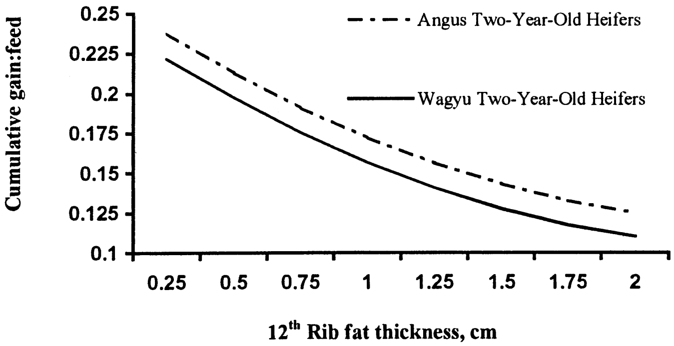

Figure 4. Regression of gain:feed (kg/kg) on 12th-rib fat thickness (based on ultrasound) of early-weaned Angus and Wagyu heifers finished as 2-yr-olds. Gain:feed decreased quadratically as 12th-rib fat thickness increased for Angus ($P = 0.01$) and Wagyu ($P = 0.04$) heifers finished as 2-yr-olds. The slope of these lines did not differ ($P = 0.52$).

B-maturity. Because heifers finished as calves deposit less s.c. fat relative to i.m. fat, they are less likely to reach a yield grade 4 when fed to high quality grades.

Relationship Among Intramuscular Fat, Subcutaneous Fat, and Feed Efficiency, as Affected by Breed Within Age Group. Gain:feed decreased quadratically ($P \leq 0.05$) as 12th-rib fat thickness increased among Angus and Wagyu heifers, but the slope of gain:feed regressed on 12th-rib fat thickness was not different ($P = 0.52$) as a result of breed of 2-yr-olds (Figure 4, Table 5). Wagyu 2-yr-olds tended ($P = 0.07$) to be less efficient than Angus heifers at similar 12th-rib fat thickness. Among early-weaned heifers finished as calves, gain:feed decreased as s.c. fat thickness increased (Figure 5, Table 5). The relationship was linear ($P \leq 0.01$) for Wagyu calves and quadratic ($P \leq 0.01$) among Angus calves. However,

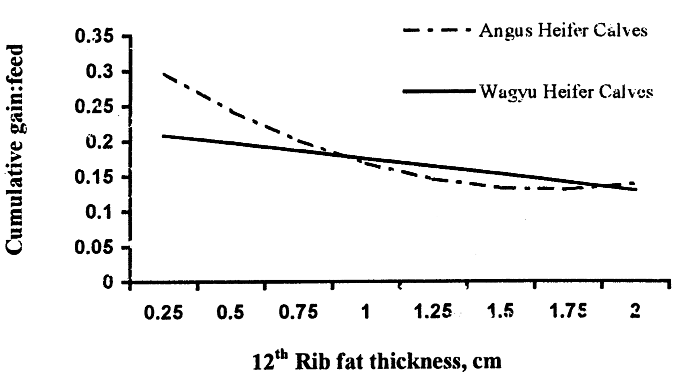

Figure 5. Regression of gain:feed (kg/kg) on 12th-rib fat thickness (based on ultrasound) for early-weaned Angus and Wagyu heifers finished as calves. Gain:feed decreased quadratically ($P \leq 0.01$) as 12th-rib fat increased for Angus heifer calves, whereas the decrease was linear ($P \leq 0.01$) for Wagyu heifer calves. The slopes ($P = 0.34$) and intercepts ($P = 0.65$) of these lines did not differ.

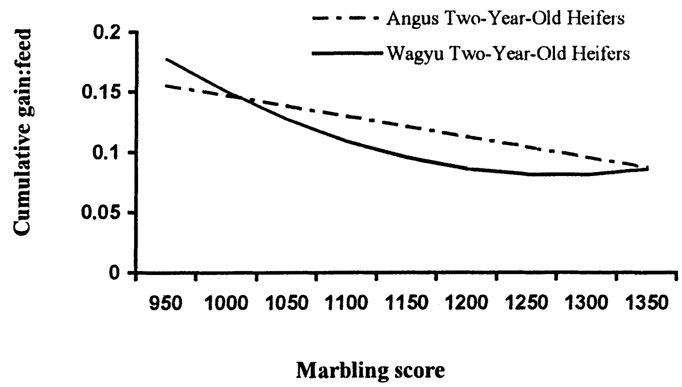

Figure 6. Regression of gain:feed (kg/kg) on marbling score (based on ultrasound) for early-weaned Angus and Wagyu heifers finished as 2-yr-olds. Marbling score was based on the following scale: 900 = slight, 1,000 = small, 1,100 modest, 1,200 = moderate, 1,300 = slightly abundant, 1,400 = moderately abundant, 1,500 = abundant. Gain:feed decreased linearly ($P \leq 0.01$) as marbling score increased for Angus heifers, whereas gain:feed decreased quadratically ($P = 0.03$) as marbling score increased among 2-yr-old Wagyu heifers. The intercepts of these lines differed ($P = 0.05$), but the slopes did not differ ($P = 0.20$).

differences in slope ($P = 0.34$) and intercept ($P = 0.65$) that resulted from breed were not significant among heifers finished as calves.

The intercept for gain:feed regressed on marbling score was lower ($P = 0.05$) for Angus than for Wagyu heifers (Figure 6, Table 5). Gain:feed decreased linearly ($P \leq 0.01$) as marbling score increased among Angus heifers. In contrast, the decrease in gain:feed relative to increasing marbling score was quadratic ($P = 0.02$) among Wagyu heifers. Among heifers finished as calves,

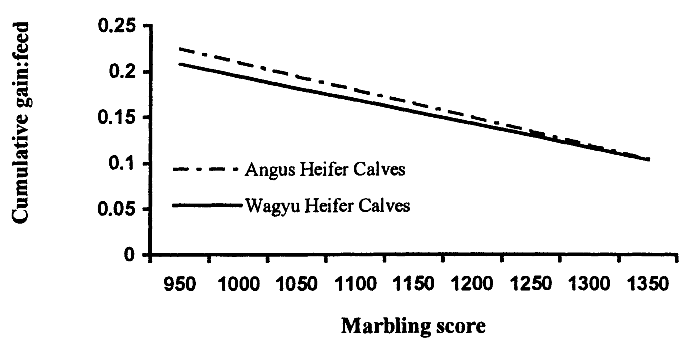

Figure 7. Regression of gain:feed (kg/kg) on marbling score (based on ultrasound) for early-weaned Angus and Wagyu heifers finished as calves. Marbling scores were based on the following scale: 900 = slight, 1,000 = small, 1,100 modest, 1,200 = moderate, 1,300 = slightly abundant, 1,400 = moderately abundant, 1,500 = abundant. Gain:feed decreased linearly ($P \leq 0.01$) as marbling score increased for Angus and Wagyu heifers. The intercepts ($P = 0.48$) and slopes ($P = 0.63$) of these lines did not differ.

Table 5. Regression coefficients for feed efficiency regressed over 12th-rib fat thickness and marbling score and for the regression of marbling score over 12th-rib fat thickness for Angus and Wagyu heifers finished as 2-yr-olds or as calves

Item	Intercept ± SE	b_1 ± SE	b_2 ± SE	RSE[a]
Gain:feed regressed on 12th-rib fat thickness (Figure 4)				
Angus 2-yr-old heifers[b]	0.265 ± 0.0229	−0.116 ± 0.0267	0.0227 ± 0.0074	2.80×10^{-4}
Wagyu 2-yr-old heifers[c]	0.250 ± 0.0259	−0.118 ± 0.0340	0.024 ± 0.0108	3.52×10^{-4}
Gain:feed regressed on 12th-rib fat thickness (Figure 5)				
Angus heifer calves[d]	0.361 ± 0.0363	−0.275 ± 0.0655	0.0821 ± 0.02835	5.65×10^{-4}
Wagyu heifer calves[e]	0.219 ± 0.0145	−0.045 ± 0.0111	NA[f]	5.98×10^{-4}
Gain:feed regressed on marbling score (Figure 6)				
Angus 2-yr-old heifers	0.317 ± 0.0440	$-1.66 \times 10^{-4} \pm 4.18 \times 10^{-5}$	NA	4.76×10^{-4}
Wagyu 2-yr-old heifers	1.55 ± 0.497	$-2.25 \times 10^{-3} \pm 8.89 \times 10^{-4}$	$8.82 \times 10^{-7} \pm 3.96 \times 10^{-7}$	2.62×10^{-4}
Gain:feed regressed on marbling score (Figure 7)				
Angus heifer calves	0.510 ± 0.0493	$-3.15 \times 10^{-4} \pm 4.68 \times 10^{-5}$	NA	5.78×10^{-4}
Wagyu heifer calves	0.454 ± 0.0615	$-2.58 \times 10^{-4} \pm 5.54 \times 10^{-5}$		
	NA	5.63×10^{-4}		
Marbling score regressed on 12th-rib fat thickness (Figure 8)				
Angus 2-yr-old heifers	900.3 ± 33.94	90.0 ± 16.50	NA	2,874
Wagyu 2-yr-old heifers	937.6 ± 27.74	129.5 ± 19.65	NA	2,390
Marbling score regressed on 12th-rib fat thickness (Figure 9)				
Angus heifer calves	913.7 ± 42.36	136.5 ± 40.43	NA	4,930
Wagyu heifer calves	1,009.0 ± 31.23	86.5 ± 25.93	NA	4,351

[a]Residual standard error.
[b]Angus 2-yr-old heifers grazed on endophyte-infected tall fescue 16 mo before being finished on a high-concentrate diet.
[c]½ Wagyu × ½ Angus 2-yr-old heifers grazed on endophyte-infected tall fescue 16 mo before being finished on a high-concentrate diet.
[d]Angus heifers early-weaned and immediately finished on a high-concentrate diet.
[e]½ Wagyu × ½ Angus heifers early-weaned and immediately finished on a high-concentrate diet.
[f]NA = not applicable.

breed was not a significant source of variation for differences in slope ($P = 0.63$) or intercept ($P = 0.48$) of feed efficiency regressed on marbling score (Figure 7, Table 5). Gain:feed decreased linearly ($P \le 0.01$) as marbling score increased between Angus and Wagyu heifers finished as calves.

Marbling score increased linearly ($P \le 0.01$) as s.c. fat thickness increased for both Angus and Wagyu 2-yr-olds (Figure 8, Table 5). Wagyu 2-yr-olds had higher ($P \le 0.01$) marbling scores at any given s.c. fat thickness than Angus heifers. However, slope did not differ ($P = 0.18$) as a result of breed between 2-yr-olds. Breed was a significant ($P = 0.04$) source of variation for the intercept of the regression line of marbling score regressed on 12th-rib fat thickness between early-weaned heifers finished as calves (Figure 9, Table 5). At the start of

Table 6. Relationship of actual and regression-predicted marbling scores and 12th-rib fat thickness of Angus and Wagyu heifers finished as calves and as 2-yr-olds

	Angus		Wagyu	
Item	Actual carcass	Ultrasound regression	Actual carcass	Ultrasound regression
Two-year-old heifers				
12th-Rib fat, cm	2.7	2.2[a]	1.9	1.7[a]
Marbling score[b]	1,298	1,133[c]	1,349	1,182[c]
Heifer calves				
12th-Rib fat, cm	1.5	0.97[d]	2.1	1.4[d]
Marbling score[b]	1,219	1,132[e]	1,305	1,184[e]

[a]Angus = 0.926 + 0.006 (d on high-concentrate diet); Wagyu = 0.816 + 0.004 (d on high-concentrate diet).
[b]Marbling score: 900 = slight, 1,000 = small, 1,100 modest, 1,200 = moderate, 1,300 = slightly abundant, 1,400 = moderately abundant, 1,500 = abundant.
[c]Angus = 937.0 + 0.90 (d on high-concentrate diet); Wagyu = 1,030.4 + 0.041 (d on high-concentrate diet) + 0.003 (d on high-concentrate diet)^2.
[d]Angus = 0.437 + 0.007 (d on high-concentrate diet) − 0.00002 (d on high-concentrate diet)^2; Wagyu = 0.671 + 0.003 (d on high-concentrate diet).
[e]Angus = 919.7 + 0.89 (d on high-concentrate diet); Wagyu = 986.5 + 0.83 (d on high-concentrate diet).

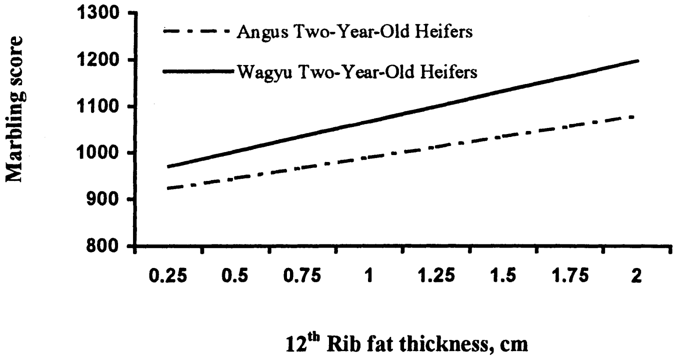

Figure 8. Regression of marbling score on 12th-rib fat thickness (both based on ultrasound) for early-weaned Angus and Wagyu heifers finished as 2-yr-olds. Marbling score was based on the following scale: 900 = slight, 1,000 = small, 1,100 modest, 1,200 = moderate, 1,300 = slightly abundant, 1,400 = moderately abundant, 1,500 = abundant. Marbling score increased linearly ($P \leq 0.01$) as 12th-rib fat thickness increased. Wagyu heifers had a higher ($P \leq 0.01$) marbling scores at any given fat thickness than Angus heifers. The slopes of these lines did not differ ($P = 0.18$).

the trial, Wagyu heifers finished as calves had higher marbling scores than Angus heifers at a similar fat thickness. Marbling score increased linearly ($P \leq 0.01$) as s.c. fat thickness increased between Angus and Wagyu heifers finished as calves, but the slope of these lines was not significantly affected ($P = 0.96$) by breed. Both Xie et al. (1996) and Mir et al. (1997) reported Wagyu-cross cattle to have higher marbling scores at

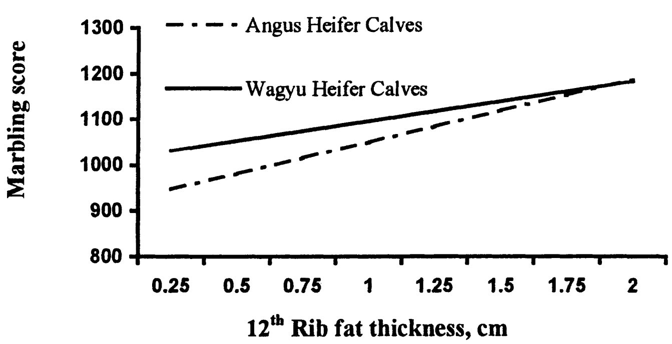

Figure 9. Regression of marbling score on 12th-rib fat thickness (both based on ultrasound) for early-weaned Angus and Wagyu heifers finished as calves. Marbling score was based on the following scale: 900 = slight, 1,000 = small, 1,100 modest, 1,200 = moderate, 1,300 = slightly abundant, 1,400 = moderately abundant, 1,500 = abundant. Marbling scored increased linearly ($P \leq 0.01$) as 12th-rib fat thickness increased for Angus and Wagyu heifers finished as calves. Initially, Wagyu heifers had a higher ($P = 0.04$) marbling score at a similar 12th-rib fat thickness (0.25 cm) than Angus heifers. The slopes of these lines did not differ ($P = 0.96$).

lower s.c. fat thickness than British or British-Continental crosses. Additionally, Mir et al. (1999) reported that ½ Wagyu × ½ British-cross heifers had more s.c. fat but similar marbling scores compared with ¾ Wagyu × ¼ Continental crosses. Feed efficiency was similar between these two breed groups.

Carcass 12th-rib fat thickness measurements recorded at slaughter were numerically higher than fat thickness predicted by the ultrasound-based regression equation (Table 6). Marbling scores predicted by regression equations generated with ultrasound data underpredicted actual marbling scores recorded at slaughter and those predicted from extractable lipid values (Table 6). Rouse et al. (1999) reported that ultrasound equipment and(or) software currently available generally underpredicted fat thickness and marbling scores of cattle with high marbling scores and 12th-rib fat thickness. The differences in final ultrasound measurement and actual carcass measurements recorded 8 d later reflect the potential error associated with ultrasound measurement. As with the 2-yr-old heifers, ultrasound underpredicted marbling score for calves (Table 6).

Implications

Early-weaning heifers and finishing them in an accelerated program allows i.m. fat deposition while heifers are gaining more efficiently compared with heifers grown on pasture and finished as 2-yr-olds. Because finishing heifer calves increase i.m. fat relative to s.c. fat deposition, calves are likely to reach quality grades that are eligible for grid premiums before they attain a yield grade that is discounted. Crossbreeding Angus and Wagyu cattle may increase marbling scores but also may compromise feed efficiency.

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