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THE EFFECTS OF RATE OF CHANGE IN BODY WEIGHT ON TISSUE DEVELOPMENT AND MEAT QUALITY OF YOUTHFUL BULLS^{1,2}

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ABSTRACT

Forty-eight Angus bulls about 13 mo of age were used to study the effects of rate of change in live weight on muscle fiber, collagen and sensory characteristics of meat. Bulls were fed a finishing diet before treatment, and assigned to three treatments: 1) negative, 2) zero or 3) positive weight gain for 30 or 60 d prior to slaughter. Treatments were imposed by adjusting feed intake. Seventy-two hours after slaughter, carcasses were observed for quality and yield grade characteristics and longissimus muscle samples were obtained for fiber type, collagen and sensory characterization. Carcass lean at the 12th rib interface became darker in color ($P < .01$), softer ($P < .05$), coarser textured ($P < .01$) and more physiologically mature ($P < .01$) when bulls were fed an additional 30 d. Increases in average daily gain improved lean texture ($P < .05$), but had insignificant effects on lean color. Marbling scores and percentages of kidney and pelvic fat increased ($P < .01$) with length of time fed. Quantities of carcass fat were reduced by reducing daily weight gains through restricting dietary intake. Neither length of time fed nor rate of change in live weight affected ($P > .05$) muscle fiber characteristics. Increased age of bulls tended ($P > .05$) to be associated with an increase in red muscle-fiber quantity. Length of time fed or rate of change in live weight did not affect collagen characteristics or tenderness of meat. It was concluded that the collagen content and solubility of muscle from bulls 14 to 15 mo of age cannot be varied through altering rate of weight change. (Key Words: Bulls, Growth, Meat Composition, Meat Quality, Palatability.)

Introduction

Growth and development of meat-producing animals involve a complex integrated system of changes in the structure and mass of body tissues. Researchers have observed and documented that meat animal growth and development may be altered through the diet or alteration of the sex condition (Meyer et al., 1960; Ferrell et al., 1977; Prior et al., 1977; Smith et al., 1977; Tatum, 1981; Dolezal et al., 1982; Crouse et al., 1985a,b). Most significant alterations are in rates of deposition of protein, fat and connective tissue, as well as the palatability of the cooked meat. Changes in weight

of cattle beyond 14 mo of age have been largely associated with the fat deposition in the body. Studies have shown that youthful bulls have advantages in performance of growth and leanness and disadvantages in tenderness when compared with steers. Differences in tenderness have been attributed to differences in fatness (Riley et al., 1983) and differences in connective tissue (Boccard et al., 1979; Crouse et al., 1983). Connective tissue has been reported to increase markedly at about 12 mo of age and to decrease in solubility with age (Cross et al., 1973, 1984). These age-related changes in connective tissue also have been reported to be more pronounced in bulls than steers (Kousgaard and Klastrup, 1980).

Johnston et al. (1975) reported that steers fed grain for 233 d had significantly larger red fiber diameters than steers fed for 153 d. Johnston et al. (1981) reported that, in general, as the energy level in the diet increased, the percentage of intermediate muscle fibers decreased and the percentage of white fibers increased. Rompala and Jones (1984) observed that the energy density of the diet and length of time fed affected the solubility of collagen in muscle. Moody et al. (1980) postulated that the available source of energy in lamb diets appeared

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to cause a physiological shift from intermediate fibers to white fibers.

It appears that, as steers are fed dietary energy above maintenance, body protein accretion increases. The alteration in protein content is associated with improved product tenderness. Aberle et al. (1981) and Fishell et al. (1985) concluded that growth rate of cattle before slaughter may affect tenderness, and that growth rate may be a more important determinant of tenderness than the length of time that cattle are fed a high energy diet. Proteolytic enzymes are needed to increase protein turnover and these enzymes may also influence postmortem changes in meat properties. Animals gaining weight or losing weight may alter these enzyme profiles. Therefore, a strong possibility exists that protein turnover is increased and a more youthful connective tissue is present during weight gain. This experiment was undertaken to determine the effects of change in body weight on body tissue development and meat quality from youthful bulls.

Materials and Methods

Animals. Forty-eight Angus bulls about 13 mo of age were used. Bulls were fed a corn and corn-silage growing diet (74% TDN) for 4 mo and then placed on a finishing diet (84% TDN) composed of corn and corn silage.

After 30 d on the finishing diet, bulls were randomly assigned to one of three groups: 1) ad libitum-fed (gained 1.00 kg/d), 2) restriction-fed to maintain weight (lost .16 kg/d) or 3) restriction-fed to lose weight (lost .57 kg/d). Bulls were penned by treatment and fed in four replicated pens.

After 30 d on trial, two bulls per pen (24 bulls total) were slaughtered. The remaining bulls were slaughtered after an additional 30 d on trial. Bulls were slaughtered in the abattoir at the Roman L. Hruska U. S. Meat Animal Research Center.

Carcass Data. Carcasses were evaluated and graded (USDA, 1976) after being held in a 2 C cooler for 72 h. Carcasses were scored for lean color (1 = black; 8 = grayish red), lean firmness (1 = very soft; 8 = very firm) and lean texture (1 = very coarse; 8 = very fine), lean, skeletal and overall maturity (100 to 199 = A; 200 to 299 = B) and marbling (100 to 199 = traces; 200 to 299 = slight; 300 to 399 = small).

A 9-10-11th rib section was removed and dissected into bone, subcutaneous fat, seam fat and lean components according to procedures

of Hankins and Howe (1946). Components were weighed and expressed as a percentage of total ribsection weight.

Textural Properties. One loin was removed from the left side of each carcass 7 d postmortem, vacuum-packaged and subsequently frozen. Loins were later cut into steaks while frozen. One 2.5-cm-thick steak was removed from each loin immediately posterior to the 13th rib region. The steak was tempered 24 h at 4 C and cooked to an internal temperature of 70 C on Farberware Open Hearth broilers. The internal temperature of each steak was monitored by copper/constantan thermocouples placed in the geometric center of each steak. Steaks were then cooled for 24 h or to 4 C. Six cores (1.3 cm diameter \times 5 cm long) were removed from each steak parallel to fiber direction. Each core was sheared once with a Warner-Bratzler shear device attached to an Instron Universal Testing machine (Model 1132) with a micro-processor (Microcon II). Textural analysis data included peak load.

An additional steak was removed from the loin in the region of the last lumbar vertebra prior to freezing. The steak was utilized to determine fragmentation index according to the procedure of Davis et al. (1980) and sarcomere length using the neon diffraction technique of Cross et al. (1980).

Sensory Panel. A descriptive attribute panel was trained and tested according to methods described by AMSA (1978) and Cross et al. (1978). Panelists evaluated samples in individual booths. Two mid-morning sessions were scheduled 3 d per week. Each session comprised five randomly selected samples; a 10-min intermission separated sessions. Each panelist received three pieces of each sample. The mean of the three samples and 10 panelists for each carcass was used for data analyses. Panelists evaluated each sample for variation in juiciness (1 = extremely dry; 8 = extremely juicy), ease of fragmentation (1 = extremely difficult; 8 = extremely easy), amount of connective tissue (1 = abundant; 8 = none), overall tenderness (1 = extremely tough; 8 = extremely tender), flavor intensity (1 = extremely bland; 8 = extremely intense) and off flavor (1 = intense; 4 = none).

Collagen Analysis. Samples were trimmed of epimysial connective tissue and powdered in a blender with liquid nitrogen. Frozen, powdered samples (4 g) were heated for 70 min at 77 C in one-fourth strength Ringer's solution and separated into supernatant and residue fractions

following the procedure of Hill (1966). Each fraction was individually hydrolyzed in 6 N HCl for 6 h at an oven temperature of 115 C. The hydroxyproline content was determined as outlined by Bergman and Loxley (1963). Collagen content (mg/g, fresh tissue basis) was computed by multiplying the hydroxyproline content of the insoluble portion by 7.25 and that of the soluble portion by 7.52 (Cross et al., 1973). Collagen content of the supernatant fraction was expressed as a percentage of total collagen as specified by Hill (1966).

Fiber-Type Characteristics. A center section of the longissimus muscle was removed from the region of the last lumbar vertebra of each carcass. The section was frozen in liquid nitrogen, wrapped in aluminum foil and stored in an ultralow freezer (-63 C). Transverse sections of each muscle sample were cut 10 μm thick using a cryostat and stained for alkali-stable ATPase as described by Guth and Samaha (1970). Serial sections were stained for succinate dehydrogenase activity according to procedures described by Troyer (1980). Sections were later photographed by a photomicroscope and enlarged. Fibers were then counted and classified as red, white or intermediate based on staining intensity. The area of ten fibers of each type was then determined using a Bioquant particle size analyzer. Red, intermediate and white fibers were expressed as percentages of total fiber numbers, their mean areas as μm^2 and total areas as percentages of total area.

Statistical Analysis. Response variables were analyzed by least-squares analysis of covariance. The model included fixed effects for slaughter groups (Sgp) and a linear term for covariate mean average daily change in weight (Rg). Average daily change in weight was the mean change in weight over the entire portion of the trial that the individual animal represented. Residual variation was used as an error term. Preliminary analysis indicated that the quadratic covariate term and Sgp by Rg interactions were unimportant sources of variation.

Results and Discussion

Live Weight. Treatment effects due to slaughter group and daily rate of change in weight are given in table 1. Feeding an additional 30 d had no effect on live weights or hot carcass weights. Lack of variation in weight associated with slaughter group is primarily due to experimental design. For each unit increase

in average daily gain over the trial, live weight increased ($P < .01$) 38 units. Variation in daily rate of change in weight was also reflected in hot carcass weight.

Quality Traits. Longissimus muscle at the 12th rib became darker in color ($P < .01$), softer ($P < .05$), coarser textured ($P < .01$) and more physiologically mature ($P < .01$) when bulls were fed an additional 30 d. Increased daily rate of weight change improved lean texture ($P < .05$), but had insignificant effects on lean color or maturity scores. These data indicate that age of the animal had more of an effect on lean color and physiological maturity than rate of change of weight.

Previous observations by Smith et al. (1977) indicated that feeding regimen and length of time fed affected carcass maturity scores. Crouse et al. (1978) observed that length of time that a steer was fed accounted for about 50% of the variation in final maturity scores of carcasses. Evidently chronological age, in addition to other factors, influences physiological maturity.

Composition. No effects ($P > .05$) due to length of time fed were observed for fat thickness or percentage of rib fat (table 1). Marbling scores and percentage of kidney and pelvic fat (KPF), however, increased ($P < .01$) during the final 30-d feeding period. No changes ($P > .05$) in longissimus muscle area were observed during the final 30-d feeding period; however, percent lean of the rib tended ($P > .05$) to decrease with additional time fed. Greater effects due to length of time fed were probably not observed due to design of the experiment. The overall effects of length of time fed included losses in weight as well as gains. Increases in fat deposition within the KPF and longissimus muscle depot sites were associated with increases in physiological age as opposed to increases in body weight.

Daily rate of change in weight (regression coefficients, table 1) affected composition. Increasing the rate of animal weight gains increased fat deposition within all the fat depot sites, except KPF sites, and decreased percentage of lean in the rib. Longissimus muscle area also increased with increases in daily rates of changes in weight. Aberle et al. (1981) observed that feeding cattle high energy diets increased rates of gain, as well as the fat content of the carcass. Moody (1976) reviewed the literature and concluded that high energy diets result in more rapid growth and generally produce cattle with

TABLE 1. SLAUGHTER GROUP MEANS, REGRESSION COEFFICIENTS AND RESIDUAL STANDARD DEVIATIONS

Trait	Days fed		Regression coefficient ^a	Residual SD
	30	60		
Live wt, kg	395	394	38**	30
Hot side wt, kg	118	118	10**	12
Lean color ^b	5.34	4.60**	.29	.81
Lean firmness ^b	5.30	4.54*	.37	.94
Lean texture ^b	5.59	4.71**	.39*	.90
Lean maturity ^c	A26	A33**	-2	7
Skeletal maturity ^c	A24	A32**	1	5
Overall maturity ^c	A25	A33**	0	5
Marbling ^d	SI15	SI72	36*	70
Fat thickness, cm	.43	.38	.16**	.19
Adj. fat thickness, cm	.38	.36	.10**	.18
Longissimus muscle area, cm ²	74	69	4**	7
KPF, %	.53	1.61**	.12	.34
Rib fat, %	17.9	17.2	3.2**	4.0
Rib bone, %	21.5	23.7**	-2.0**	2.4
Rib lean, %	59.7	58.5	-1.2*	3.0
Red fibers, %	24.6	26.7	-.4	4.9
Intermediate fibers, %	32.8	31.5	1.1	8.3
White fibers, %	42.6	41.8	-.7	8.2
Red fiber area, %	17.5	18.0	-1.1	3.9
Intermediate fiber area, %	29.4	30.0	.4	9.7
White fiber area, %	53.1	52.0	.7	10.3
Sarcomere length, μ m	1.63	1.67	-.03	.21
Fiber size, μ m ²	3,092	3,303	5	604
Total collagen, mg/g	4.51	4.56	.09	.84
Insoluble collagen, %	84.2	83.8	-.09	4.8
Cooking loss, %	39.2	38.6	.1	3.5
Juiciness ^e	5.12	5.20	.00	.33
Ease of fragmentation ^e	5.17	4.94	.09	.43
Amount of connective tissue ^f	5.12	4.87	.14	.45
Overall tenderness ^e	5.18	4.96	.10	.43
Flavor intensity ^e	5.25	5.12*	.04	.18
Off flavor ^g	2.86	2.72	.06	.20
Peak load, kg	5.9	6.2	-.15	2.1

^aComputed from variation in response trait associated with variation in mean average daily change in weight among bulls. Interaction regression by slaughter group was not an important source of variation.

^bScored: 1 = black, very soft or very coarse to 8 = grayish red, very firm or very fine.

^cScored: 100 to 199 = A, 200 to 299 = B.

^dScored: 100 to 199 = traces, 200 to 299 = slight, 300 to 399 = small.

^eScored: 1 = extremely dry, juicy, difficult, tough or bland to 8 = extremely juicy, none, tough or intense.

^fScored: 1 = abundant to 8 = none.

^gScored: 1 = intense to 4 = none.

*P<.05.

**P<.01.

higher dressing percentages and more carcass fat. The present study indicates that quantities of body fat can be altered by varying daily weight change through restriction of diet.

Muscle-Fiber Characteristics. Sarcomere length was not affected (P>.05) by slaughter group or daily rate of change in weight (table

1). Percentage of red fibers and percentage area of red fibers tended (P>.05) to increase with length of time fed (table 1). However, these percentages for red fibers were negatively associated with daily rate of change in weight. White fibers tended (P>.05) to decrease in relative number and percentage area over the

30-d period and with increased daily rate of change in weight. These data suggest that neither length of time fed nor rate of change in weight have significant, meaningful effects on fiber-type characteristics. This may be expected since no variation in weight or longissimus muscle area was observed between slaughter groups. However, positive increases in rate of daily change in weight increased ($P < .01$) longissimus area.

Results of the present study in bulls tend to contradict previous observations in steers and lambs. Johnston et al. (1981) reported that, in general, as the energy level in the diet increased, the percentage of intermediate fibers decreased and the percentage of white fibers increased. Moody et al. (1980) postulated that the available source of energy in lamb rations appeared to cause a physiological shift from intermediate fibers to white fibers. These references refer to work on castrated or female animals. Dreyer et al. (1977) concluded that muscles from bulls have a higher percentage of red fibers than muscles from steers.

Collagen Characteristics. Feeding the additional 30 d or daily rate of change in weight had no appreciable ($P > .05$) effect on collagen characteristics (table 1). Decreased solubility of collagen has previously been observed in bulls, and with increased age of the animal (Cross et al., 1984). Collagen turnover has been observed to be accelerated during periods of rapid growth (Wu et al., 1981). Variation in the solubility of collagen also has been associated with meat tenderness (Berry et al., 1974; Crouse et al., 1983, 1985a).

Sensory Characteristics. A slight decrease ($P < .05$) in flavor intensity was observed to be associated with an additional 30 d of feeding (table 1). However, this was not associated with daily rate of change in weight. No significant variation in tenderness or other observed sensory characteristics was associated with length of time fed or daily rate of change in weight.

It was anticipated that varying daily gain prior to slaughter would affect tenderness. However, tenderness was not significantly affected by treatments in this experiment. Aberle et al. (1981) observed that cattle fed a low energy diet immediately before slaughter produced meat that is less acceptable, particularly in tenderness, than meat from cattle fed a high energy diet. The reduced tenderness of muscle from cattle fed the low energy diet was

a result of lower myofibril fragmentation and some reduction in collagen solubility (Aberle et al., 1981). Most of the improved tenderness associated with feeding occurred during the first 70 d. Similar results were observed by Smith et al. (1977). Results of these studies suggest that growth rate of cattle before slaughter has an important effect on meat tenderness. It was hypothesized that preslaughter growth rate affected connective tissue stability and ease of myofibrillar fragmentation in postmortem muscle. It also was hypothesized (Aberle et al., 1981) that under these conditions a newly synthesized collagen would represent a greater proportion of the total muscle collagen. Newly synthesized collagen contains fewer intermolecular crosslinks, resulting in less stable collagen fibers with higher solubility (McClain, 1976).

In the present experiment, intact males were studied instead of castrates. Perhaps degree of maturity of the collagen was altered by the intact male condition of the animals studied when comparing results with observations reported in the literature of other sex conditions. Total collagen values (table 1) in the present study are considerably greater than those reported by Aberle et al. (1981) in steer treatment groups that were observed to be tender and reflect values in the less tender groups. Collagen in the present study also was observed to be considerably less soluble than the collagen in steers observed to be tender by Aberle et al. (1981). Future studies on the growth rate of cattle need to consider interactions of sex conditions. Dietary treatments in the present study failed to affect collagen characteristics in bulls.

Literature Cited

- Aberle, E. D., E. S. Reeves, M. D. Judge, R. E. Hunsley and T. W. Perry. 1981. Palatability and muscle characteristics of cattle with controlled weight gain: Time on a high energy diet. *J. Anim. Sci.* 52:757.
- AMSA. 1978. Guidelines for cookery and sensory evaluation of meat. American Meat Science Association and National Live Stock and Meat Board, Chicago, IL.
- Bergman, I. and R. Loxley. 1963. Two improved and simplified methods for the spectrophotometric determination of hydroxyproline. *Anal. Chem.* 35:1961.
- Berry, B. W., G. C. Smith and Z. L. Carpenter. 1974. Relationships of certain muscle, cartilage, and bone traits to tenderness of the beef longissimus. *J. Food Sci.* 39:819.
- Boccard, R. L., R. T. Naude, D. E. Cronje, M. C.

- Smith, H. J. Venter and E. J. Rossouw. 1979. The influence of age, sex and breed of cattle on their muscle characteristics. *Meat Sci.* 3:261.
- Cross, H. R., Z. L. Carpenter and G. C. Smith. 1973. Effects of intramuscular collagen and elastin upon bovine muscle tenderness. *J. Food Sci.* 38:998.
- Cross, H. R., R. Moen and M. Stanfield. 1978. Training and testing of judges for sensory analysis of meat quality. *Food Technol.* 32:48.
- Cross, H. R., B. D. Schanbacher and J. D. Crouse. 1984. Sex, age and breed related changes in bovine testosterone and intramuscular collagen. *Meat Sci.* 10:187.
- Cross, H. R., R. L. West and T. R. Dutson. 1980. Comparison of methods for measuring sarcomere length in beef semitendinosus muscle. *Meat Sci.* 5:261.
- Crouse, J. D., H. R. Cross and S. C. Seidemann. 1985a. Effects of sex condition, genotype, diet and electrical stimulation on the collagen content and palatability of two bovine muscles. *J. Anim. Sci.* 60:1228.
- Crouse, J. D., C. L. Ferrell and L. V. Cundiff. 1985b. Effects of sex condition, genotype and diet on bovine growth and carcass characteristics. *J. Anim. Sci.* 60:1219.
- Crouse, J. D., R. A. Field, J. L. Chant, Jr., C. L. Ferrell, G. M. Smith and V. L. Harrison. 1978. Effect of dietary energy intake on carcass composition and palatability of different weight carcasses from ewe and ram lambs. *J. Anim. Sci.* 47:1207.
- Crouse, J. D., S. C. Seidemann and H. R. Cross. 1983. The effects of carcass electrical stimulation and cooler temperature on the quality and palatability of bull and steer beef. *J. Anim. Sci.* 56:81.
- Davis, G. W., T. R. Dutson, G. C. Smith and Z. L. Carpenter. 1980. Fragmentation procedure for bovine longissimus muscle as an index of cooked steak tenderness. *J. Food Sci.* 45:880.
- Dolezal, H. G., G. C. Smith, J. W. Savell and Z. L. Carpenter. 1982. Effect of time-on-feed on the palatability of rib steaks from steers and heifers. *J. Food Sci.* 47:368.
- Dreyer, J. H., R. T. Naude, J.W.N. Henning and E. Rossouw. 1977. The influence of breed, castration and age on muscle fiber type and diameter in Friesland and Afrikaner cattle. *S. Afr. J. Anim. Sci.* 7:171.
- Ferrell, C. L., R. H. Kohlmeier, J. D. Crouse and H. Glimp. 1977. Influence of dietary energy protein and biological steer type on gain and carcass characteristics. *J. Anim. Sci.* 46:255.
- Fishell, V. K., E. D. Aberle, M. D. Judge and T. W. Perry. 1985. Palatability and muscle properties of beef as influenced by preslaughter growth rate. *J. Anim. Sci.* 61:151.
- Guth, L. and F. J. Samaha. 1970. Procedure for the histochemical demonstration of actomyosin ATPase. *Exp. Neurol.* 28:365.
- Hankins, I. G. and P. E. Howe. 1946. Estimation of the composition of beef carcasses and cuts. *USDA Tech. Bull.* 926.
- Hill, F. 1966. The solubility of intramuscular collagen in meat animals of various ages. *J. Food Sci.* 31:161.
- Johnston, D. M., W. G. Moody, J. A. Boling and N. W. Bradley. 1981. Influence of breed type, sex, feeding systems and muscle bundle size on bovine fiber type characteristics. *J. Food Sci.* 46:1760.
- Johnston, D. M., D. F. Stewart, W. G. Moody, J. A. Boling and J. D. Kemp. 1975. Effect of breed and time on the size and distribution of beef muscle fiber types. *J. Anim. Sci.* 40:613.
- Kousgaard, K. and S. Klastrup. 1980. Kreaturer, Slagte and Kodkvalitet. Rep. No. 01.524. Danish Meat Research Institute, Roskilde.
- McClain, P. E. 1976. Chemistry of collagen crosslinking. *Proc. Recip. Meat Conf.* 29:350.
- Meyer, B., J. Thomas, R. Buckley and J. Cole. 1960. The quality of grain finished and grass finished beef as affected by ripening. *Food Technol.* 1:4.
- Moody, W. G. 1976. Quantitative and qualitative differences in beef from various energy regimes. *Proc. Recip. Meat Conf.* 29:128.
- Moody, W. G., J. D. Kemp, M. Mahyuddin, D. M. Johnston and D. G. Ely. 1980. Effect of feeding systems, slaughter weight and sex on histological properties of lamb carcasses. *J. Anim. Sci.* 50:249.
- Prior, R. L., R. H. Kohlmeier, L. V. Cundiff, M. E. Dikeman and J. D. Crouse. 1977. Influence of dietary energy and protein on growth and carcass composition in different biological types of cattle. *J. Anim. Sci.* 45:132.
- Riley, R. R., J. W. Savell, C. E. Murphey, G. C. Smith, D. M. Stiffler and H. R. Cross. 1983. Palatability of beef from steer and young bull carcasses as influenced by electrical stimulation, subcutaneous fat thickness and marbling. *J. Anim. Sci.* 56:592.
- Rompala, R. E. and S.D.M. Jones. 1984. Changes in the solubility of bovine intramuscular collagen due to nutritional regime. *Growth* 48:466.
- Smith, G. M., J. D. Crouse, R. W. Mandigo and K. L. Neer. 1977. Influence of feeding regime and biological type on growth, composition and palatability of steers. *J. Anim. Sci.* 45:236.
- Tatum, J. D. 1981. Is tenderness nutritionally controlled? *Proc. Recip. Meat Conf.* 34:65.
- Troyer, H. 1980. Oxidoreductases. In: *Principles and Techniques of Histochemistry.* pp 299-300. Little, Brown and Co., Boston.
- USDA. 1976. Official United States standards for grades of carcass beef. Title 7, Ch. 28, Pt. 2853, Sections 102-107. Code of Federal Regulations, U. S. Department of Agriculture, Washington, DC.
- Wu, J. J., C. L. Kastner, M. C. Hunt, D. H. Kropf and D. M. Allen. 1981. Nutritional effects on beef collagen characteristics and palatability. *J. Anim. Sci.* 53:1256.