Influence of Realimentation of Mature Cows on Maturity, Color, Collagen Solubility, and Sensory Characteristics[1]

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ABSTRACT: Cull beef cows (n = 80) that had consumed similar grassland diets were assigned to one of four feeding periods (0, 28, 56, and 84 d) and subdivided into two groups fed either a high-energy, high-protein diet or a high-energy, low-protein diet. Treatments were designed to examine the effect of time on feed, dietary protein, and electrical stimulation on carcass traits, composition, shear force, sensory profile, collagen characteristics, and myoglobin state. Within 1 h of slaughter, the right side of each carcass was electrically stimulated, and the left side served as the control. The only trait influenced by protein level was longissimus muscle area, for which a high-protein diet resulted in larger ($P < .05$) longissimus muscle areas. Increased time on a high-energy diet increased USDA yield grade and sensory ratings; however, metmyoglobin and reduced myoglobin values decreased between 0 and 28 d on feed. Electrical stimulation improved lean color, shear force values, and sensory attributes. Electrical stimulation decreased shear force by 2.8 kg for 0-d carcasses. With subsequent days on feed, shear force values continued to decrease, but this effect was minimal in electrically stimulated carcasses. However, protein level did not significantly influence palatability and quality attributes. The greatest ($P < .05$) improvement in marbling score was observed in electrically stimulated carcasses from cows fed for 84 d. Additionally, feeding a high-protein diet for 84 d resulted in a slightly lower maturity score. Even though values for palatability and quality traits were improved by antemortem and postmortem treatments, the magnitude of improvement may not be great enough for steaks from mature fed cows to be considered as acceptable as steaks from young fed beef.

Key Words: Cows, Feeding, Tenderness, Color, Collagen

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Introduction

Because of inferior palatability of meat from mature cull cows, limited marketing options exist. If tenderness could be improved, marketing flexibility of the more valuable parts of their carcass, such as the rib and loin, would be increased. The relationship of beef carcass maturity to the palatability attributes of beef has been well documented (Breidenstein et al., 1968; Cross et al., 1973; Berry et al., 1974); physiological maturity of the carcass and tenderness are inversely related.

Intensive pre-slaughter feeding has a beneficial effect on sensory properties of beef (Tatum, 1981). Cattle fed high-energy diets experience rapid rates of protein synthesis, and, therefore, would be expected to produce beef with a high proportion of newly synthesized, heat-labile collagen (Aberle et al., 1981). Miller et al. (1983, 1987) reported increased percentages of soluble collagen with the feeding of high-energy diets to mature steers and cows, respectively. Thus, intensive pre-slaughter feeding may reduce age-associated toughening of beef. If that is the case, beef from mature animals fed high-energy diets should have cooked muscle properties that are more highly associated with palatable meat products. Therefore, the objective of this study was to evaluate the effects of protein content in the diet, time of feeding a high-energy diet, and electrical stimulation on maturity, color, collagen solubility, and sensory characteristics of mature cows.

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Materials and Methods

Selection of Animals. Protocol was approved by the Animal Use and Care Committee. Mature beef cows (n = 80) were selected by a trained three-member committee from a typical grazing herd at the Roman L. Hruska U. S. Meat Animal Research Center (MARC) to be similar in age, subcutaneous fat thickness, and muscling. To reduce variation in subcutaneous fat thickness, cows that were heavy in condition were placed on a submaintenance diet for approximately 30 to 60 d to ensure that all cows had subcutaneous fat levels that were similar and typical of most cull mature cows in the United States. Cows were assigned randomly to 1 of 16 pens with five animals per pen, thus providing two replications per feeding period within diet. Average daily gain data were evaluated to determine whether cows fed the submaintenance diet displayed compensatory growth different from cows not fed the submaintenance diet, and no effects were found. Cows were fed a high-energy diet with either a low (10.21% CP) or high (12.82% CP) protein level for one of four feeding periods (0, 28, 56, or 84 d).

As designated by design, cows were transported by pen to the MARC abattoir the morning of slaughter. Approximately 45 min after bleeding, the right side of each carcass was electrically stimulated with high voltage electrical current (500 V, 60 Hz, 2 min duration; 1.5 s on, .5 s off). The left side (nonstimulated) served as the control.

Carcass Evaluation and Fabrication. After chilling for 24 h postmortem at 0 to 2°C, each carcass was ribbed, and trained personnel evaluated both sides of the carcass, independent of one another, at the 12–13th rib interface of the longissimus muscle for color, texture, firmness, and presence of heat ring as described by Savell et al. (1978) and skeletal, lean, and overall maturity scores and marbling score. All other traits, including fat color, fat thickness (12–13th rib interface), longissimus muscle area, estimated kidney, pelvic, and heart fat, and USDA yield grade (USDA, 1989) were calculated on the left side of the carcass only.

Carcass Composition. Carcass composition was estimated using the 9–10–11th rib section (Hankins and Howe, 1946). The rib section was removed from each left side 7 d postmortem and transported to the Rosenthal Meat Science and Technology Center at Texas A&M University. The rib section was weighed and separated into bone plus heavy connective tissue and soft tissue. Each component was weighed to ensure at least 99% recovery as a percentage of the total weight. The soft tissue was ground three times through a .30-cm-diameter plate and subsampled for chemical analyses, which included moisture, fat (AOAC, 1990) and protein by difference (assuming an ash content of 2.0%).

Shear and Sensory Determinations. Longissimus steaks (2.54 cm thick) were removed from the loin section of each carcass side 7 d postmortem, double-wrapped in polyethylene-coated paper, immediately frozen, and transported to the Texas A&M University Sensory Testing Facility. Steaks were thawed at 2°C and broiled on Farberware Open-Hearth broilers (Farberware Co., Bronx, NY) to an internal temperature of 70°C (monitored by copper constantan thermocouples and a recording potentiometer). Upon reaching the desired internal temperature, steaks were removed and sectioned into 1.3 cm × 1.3 cm × 1.9 cm pieces and distributed randomly to each panelist. Sensory evaluations were performed by a nine-member trained descriptive attribute panel. Panelists were selected and trained according to AMSA (1978) and Cross et al. (1978). Two sessions of four samples per session were conducted each day, 3 d per week for 20 d. Panel members scored the samples using the following structured scales: juiciness (8 = extremely juicy and 1 = extremely dry), muscle fiber and overall tenderness (8 = extremely tender and 1 = extremely tough), connective tissue amount (8 = none and 1 = abundant), and off-flavor (4 = none and 1 = intense). In addition, when the panelists detected an off-flavor, the flavor was characterized (e.g., acidic, fish-like, liver-like, metallic, old, or other). An adjacent loin steak was used to determine shear force requirements. The adjacent steak was cooked in the same manner as described for sensory steaks; however, steaks were allowed to cool to 25°C before testing. Six 1.27-cm-diameter cores were removed parallel to the longitudinal orientation of the muscle fibers. Each core was sheared perpendicular to the grain of the muscle fiber using an Instron Universal Testing Instrument (Instron, Canton, MA) equipped with a Warner-Bratzler shearing device.

Collagen Characteristics. Hydroxyproline content (as an estimate of muscle collagen) was determined from longissimus muscle samples from the left side (nonstimulated) of each carcass. Samples (4 g) were homogenized in a Robot Coupe commercial food processor (model R6, Robot Coupe USA, Jackson, MS) for 30 s and heated in a water bath (78°C) for 70 min in .25 strength Ringer's solution (Hill, 1966). Following centrifugation, the supernatant and residue fractions were individually hydrolyzed in 6 *N* HCl for 20 h at 115°C. After neutralization, hydroxyproline content of each hydrolyzate was determined according to the procedure outlined by Bergman and Loxley (1963). Collagen content was determined by multiplying the hydroxyproline content of the residue and the supernatant by 7.25 and 7.52, respectively (Cross et al., 1973). Percentage of soluble (heat-labile) collagen was calculated by dividing the supernatant collagen by the total collagen content and multiplying by 100.

Myoglobin Pigment States. A 2.54-cm-thick steak was removed from the short loin region at 24 h postmortem from the right and left sides of the carcass. The steaks were wrapped in polyvinylchloride film and exposed to ambient air for 60 min at 2°C before evaluation (MacDougall, 1974). Myoglobin pigment states were analyzed by using the D54-P Hunter Spectrophotometer (Hunter Associates Laboratories, Reston, VA) and those formulas described by Claus et al. (1984). Reflectance values at 474, 525, 580, and 630 nm were used to indicate oxymyoglobin (%R630 nm/%R580 nm), metmyoglobin (%R630 nm/%R525 nm), and reduced myoglobin (%R474 nm/%R525 nm).

Statistical Analysis. Data were analyzed by analysis of variance using the GLM procedure of SAS (1985) where dietary protein level (low, high) and days on a high-energy diet (0, 28, 56, 84) were whole-plot main effects. Electrical stimulation (stimulated, nonstimulated) was analyzed as the split plot. Data were analyzed using final live weight as a covariate. Mean separations were performed using least significant differences, with a predetermined significance level of $P < .05$.

Results and Discussion

Carcass Characteristics. Carcasses from cows fed a low-protein diet for 28 d had the lowest skeletal and overall maturity scores (Table 1). Within days on feed, electrical stimulation did not affect marbling score except in carcasses from cows fed 84 d, where marbling score was higher ($P < .05$) for electrically stimulated carcasses than for nonstimulated car-

Table 1. Least squares means of carcass quality traits as influenced by time on feed and electrical stimulation

Treatments	SM[a,b]	LM[b]	OM[b]	MS[c]	LC[d]	LF[d]	LT[d]	HR[e]	FC[f]
Time on feed (T), d				**	*		**	*	**
0	535.6	523.5	530.2	303.0^{h}	2.6^{h}	4.3	2.4^{h}	1.7^{h}	5.0^{g}
28	530.8	515.6	521.1	320.2^{h}	3.6^{g}	4.6	3.8^{g}	2.2^{g}	4.7^{gh}
56	519.8	496.7	509.1	289.8^{h}	4.0^{g}	4.1	3.9^{g}	1.7^{h}	4.2^{i}
84	526.6	502.6	517.3	382.8^{g}	3.7^{g}	5.1	4.6^{g}	1.4^{h}	4.5^{h}
Electrical stimulation (ES)					**	**		**	
Nonstimulated	528.2	509.5	519.3	321.1	3.1^{h}	4.8^{g}	3.8	2.0^{g}	
Stimulated	528.2	509.7	519.5	326.8	3.9^{g}	4.2^{h}	3.5	1.5^{h}	
T × Protein (P)	**		**						
0, Low	535.4^{ghi}	523.7	529.4^{ghi}	275.8	2.5	4.3	2.3	1.6	4.9
28, Low	499.8^{j}	490.0	490.8^{j}	306.3	4.1	4.4	3.8	2.0	4.7
56, Low	519.2^{hij}	507.2	513.7^{hij}	288.7	3.9	3.4	3.1	1.7	4.3
84, Low	550.6^{gh}	536.2	543.2^{gh}	388.8	3.4	4.7	4.2	1.5	4.8
0, High	535.8^{gh}	523.3	530.9^{ghi}	330.2	2.8	4.4	2.4	1.8	5.1
28, High	561.7^{g}	541.2	551.4^{g}	334.2	3.0	4.7	3.8	2.3	4.8
56, High	520.5^{hij}	486.2	504.4^{ij}	290.9	4.0	4.7	4.6	1.6	4.0
84, High	502.6^{ij}	469.0	491.4^{j}	376.8	4.0	5.4	4.9	1.4	4.2
T × ES				*		**	**	**	
0, Nonstimulated	535.6	523.0	529.9	315.7^{ij}	2.4	4.5^{h}	2.3^{j}	2.1^{h}	
28, Nonstimulated	530.6	515.6	521.1	314.0^{ij}	3.2	4.5^{h}	3.8^{h}	2.6^{g}	
56, Nonstimulated	519.8	496.7	509.1	287.0^{k}	3.3	4.8^{h}	4.6^{g}	1.7^{i}	
84, Nonstimulated	526.6	502.6	517.3	367.5^{h}	3.5	5.6^{g}	4.5^{g}	1.6^{ij}	
0, Stimulated	535.6	524.0	530.4	290.2^{jk}	2.9	4.2^{h}	2.4^{j}	1.3^{j}	
28, Stimulated	530.6	515.6	521.1	326.5^{i}	4.0	4.6^{h}	3.8^{h}	1.7^{i}	
56, Stimulated	519.8	496.7	509.1	292.5^{jk}	4.7	3.4^{i}	3.1^{i}	1.6^{ij}	
84, Stimulated	526.6	502.6	517.3	398.1^{g}	3.9	4.6^{h}	4.7^{g}	1.3^{j}	
P × ES		*	*						
Low, Nonstimulated	526.2	513.1^{g}	518.7^{h}	313.3	3.1	4.6	3.4	1.9	
High, Nonstimulated	530.1	505.8^{h}	520.0^{g}	328.9	3.0	5.1	4.1	2.1	
Low, Stimulated	526.2	515.4^{g}	519.8^{gh}	316.5	3.8	3.8	3.3	1.5	
High, Stimulated	530.1	504.0^{h}	519.1^{gh}	337.2	3.9	4.5	3.7	1.5	
Residual SD	65.6	61.6	62.1	121.7	1.2	1.3	1.1	.7	.6

[a]SM = skeletal maturity; LM = lean maturity; OM = overall maturity; MS = marbling score; LC = lean color; LF = lean firmness; LT = lean texture; HR = heat ring; FC = fat color.

[b]100 = A^{00} and 500 = E^{00}.

[c]100 = Practically devoid^{00} and 900 = Abundant^{00}.

[d]8-pt scale: 1 = bleached red, soft, rough and 8 = very dark red, firm, fine.

[e]5-pt scale: 1 = no heat ring and 5 = definite heat ring.

[f]5-pt scale: 1 = white fat and 5 = yellow fat.

[g,h,i,j,k]Means with different superscripts within a main effect or interaction within a column are different ($P < .05$).

*Significance level reported in analysis of variance ($P < .05$).

**Significance level reported in analysis of variance ($P < .01$).

Table 2. Least squares means of carcass yield traits as influenced by time on feed and protein level

Treatments	LW[a]	FT	AFT	LMA	KPH	HCW	YG
Time on feed, d	**	**	**	**	**	**	*
0	481.8[e]	.15[d]	.24[d]	69.8[c]	1.0[d]	283.9[e]	.5[c]
28	537.6[d]	.29[d]	.31[d]	70.4[c]	1.3[c]	301.0[d]	.7[c]
56	568.5[c]	.70[c]	.78[c]	78.1[b]	.9[d]	332.7[c]	.8[c]
84	599.9[b]	.99[b]	1.24[b]	79.5[b]	1.8[b]	361.8[b]	1.5[b]
Protein level				*			
Low	550.1	.48	.62	72.6[c]	1.1	320.8	.9
High	543.8	.59	.66	76.0[b]	1.3	318.9	.8
Residual SD	18.1	.39	.46	7.4	.5	16.9	.7

[a]LW = live weight, kg; FT = fat thickness, cm; AFT = adjusted fat thickness, cm; LMA = longissimus muscle area, cm^2; KPH = kidney, pelvic, and heart fat, %; HCW = hot carcass weight, kg; YG = USDA Yield grade.

[b,c,d,e]Means with different superscripts within a main effect or interaction within a column are different ($P < .05$).

*Significance level reported in analysis of variance ($P < .05$).

**Significance level reported in analysis of variance ($P < .01$).

casses. Electrically stimulated carcasses from the 56-d feeding period had the softest ($P < .05$) lean, whereas nonstimulated carcasses from the 84-d feeding period had the firmest ($P < .05$) lean. Lean texture tended to be coarser in nonstimulated carcasses compared with electrically stimulated carcasses, except in animals fed 56 d, in which the lean from nonstimulated carcasses was finer ($P < .05$). Nonstimulated carcasses from cows fed 28 d had the highest ($P < .05$) scores for heat ring. However, regardless of time on feed, stimulated carcasses received lower scores for heat ring than did nonstimulated carcasses. Regardless of postmortem treatment, lean maturity scores were lower ($P < .05$) in carcasses from cows fed a high-protein diet. Overall maturity scores were the highest in nonstimulated carcasses from cows fed a high-protein diet. Least squares means for main effects showed that carcasses from cows fed 56 d had the whitest ($P < .05$) fat. Additionally, 0 d on feed resulted in the least ($P < .05$) desirable lean color, and electrical stimulation resulted in carcasses with brighter ($P < .05$) lean color, which coincides with the findings of Salm et al. (1981) and Savell et al. (1978).

Table 2 presents the effects of time on feed and protein level on carcass yield traits. As time on feed increased, live weight, fat thickness, adjusted fat thickness, ribeye area, hot carcass weight, and yield grade increased ($P < .05$). Percentage of kidney, pelvic, and heart fat tended to increase with time on feed; however, a decrease was seen at 56 d. Larger longissimus muscle areas ($P < .05$) were observed with a higher protein level in the diet.

Carcass Composition. Bone weight was the only compositional characteristic that displayed an interaction ($P < .05$) between time on feed and protein level in the diet (Table 3). The heaviest ($P < .05$) bone weight was observed when cows were fed a high-protein diet for 28 d. Total rib weight, soft tissue weight, and percentage of soft tissue all increased with increased time on feed, whereas percentage of bone decreased with increased time on feed. As would be expected, percentage of fat in the rib section soft tissue increased ($P < .05$) with time on feed, whereas percentage of moisture and percentage of protein decreased. Protein level in the diet did not affect ($P > .05$) rib section composition.

Collagen Characteristics. Although no large differences were seen in collagen traits throughout the feeding periods, percentage of soluble collagen tended to increase with time on feed (Table 4). This increase follows the findings of Aberle et al. (1981), who showed that 70 d of intensive preslaughter feeding resulted in an increased percentage of soluble collagen. During periods of rapid growth, the rate of protein synthesis is elevated, which results in an increased proportion of newly synthesized collagen. Newly synthesized collagen contains fewer intermolecular crosslinks, resulting in less stable collagen fibers with higher solubility (McClain and Wiley, 1971).

Collagen characteristics were not affected ($P > .05$) by protein level of the diet. The overall collagen contents were quite low in comparison to younger animals from other studies. Miller et al. (1983) studied both young and mature steers and found the total collagen content to be 11.0 and 12.6 mg/g, respectively. The current study reported lower total collagen content. Results from the current study were confirmed by subsample analysis at the MARC to ensure consistent results. Similar results for total collagen were found regardless of location of chemical analysis. It should be noted that Wilson et al. (1954) and Cross et al. (1973) reported total collagen content in older animals to be similar to that reported in the current study.

Shear and Sensory Determinations. Shear force displayed a significant ($P < .05$) interaction between time on feed and postmortem treatment (Table 5). Meat from electrically stimulated carcasses had lower ($P < .05$) shear force values within time on feed treatments for all feeding periods except 84 d. For

Table 3. Least squares means of 9–10–11th rib section composition as influenced by time on feed and protein level

Treatments	Total wt, kg	Soft tissue wt, kg	Bone wt, kg	Bone, %	Soft tissue, %	Proximate analysis of soft tissue: Moisture, %	Fat, %	Protein, %
Time on feed (T), d	**	**	*	**	**	**	**	**
0	8.95[c]	6.69[c]	2.23[ab]	25.6[a]	74.1[c]	69.9[a]	10.2[d]	17.8[a]
28	9.41[c]	7.07[c]	2.33[a]	25.0[a]	74.8[c]	66.4[a]	16.1[c]	15.5[b]
56	10.95[b]	8.77[b]	2.17[bc]	20.2[b]	79.7[b]	60.0[b]	23.7[b]	14.4[b]
84	11.92[a]	9.84[a]	2.06[c]	17.5[c]	82.4[a]	50.4[c]	35.6[a]	12.0[c]
T × Protein			*					
0, Low	8.90	6.59	2.28[b]	26.3	73.4	71.4	8.4	18.1
28, Low	9.23	7.08	2.13[bc]	23.6	76.2	67.1	15.3	15.5
56, Low	10.82	8.61	2.20[bc]	20.8	79.1	61.2	22.2	14.6
84, Low	11.67	9.57	2.09[c]	18.0	81.9	51.5	34.1	12.4
0, High	9.00	6.79	2.19[bc]	25.0	74.7	68.4	12.0	17.6
28, High	9.61	7.07	2.52[a]	26.4	73.4	65.7	16.9	15.4
56, High	11.08	8.92	2.14[bc]	19.7	80.2	58.7	25.1	14.2
84, High	12.17	10.11	2.04[c]	17.0	82.9	49.3	37.2	11.5
Residual SD	1.06	1.12	.26	3.5	3.5	6.0	7.8	1.9

[a,b,c,d]Means with different superscripts within a main effect or interaction within a column are different ($P < .05$).
*Significance level reported in analysis of variance ($P < .05$).
**Significance level reported in analysis of variance ($P < .01$).

nonstimulated carcasses, shear force values decreased by 3.2 kg with increased time on feed from 0 to 84 d; however, the application of electrical stimulation decreased shear force by 2.8 kg for 0-d carcasses. Subsequent days on a high-energy diet resulted in only a .9-kg improvement in shear force for stimulated carcasses. Frequency distribution of carcasses that had shear force values ≤ 3.86 kg was 10.0, 10.0, 5.3, and 10.5% for carcasses stimulated and fed for 28 d, stimulated and fed for 56 d, nonstimulated and fed for 84 d, and stimulated and fed for 84 d, respectively. Frequency distribution of carcasses that had shear force values ≤ 4.54 kg was 4.8, 19.1, 15.0, 60.0, 31.6, and 47.4% for carcasses nonstimulated and fed for 0 d, stimulated and fed for 0 d, stimulated and fed for 28 d, and stimulated and fed for 56 d, nonstimulated and fed for 84 d, and stimulated and fed for 84 d, respectively. Feeding a high-concentrate diet and electrically stimulating cow carcasses slightly improved the percentage of tender steaks (≤ 3.86 kg) and moderately improved the frequency of steaks with acceptable tenderness (≤ 4.54 kg); however, the improved shear force was not substantial.

The possibility that the increase in subcutaneous fat thickness was responsible for a partial reduction in cold shortening was investigated. Fat thickness and shear force were found to be significantly ($P < .01$) correlated (−.36). Therefore, it is likely that part of the reduction in shear force was due to the increase of fat thickness and the subsequent reduction in cold shortening. This is further substantiated by the improvement in shear force values with electrical stimulation. These data suggest that carcasses of mature cows, regardless of days on feed, should be electrically stimulated to maximize tenderness.

Overall tenderness tended to increase with in-

Table 4. Least squares means of collagen characteristics as influenced by time on feed and protein level

Treatments	Soluble collagen, mg/g	Insoluble collagen, mg/g	Total collagen, mg/g	Soluble collagen, %
Time on feed (T), d	*			*
0	.15[a]	3.63	3.78	4.1[b]
28	.11[b]	2.86	2.97	3.9[b]
56	.14[a]	2.96	3.10	4.9[a]
84	.14[a]	3.22	3.37	4.5[ab]
Residual SD	.04	.86	.87	1.4

[a,b]Means with different superscripts within a main effect or interaction within a column are different ($P < .05$).
*Significance level reported in analysis of variance ($P < .05$).

Table 5. Least squares means of shear and sensory traits as influenced by time on feed, protein level, and electrical stimulation

Treatments	Shear force, kg	Juiciness[a]	Fragmentation ease[a]	Connective tissue[a]	Overall tenderness[a]	Flavor intensity[a]	Off-flavor[b]
Time on feed (T), d	*	*		*		*	**
0	7.1[c]	5.0[e]	4.6	4.5[d]	4.7	4.9[e]	2.4[d]
28	6.7[cd]	5.3[c]	4.6	4.5[d]	4.7	5.0[de]	2.5[c]
56	5.7[de]	5.1[de]	4.7	4.6[d]	4.8	5.1[cd]	2.6[c]
84	5.0[e]	5.2[cd]	4.9	4.8[c]	4.9	5.2[c]	2.7[c]
Electrical stimulation (ES)	**		**	*	**	*	
Nonstimulated	7.1[c]	5.1	4.6[d]	4.5[d]	4.6[d]	5.0[d]	2.5
Stimulated	5.2[d]	5.2	4.8[c]	4.7[c]	4.9[c]	5.1[c]	2.6
T × ES	*						
0, Nonstimulated	8.5[c]	5.0	4.5	4.4	4.5	4.9	2.4
28, Nonstimulated	7.7[cd]	5.4	4.4	4.3	4.5	4.9	2.5
56, Nonstimulated	7.0[d]	5.0	4.5	4.4	4.6	5.1	2.6
84, Nonstimulated	5.3[ef]	5.2	4.9	4.8	4.9	5.1	2.7
0, Stimulated	5.7[e]	5.1	4.7	4.6	4.8	4.9	2.4
28, Stimulated	5.8[e]	5.3	4.8	4.6	4.8	5.0	2.6
56, Stimulated	4.4[f]	5.1	4.9	4.8	4.9	5.1	2.6
84, Stimulated	4.8[ef]	5.2	4.9	4.8	5.0	5.2	2.7
Residual SD	1.6	.4	.4	.4	.4	.2	.2

[a]8-pt scale: 1 = extremely dry, difficult, abundant, tough, or bland and 8 = extremely juicy, easy, none, tender or intense, respectively.
[b]4-pt scale: 1 = intense off-flavor and 4 = off-flavor.
[c,d,e,f]Means with different superscripts within a main effect or interaction within a column are different ($P < .05$).
*Significance level reported in analysis of variance ($P < .05$).
**Significance level reported in analysis of variance ($P < .01$).

creased time on a high-energy diet, although this increase was not significant. Panel ratings for fragmentation ease, connective tissue amount, and flavor intensity increased with time on feed. These results would indicate that increased time on a high-energy diet results in easier fragmentation, less connective tissue, and a more intense flavor. Interestingly, overall tenderness and shear force values did not concur. In samples with high connective tissue, muscle fiber differences may have been masked and, therefore, undetectable by panelists. In addition, cows fed for 84 d had less ($P < .05$) detectable connective tissue than cows fed for 0, 28, or 56 d. This would follow the previously stated findings of Aberle et al. (1981) that intensive preslaughter feeding results in increased collagen solubility. Meat from cows fed 0 d had a more intensive ($P < .05$) off-flavor than that from cows fed 28, 56, or 84 d. Mean ratings for juiciness did not show a pattern across different feeding periods. Electrical stimulation improved ($P < .05$) sensory ratings for fragmentation ease, connective tissue amount, overall tenderness, and flavor intensity. These ratings indicated that with electrical stimulation samples fragmented more easily and had less detectable connective tissue, higher overall tenderness, and a more intense flavor. The improved panel ratings for connective tissue amount are probably the result of increased muscle fiber and overall tenderness, which influenced panelist ratings of amount of connective tissue. Savell et al. (1979) reported similar findings for panel evaluations of heavy-weight, grain-fed cattle, whereas Savell et al. (1978) indicated that panel ratings, as well as shear force values, were improved by stimulating lightweight heifers. Protein level of the diet did not affect ($P > .05$) shear force or sensory traits.

Myoglobin Traits and Hunter Color. An interaction ($P < .05$) between time on feed and postmortem treatment was present for the metmyoglobin pigment state and between protein level in the diet and postmortem treatment for L* Hunter color values (Table 6). Metmyoglobin was numerically lower in nonstimulated carcasses within time on feed treatments, and meat from cows fed 0 d had higher ($P < .05$) metmyoglobin levels than from cows fed 28 or 56 d. When cows were fed 0 d, metmyoglobin was higher ($P < .05$) in meat from stimulated carcasses than in meat from nonstimulated carcasses. L* values were the lowest ($P < .05$) for stimulated carcasses from cows fed a high-protein diet, which indicates that the meat from these carcasses was darker in color.

Reduced myoglobin, a* values, and b* values were higher ($P < .05$) in meat from animals fed 0 d than that from cows fed 28 and 56 d. Additionally, a* and b* values were higher ($P < .05$) in stimulated carcasses, which suggests that they displayed higher levels of red and yellow. Most studies that were based on panel evaluations found that meat from stimulated carcasses generally was brighter (Savell et al., 1978; Calkins et al., 1980; Salm et al., 1981) than meat from nonstimulated carcasses. However, Grusby et al. (1976), Stiffler and Ray (1979), and Nichols and Cross (1980) did not find any improvements in lean color upon stimulation. Protein level of the diet did not

Table 6. Least squares means of myoglobin and Hunter color traits as influenced by time on feed, protein level, and electrical stimulation

Treatments	Oxymyoglobin[a]	Metmyoglobin	Reduced myoglobin	L*	a*	b*
Time on feed (T), d[b]		**	**	**	**	**
0	15.9	3.9[c]	1.1[c]	28.3[d]	15.7[c]	7.6[c]
28	13.8	1.9[d]	1.0[d]	40.1[c]	9.4[d]	5.1[d]
56	13.7	1.9[d]	1.0[d]	39.5[c]	9.7[d]	4.7[d]
Electrical stimulation (ES)		**		*	**	**
Nonstimulated	14.2	2.4[d]	1.0	36.7[c]	11.0[d]	5.5[d]
Stimulated	14.7	2.7[c]	1.0	35.3[d]	12.2[c]	6.1[c]
T × ES		*				
0, Nonstimulated	15.7	3.4[d]	1.1	29.4	14.5	7.0
28, Nonstimulated	13.6	1.8[e]	1.0	41.0	9.0	4.9
56, Nonstimulated	13.4	1.9[e]	1.0	39.8	9.5	4.6
0, Stimulated	16.1	4.3[c]	1.1	27.3	17.0	8.2
28, Stimulated	14.1	2.0[e]	1.0	39.2	9.8	5.3
56, Stimulated	14.0	1.9[e]	1.0	39.3	9.9	4.8
Protein × ES				*		
Low, Nonstimulated	14.2	2.4	1.0	36.5[c]	11.1	5.6
High, Nonstimulated	14.2	2.3	1.0	36.9[c]	10.9	5.4
Low, Stimulated	14.9	2.6	1.0	36.1[c]	11.7	5.9
High, Stimulated	14.5	2.9	1.0	34.4[d]	12.7	6.3
Residual SD	1.8	1.2	.04	2.7	2.1	1.1

[a]Reflectance values: oxymyoglobin (%R630 nm/%R580 nm); metmyoglobin (%R630 nm/%R525 nm); and reduced myoglobin (%R474 nm/%R525 nm).
[b]Means for the 84 d feeding period are not presented due to mechanical failure with the spectrophotometer.
[c,d,e]Means with different superscripts within a main effect or interaction within a column are different ($P < .05$).
*Significance level reported in analysis of variance ($P < .05$).
**Significance level reported in analysis of variance ($P < .01$).

affect ($P > .05$) myoglobin traits or Hunter color values.

This study indicates that feeding a high-energy diet to mature cows to improve palatability, maturity scores, color, and collagen solubility had limited success. It was interesting to find that the level of protein in the diet for mature cows did not affect rib section composition, collagen characteristics, sensory traits, shear force values or the color of the lean in the longissimus muscle and affected only the carcass trait of longissimus muscle area. However, as time on feed increased, adjusted fat thickness, longissimus muscle area, kidney, pelvic, and heart fat, hot carcass weight, and percentage of fat in the rib section tended to increase. Additionally, sensory ratings generally increased as time on feed increased. With increased time on a high-energy diet, the estimated myoglobin pigments decreased, indicating a lighter lean color due to high concentrate feeding. Electrical stimulation of carcasses improved lean color and shear force values, as well as sensory attributes. Electrically stimulated carcasses from animals fed for 0 d had lower ($P < .05$) shear force values than their nonstimulated counterparts. Likewise, as time on feed increased, shear force values tended to decrease for stimulated and nonstimulated carcasses. When cows were fed for 84 d and their carcasses electrically stimulated, the greatest improvement in marbling score was observed. Additionally, feeding a high-protein diet for 84 d resulted in a slight improvement in maturity score.

Realistically, even though increased time on a high-energy diet and the use of electrical stimulation improved certain postmortem muscle quality characteristics, the improvement obtained was not great enough to result in meat from mature fed cows that would be similar to meat from young fed beef. Feeding high-energy diets and the use of electrical stimulation may be applied to younger animals to further increase the palatability attributes of the carcass. Results from this study indicate that the same techniques improve shear force values but do not totally reverse the effects of age on palatability of mature cow carcasses.

Implications

The improvements observed in this study as a result of increased time on feed and electrical stimulation are more beneficial in improving palatability and quality attributes of fed mature cows than is feeding a high-protein diet. However, these improvements may not be of the magnitude sufficient to allow steaks from mature cows to be interchangeable with those from young steers and heifers.

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