Live Animal Performance, Carcass Traits, and Meat Palatability of Calf- and Yearling-Fed Cloned Steers[1]

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ABSTRACT: Two groups of Brangus steers produced by nuclear transplantation cloning were used in parallel studies investigating the impact of calf- and yearling-feeding. The first group (n = 8) were fed as calves (CF; n = 4) or yearlings (YF; n = 4) to a constant age end point of 16 mo. The second group (n = 10) were fed as calves (CF; n = 5) or yearlings (YF; n = 5) to a constant live weight end point (530 kg). When slaughtered at the same age, CF and YF steers did not differ ($P > .05$) in feedlot ADG, but the CF steers were heavier and had higher dressing percentages, numeric yield grades, and quality grades ($P < .05$). Top loin steaks from the groups of steers did not differ ($P > .05$) in palatability traits. When fed to a constant live weight, the YF steers gained more rapidly ($P < .05$) and had lower ($P < .05$) numeric yield grades than did CF steers. Again CF steers had higher ($P < .05$) dressing percentages. There was no difference ($P > .05$) between the treatments in carcass quality grade or meat palatability characteristics. Thus, when finished to a constant weight end point, YF steers gained more rapidly, with no adverse effects on carcass quality grade or palatability traits; however, CF steers consistently produced higher dressing percentages, largely due to greater external fatness.

Key Words: Steers, Performance, Carcasses, Palatability, Cloning

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Introduction

According to the National Beef Quality Audit (Smith et al., 1992; Lorenzen et al., 1993), production defects and inefficiencies cause approximately $280 lost value for every steer and heifer produced in the United States. Whereas the average USDA yield grade has remained virtually unchanged over the last 20 yr, there has been a substantial reduction in beef carcass quality grade during the same period (Smith et al., 1992). Some in the beef industry have claimed that this decrease in marbling can be explained, at least partially, by more cattle being fed as calves rather than the more traditional yearling-feeding. However, there is little agreement in the literature on the impact of feeding calves vs yearlings on production performance, carcass traits, or palatability. There is some evidence that calf-fed cattle gain more efficiently than yearlings with minimal effects on carcass quality grade or meat palatability (Dikeman et al., 1985a; Huffman et al., 1990). Others have demonstrated that yearlings gained more rapidly and had more desirable yield and quality grades compared with calves (Lunt and Orme, 1987). Dikeman et al. (1985b) concluded that calf-fed steers produced more tender meat than yearling-fed steers. Therefore, this study used steers created by nuclear transplantation to evaluate the effects of calf- and yearling-feeding on production performance and carcass and meat palatability traits.

Materials and Methods

Parallel studies were conducted to allow for separation of the effects of animal age and feeding regimen. Nuclear transfer clones were used to eliminate most, or all, of the genetic variability, so that meaningful

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experimental results could be obtained with a relatively small number of animals. Two groups of Brangus steers created by nuclear transplantation cloning were used in these experiments. The first group (n = 8) was calf- or yearling-fed to a constant age end point (Exp. 1). The second group (n = 10) was calf- or yearling-fed to a constant live weight end point (Exp. 2).

Cloning Techniques. The cloned steers were produced by a private laboratory (Granada Biosciences, College Station, TX) following procedures developed in their laboratory (Bondioli et al., 1990; Westhusin et al., 1992). Briefly, recipient oocytes were harvested from superovulated donor cows following surgical removal of the ovaries and oviducts. The oocytes were enucleated according to the procedures of Willadsen (1986) in preparation for implantation with donor nuclei.

The donor embryos were recovered from superovulated cattle at 5.0 to 6.5 d after estrus by routine nonsurgical collection procedures. All embryos were at the 16- to 64-cell stage of development at the time of collection. From a single embryo, individual nuclei were transplanted into the enucleated oocytes following the electrofusion techniques described by Westhusin et al. (1992). The nuclear transplantation embryos were cultured for 5 to 6 d in ligated sheep oviducts before being transferred into synchronous bovine recipients using traditional nonsurgical techniques.

Experiment 1. Steers were assigned randomly at weaning (8 mo of age) to calf- or yearling-feeding (n = 4 per treatment). Within these eight steers, two dams were represented; all calves were from the same sire, but there were four calves each from embryos recovered from two dams. Therefore, although they were not eight identical clones, there were two sets of four identical calves, and two sets were half-siblings to each other. In assigning the weaned calves to the treatments, two calves from each dam were assigned to the calf- or yearling-feeding treatments.

The calf-fed steers (**CF**) were started immediately after weaning on feed (described below), and the yearling-fed (**YF**) steers were allowed to graze bermudagrass pasture for 123 d before starting the feeding period. Both treatment groups were fed to an age-constant end point of 16 mo. This age was selected to allow sufficient time for the YF steers to spend approximately 120 d on pasture followed by approximately 100 d on feed. The CF and YF steers in Exp. 1 were fed for 217 and 93 d, respectively.

Experiment 2. The steers for this phase (n = 10) were assigned randomly at weaning (8 mo of age) to the CF or YF treatments (n = 5 per treatment). The CF steers were placed on feed at weaning, whereas the YF steers were allowed to graze native central Texas pasture and(or) oat pasture for 120 d before beginning the feeding period. Both treatment groups were fed to a constant live weight end point of approximately 530 kg. The actual times on feed for the CF and YF steers in Exp. 2 were 224 and 182 d, respectively.

Diets and Feeding Regimen. During the feeding period, all cattle were housed in pens (two to four animals per pen) approximately 6 m × 10 m in size and equipped with automatic watering devices. The eight steers in Exp. 1 were housed in two pens (four steers per pen) so that there was one pen per treatment group. In Exp. 2, the 10 steers were fed in four pens (two to three steers per pen), so that there were two pens per treatment. All steers within a pen were from the same treatment group.

At the start of the feeding period, all steers received a starter diet for 2 wk. This diet was composed of 34.5% ground milo, 10% cottonseed meal, 50% cottonseed hulls, 1.7% mineral premix, and 4% molasses. The steers then were fed a series of three subsequent diets, the percentage of corn increasing in each diet. The steers consumed each diet for 10 d before they were moved to the next diet. Following this adaptation period, the cattle were fed a finishing diet (85% concentrate) until slaughter. Steers were given ad libitum access to all diets. Throughout the feeding period, steers were given free choice access to bermudagrass hay two to three times per week as an extra source of roughage.

All steers were transported to and slaughtered at the E. M. Rosenthal Meat Science and Technology Center on the Texas A&M University campus, following all appropriate humane slaughter methods as set forth in the Humane Methods of Slaughter Act. Mechanical stunning (concussion type) was used to immobilize the steers for subsequent exsanguination.

A longissimus muscle sample, which included adhering s.c. adipose tissue, was removed immediately after exsanguination for measurement of calpain and calpastatin activities. At 3 h postmortem, approximately 10 g of longissimus muscle was removed opposite the 11th rib for measurement of muscle pH. The muscle tissue was minced and then homogenized in 50 mL of double-distilled, deionized water. The pH was determined for the resulting slurry. An additional cross-section of longissimus muscle was removed opposite the 9th rib at 24 h postmortem for quantification of post-rigor calpastatin activity. All samples were removed from the left carcass side. All carcasses were evaluated for USDA quality and yield grade characteristics (USDA, 1989) by trained carcass evaluators at 48 h postmortem.

Palatability Traits. Three top loin steaks (3.2 cm thick) were removed from the anterior end of the loin of each carcass (left carcass side) for palatability evaluations. Following vacuum-packaged storage for 14 d (2°C), the top loin steaks were frozen and stored (−10°C) until subsequent sensory analyses. All steaks were thawed (2°C for 24 h) before cooking. The steaks were broiled on a Farberware Open Hearth Broiler (Farberware Company, Bronx, NY) to an internal

temperature of 70°C, monitored by copper constantan thermocouples. Two steaks (the two most anterior) were designated for sensory panel evaluation, and the third was used for Warner-Bratzler shear force determination. The steaks designated for sensory panel were evaluated by an eight-member sensory panel trained according to the methods of Cross et al. (1978). The sensory panel evaluated warm (approximately 60°C) 1-cm^3 cubes of steak for muscle fiber tenderness, connective tissue amount, juiciness, flavor intensity, and overall tenderness using 8-point scales (1 = extremely tough, abundant connective tissue, extremely dry, or extremely bland flavor; 8 = extremely tender, no perceptible connective tissue, extremely juicy, or extremely intense flavor). The shear force steak was cooled for 2 h at room temperature (23°C). Ten 1.27-cm-diameter cores were taken from each steak parallel to the length of the muscle fibers. Each core was sheared once with a Warner-Bratzler shear machine. The shear force for each steak was the computed average value for the cores.

Calpain System Activities and Sarcomere Length. Cross-sections of longissimus muscle were obtained immediately after exsanguination, and m- and μ-calpain and calpastatin activities were quantified according to Koohmaraie (1990). An additional longissimus muscle sample was obtained at 24 h postmortem for determination of calpastatin (Shackelford et al., 1994). Sarcomere length was determined in postrigor longissimus muscle by laser diffraction (Cross et al., 1981).

Data Analysis. Data from Exp. 1 were analyzed as a randomized complete block design and subjected to analysis of variance procedures (SAS, 1990). In Exp. 1, data were blocked by dam to remove possible variation between the two sets of half-siblings. Experiment 2 was analyzed as a completely randomized design. The statistical models were $Y_{ijk} = \mu + Treatment_i + Dam_j + e_{ijk}$ for Exp. 1 and $Y_{ij} = \mu + Treatment_i + e_{ij}$ for Exp. 2, where μ is the population mean, $Treatment_i$ is the i^{th} treatment effect, Dam_j is the j^{th} dam effect, and e_{ijk} is the random error associated with the individual animal. Additionally, the sensory panel data were blocked by replicate, because two steaks per animal were evaluated. During Exp. 2, one of the YF steers suffered a crippling injury and was killed humanely. Due to the unbalance created, least squares means (SAS, 1990) were generated for each treatment in Exp. 2.

Results and Discussion

The cloned steers in this study were very similar in their growth traits from birth until weaning within a genotype. From weaning until the end of the study, this similarity remained for the genotypes within a treatment. For Exp. 1 (constant age end point), in which two genotypes were represented, there was a significant difference between the two genotypes for all growth and performance traits throughout the study. Although the two genotypes were closely related (half-siblings), there was an effect ($P < .05$) of the dam on growth and performance traits.

Live Animal Production Performance. From birth until weaning, there were no differences in weight between the CF and YF steers in Exp. 1 (Table 1). The two groups were within .2 kg for average birth weight and within 4 kg for average weaning weight, although the dam effect contributed to the rather large SE associated with each mean. The differences between the CF and YF steers began to appear as soon as the CF steers were started on the high-concentrate diet and the YF steers were weaned and placed into the grazing program. Thus, the CF steers were lighter ($P < .05$) at the beginning of high-concentrate feeding compared with YF steers that had 123 d on forage before beginning the feeding period. The CF steers rapidly surpassed the YF steers after the feeding period began. Because they were slaughtered at a constant age (16 mo), the CF steers were fed a high-concentrate diet for over 200 d, compared with less than 100 d for the YF steers. Consequently, CF steers were heavier ($P < .05$) than YF steers at slaughter (Table 1). In Exp. 1, there was no difference ($P > .05$) in feedlot ADG between the treatments.

The steers in Exp. 2 (constant live weight end point) were all of the same genotype and, thus, were

Table 1. Growth and performance of calf- and yearling-fed steers finished to a constant age endpoint

	Calf-fed (n = 4)		Yearling-fed (n = 4)	
Trait	Mean	SE	Mean	SE
Birth wt, kg	31.2	3.2	31.4	4.4
Weaning wt, kg	244.7	15.6	248.6	23.4
On-feed wt, kg	256.5[y]	18.7	330.0[z]	30.0
Finished wt, kg	523.2[y]	40.9	447.2[z]	31.9
Time on feed, d	217	—	93	—
ADG, kg/d	1.23	.10	1.26	.03

[y,z]Means within a row lacking a common superscript differ ($P < .05$).

Table 2. Growth and performance of calf- and yearling-fed steers finished to a constant live weight end point (least squares means)

	Calf-fed (n = 5)		Yearling-fed (n = 4)	
Trait	Mean	SEM	Mean	SEM
Birth wt, kg	38.0	1.4	36.7	1.6
Weaning wt, kg	233.3	5.9	229.7	6.6
On-feed wt, kg	236.0	5.9	220.4	6.6
Finished wt, kg	530.5	10.8	526.6	12.0
Time on feed, d	224	—	182	—
ADG, kg/d	1.31[y]	.03	1.68[z]	.04

[y,z]Means within a row lacking a common superscript differ ($P < .05$).

not subjected to a dam effect. This factor is demonstrated throughout the growth of the cattle by much smaller SE for animal weights in Exp. 2 (Table 2). As in Exp. 1, there were no differences ($P > .05$) between the treatments for birth weight or weaning weight. Unlike Exp. 1, there was no difference ($P > .05$) in on-feed weight between the CF and YF steers, even though the YF steers grazed pasture for 120 d. Due to unfavorable weather patterns, the pasture conditions were harsh during the grazing period, and the YF steers did not gain weight during this period. As a result, they weighed the same as the CF steers going on feed, although they were 4 mo older at the time they went on feed. By design, there was no difference ($P > .05$) in slaughter weight between the CF and YF steers. The YF steers gained more rapidly ($P < .05$) during the feeding period than did the CF steers, putatively due to compensatory gain during the early portion of the finishing phase. From hip height measurement data it was apparent that, although the YF steers did not gain weight during the grazing period, they grew in height (from 116 cm to 120 cm) during the same period (data not presented in a table). As a result of the conditions imposed by the experiment, the CF steers were slaughtered at approximately 15 mo of age vs 18 mo for the YF steers.

These data suggest that animal age is more important than feeding regimen with respect to rate of gain. There was no difference in rate of gain between CF and YF steers when age was held constant (Exp. 1), but the YF steers gained more rapidly when finished to a constant live weight end point, although at least a portion of this advantage was due to compensatory gain. This is generally in agreement with most others, who demonstrated that yearling-feeding results in more rapid weight gains (Dikeman et al., 1985a,b; Lunt and Orme, 1987; Sindt et al., 1991). Others, however, have found either no difference (Huffman et al., 1990) or a greater rate of gain in calf-fed steers (Hickok et al., 1992).

Carcass Traits. The CF steers in Exp. 1 produced heavier ($P < .05$) carcasses with higher ($P < .05$) dressing percentages than did the YF steers (Table 3). This was due to the length of time the CF cattle were on a high-concentrate diet compared with the YF cattle. The higher dressing percentage observed for the CF steers was largely due to increased ($P < .05$) external fatness. Correspondingly, the CF steers produced carcasses with higher ($P < .05$) numeric yield grades than the YF steers. The CF carcasses had higher ($P < .05$) marbling scores and USDA quality grades than the YF carcasses, again due to the greater

Table 3. Carcass traits of calf- and yearling-fed steers finished to a constant age end point

	Calf-fed (n = 4)		Yearling-fed (n = 4)	
Trait	Mean	SE	Mean	SE
Live wt, kg	512.6[y]	37.2	433.6[z]	30.4
Warm carcass wt, kg	330.0[y]	27.0	266.5[z]	20.8
Dressing percentage	64.25[y]	.63	61.36[z]	.60
Adjusted fat thickness, mm	18.0[y]	3.7	8.6[z]	.7
Longissimus muscle area, cm^2	63.55	1.55	60.00	1.99
Kidney, pelvic, and heart fat, %	2.38[y]	.13	1.75[z]	.14
USDA yield grade	4.4[y]	.6	3.0[z]	.3
USDA marbling score[a]	453[y]	19	340[z]	4
USDA quality grade[b]	318[y]	6	240[z]	4

[a]300 = Slight[00] and 400 = Small[00].
[b]200 = Select[00] and 300 = Choice[00].
[y,z]Means within a row lacking a common superscript differ ($P < .05$).

Table 4. Carcass traits of calf- and yearling-fed steers finished to a constant live weight end point (least squares means)

	Calf-fed (n = 5)		Yearling-fed (n = 4)	
Trait	Mean	SEM	Mean	SEM
Live wt, kg	509.2	10.7	504.6	12.0
Warm carcass wt, kg	337.3	7.5	327.6	8.3
Dressing percentage	66.24[y]	.26	64.91[z]	.29
Adjusted fat thickness, mm	18.9	1.0	15.7	1.2
Longissimus muscle area, cm^2	65.04	1.49	67.42	1.67
Kidney, pelvic, and heart fat, %	2.40	.10	2.31	.12
USDA yield grade	4.5[y]	.1	3.9[z]	.1
USDA marbling score[a]	490	23	462	26
USDA quality grade[b]	330	8	319	9

[a]300 = Slight[00] and 400 = Small[00].
[b]200 = Select[00] and 300 = Choice[00].
[y,z]Means within a row lacking a common superscript differ ($P < .05$).

time on feed. Despite the higher marbling scores observed for the CF carcasses, the chemical lipid content of the longissimus muscle was not significantly greater for the CF carcasses than for the YF carcasses (5.20 ± .50 and 3.74 ± .54%, respectively). This lack of significance was due to the relatively large standard errors associated with the mean lipid values. The average lipid content percentages were in close agreement with published values for similar marbling scores (Savell et al., 1986).

When fed to a constant live weight end point (Table 4), the CF steers still had higher ($P < .05$) dressing percentages than the YF steers, although carcass weight and external fatness were not different ($P > .05$). Although not different statistically, the YF carcasses tended to have less s.c. fat, larger longissimus muscle ribeye area, and less internal fat, leading to significantly lower USDA yield grades than the CF carcasses. There was no difference ($P > .05$) in marbling score or USDA quality grade between CF and YF steers finished to a constant live weight end point. These findings are in agreement with Dikeman et al. (1985a), who also found no difference in USDA yield and quality grade characteristics between calf- and yearling-fed cattle finished to constant live weight end points.

Despite increased marbling associated with the CF carcasses, there were no significant tenderness differences between CF and YF top loin steaks in Exp. 1 (Table 5). The muscle pH measured at 3 h postmortem (Table 5) was lower ($P < .05$) in the CF carcasses. This difference was small in magnitude and not likely to be of physiological importance (CF = 6.08 ± .02 and YF = 6.12 ± .02).

Meat Palatability. In Exp. 2, there again were no differences ($P > .05$) between CF and YF steaks with respect to palatability attributes, although longissimus muscles from the YF carcasses had longer ($P < .05$) sarcomeres than did those from CF carcasses (Table 6). In both experiments, differences in tenderness between CF and YF were virtually nonexistent, and the tenderness of the meat from all of the cattle

Table 5. Palatability and related characteristics of calf- and yearling-fed steers finished to a constant age end point

	Calf-fed (n = 4)		Yearling-fed (n = 4)	
Characteristic	Mean	SE	Mean	SE
Juiciness[a]	4.00	.00	4.25	.25
Muscle fiber tenderness[b]	5.75	.25	5.25	.48
Connective tissue amount[c]	7.25	.25	6.50	.29
Overall tenderness[b]	5.75	.25	5.25	.48
Flavor intensity[d]	6.00	.00	6.00	.00
Warner-Bratzler shear, kg	2.45	.21	2.68	.35
3-h postmortem pH	6.08[y]	.02	6.12[z]	.02
Sarcomere length, μm	1.80	.04	1.73	.03

[a]8 = Extremely juicy, 1 = extremely dry.
[b]8 = Extremely tender, 1 = extremely tough.
[c]8 = None, 1 = abundant.
[d]8 = Extremely intense, 1 = extremely bland.

Table 6. Palatability and related characteristics of calf- and yearling-fed steers finished to a constant live weight end point (least squares means)

	Calf-fed (n = 5)		Yearling-fed (n = 4)	
Characteristic	Mean	SEM	Mean	SEM
Juiciness[a]	6.00	.00	6.00	.00
Muscle fiber tenderness[b]	6.80	.21	7.25	.24
Connective tissue amount[c]	7.40	.24	7.25	.26
Overall tenderness[b]	6.80	.21	6.75	.24
Flavor intensity[d]	6.00	.00	6.00	.00
Warner-Bratzler shear, kg	2.98	.12	2.58	.13
3-h postmortem pH	6.00	.10	5.92	.11
Sarcomere length, μm	1.94[y]	.04	2.28[z]	.05

[a]8 = Extremely juicy, 1 = extremely dry.
[b]8 = Extremely tender, 1 = extremely tough.
[c]8 = None, 1 = abundant.
[d]8 = Extremely intense, 1 = extremely bland.
[y,z]Means within a row lacking a common superscript differ ($P < .05$).

was well within an acceptable range (Shackelford et al., 1991). Shackelford et al. (1991) constructed confidence intervals for cooked beef tenderness based on Warner-Bratzler shear force and concluded that beef top loin steaks with shear values < 3.9 kg would have a 95% chance of being rated "slightly tender" or better by a sensory panel. All observations in the present study were well below 3.9 kg.

The calpain proteolytic system has been clearly shown to play a key role in the postmortem tenderization of beef (for review see Koohmaraie, 1988, 1992a,b). Subsequently, calpastatin activity measured 24 h postmortem has been identified as an effective predictor of cooked beef tenderness (Shackelford et al., 1994). In the present research, there were no significant differences in tenderness between the treatment groups and, correspondingly, no differences ($P > .05$) were found in calpastatin activity (Tables 7 and 8), although in Exp. 1 the YF steers had higher ($P < .05$) μ-calpain activity measured at 0 h postmortem.

The results of this study indicate that, regardless of slaughter end point, CF steers produced higher dressing percentages and USDA yield grades, but there were no differences in meat palatability traits. When slaughtered at similar live weight end points, there was no difference in USDA carcass quality grade.

Implications

Nutrient density of the diet before the feedlot phase is an important determinant of rate of gain during finishing. However, slaughter end point seems to be a more important determinant of carcass traits. Yearling-feeding, when finishing to a constant weight, of cloned Brangus steers resulted in more rapid gains and desirable carcass yield grades, without altering quality or palatability characteristics, although calf-feeding increased dressing percentages. Calf-feeding had no impact on carcass quality grade. The increased dressing percentage associated with calf-feeding may make steers more valuable to feeders, if steers are sold on a carcass weight basis.

Table 7. Calpain and calpastatin activities for calf- and yearling-fed steers finished to a constant age end point

	Calf-fed (n = 4)		Yearling-fed (n = 4)	
Item	Mean	SE	Mean	SE
0 h postmortem				
μ-calpain activity[a]	1.65[y]	.03	1.85[z]	.09
m-calpain activity[b]	1.10	.08	1.26	.07
Calpastatin activity[c]	4.75	.65	4.75	.42
24 h postmortem				
Calpastatin activity[c]	2.38	.18	2.56	.15

[a]Low Ca^{2+}-requiring calpain protease total caseinolytic activity/gram of muscle.
[b]High Ca^{2+}-requiring calpain protease total caseinolytic activity/gram of muscle.
[c]Inhibition of casein hydrolysis by m-calpain/gram of muscle.
[y,z]Means within a row lacking a common superscript differ ($P < .05$).

Table 8. Calpain and calpastatin activities of calf- and yearling-fed steers finished to a constant live weight end point (least squares means)

	Calf-fed (n = 5)		Yearling-fed (n = 4)	
Item	Mean	SEM	Mean	SEM
0 h postmortem				
μ-calpain activity[a]	.96	.10	1.12	.11
m-calpain activity[b]	1.00	.07	.92	.08
Calpastatin activity[c]	2.99	.21	2.96	.24
24 h postmortem				
Calpastatin activity[c]	1.82	.07	1.97	.08

[a]Low Ca^{2+}-requiring calpain protease total caseinolytic activity/gram of muscle.
[b]High Ca^{2+}-requiring calpain protease total caseinolytic activity/gram of muscle.
[c]Inhibition of casein hydrolysis by m-calpain/gram of muscle.

Literature Cited

Bondioli, K. R., M. E. Westhusin, and C. R. Looney. 1990. Production of identical bovine offspring by nuclear transfer. Theriogenology 33:165.

Cross, H. R., R. Moen, and M. S. Stanfield. 1978. Training and testing of judges for sensory analysis of meat quality. Food Technol. 32:48.

Cross, H. R., R. L. West, and T. R. Dutson. 1981. Comparison of methods for measuring sarcomere length in beef semitendinosus muscle. Meat Sci. 5:261.

Dikeman, M. E., A. D. Dayton, M. C. Hunt, C. L. Kastner, J. B. Axe, and H. J. Ilg. 1985a. Conventional versus accelerated beef production with carcass electrical stimulation. J. Anim. Sci. 61: 573.

Dikeman, M. E., K. N. Nagele, S. M. Myers, R. R. Schalles, D. H. Kropf, C. L. Kastner, and F. A. Russo. 1985b. Accelerated versus conventional beef production and processing. J. Anim. Sci. 61:137.

Hickok, D. T., R. R. Schalles, M. E. Dikeman, and D. E. Franke. 1992. Comparison of feeding calves vs. yearlings. Cattlemen's Day, Kansas State University. pp 64–65.

Huffman, R. D., S. E. Williams, D. D. Hargrove, D. D. Johnson, and T. T. Marshall. 1990. Effects of percentage Brahman and Angus breeding, age-season of feeding and slaughter end point on feedlot performance and carcass characteristics. J. Anim. Sci. 68:2243.

Koohmaraie, M. 1988. The role of endogenous proteases in meat tenderness. Proc. Recip. Meat Conf. 41:89.

Koohmaraie, M. 1990. Quantification of Ca^{2+}-dependent protease activities by hydrophobic and ion-exchange chromatography. J. Anim. Sci. 68:659.

Koohmaraie, M. 1992a. The role of Ca^{2+}dependent proteases (calpains) in postmortem proteolysis and meat tenderness. Biochimie 74:237.

Koohmaraie, M. 1992b. Role of the neutral proteinases in postmortem muscle protein degradation and meat tenderness. Proc. Recip. Meat Conf. 45:63.

Lorenzen, C. L., D. S. Hale, D. B. Griffin, J. W. Savell, K. E. Belk, T. L. Frederick, M. F. Miller, T. H. Montgomery, and G. C. Smith. 1993. National Beef Quality Audit: Survey of producer-related defects and carcass quality and quantity attributes. J. Anim. Sci. 71:1495.

Lunt, D. K., and L. E. Orme. 1987. Feedlot performance and carcass evaluation of heifers fed finishing diets as weanling calves or as yearlings. Meat Sci. 20:159.

Savell, J. W., H. R. Cross, and G. C. Smith. 1986. Percentage ether extractable fat and moisture content of beef *longissimus* muscle as related to USDA marbling score. J. Food Sci. 51:838.

SAS. 1990. SAS User's Guide: Statistics. SAS Inst. Inc., Cary, NC.

Shackelford, S. D., M. Koohmaraie, L. V. Cundiff, K. E. Gregory, G. A. Rohrer, and J. W. Savell. 1994. Heritabilities and phenotypic and genetic correlations for bovine postrigor calpastatin activity, intramuscular fat content, Warner-Bratzler shear force, retail product yield, and growth rate. J. Anim. Sci. 72:857.

Shackelford, S. D., J. B. Morgan, H. R. Cross, and J. W. Savell. 1991. Identification of threshold levels for Warner-Bratzler shear force in beef top loin steaks. J. Muscle Foods 2:289.

Sindt, M., R. Stock, and T. Klopfenstein. 1991. Calf vs. yearling feeding. Univ. of Nebraska Beef Cattle Rep. pp 166–176.

Smith, G. C., J. W. Savell, R. P. Clayton, T. G. Field, D. B. Griffin, D. S. Hale, M. F. Miller, T. H. Montgomery, J. B. Morgan, J. D. Tatum, and J. W. Wise. 1992. Improving the consistency and competitiveness of beef—A blueprint for total quality management in the fed-beef industry. The final report of the National Beef Quality Audit—1991, conducted by Colorado State University and Texas A&M University, for the National Cattlemen's Association on behalf of the Cattlemen's Beef Promotion and Research Board.

USDA. 1989. Official United States standards for grades of carcass beef. Agric. Marketing Serv., USDA, Washington, DC.

Westhusin, M. E., M. J. Levanduski, R. Scarborough, C. R. Looney, and K. R. Bondioli. 1992. Viable embryos and normal calves after nuclear transfer into Hoechst stained enucleated demi-oocytes of cows. J. Reprod. Fertil. 95:475.

Willadsen, S. M. 1986. Nuclear transplantation in sheep embryos. Nature (Lond.) 320:63.