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I am submitting herewith a thesis written by Alfred Benjamin Cole, Jr. entitled, "Effects of Electrical Stimulation on Physical, Chemical and Palatability Characteristics of Beef Produced From Three Feeding Regimens." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Technology and Science.

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# EFFECTS OF ELECTRICAL STIMULATION ON PHYSICAL, CHEMICAL AND PALATABILITY CHARACTERISTICS OF BEEF PRODUCED FROM THREE FEEDING REGIMENS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Alfred Benjamin Cole, Jr.

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## DEDICATION

This thesis is dedicated to my parents, Mr. and Mrs. Alfred B. Cole, whose love, guidance, support, encouragement and interest in their children's lives will always be treasured.

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ABSTRACT

Part I: Effects of Electrical Stimulation on Carcass Characteristics and Palatability Attributes of Beef Produced From Three Feeding Regimens.

Twenty forage finished, 20 limited grain finished (low energy) and 19 grain finished (high energy, ad libitum) steers were slaughtered in a commercial meat packing firm. A randomly selected side from each carcass was electrically stimulated (625 volts, 3-5 amps, 20 impulses of 1 sec duration each) within one hour post-exsanguination. All sides were chilled in a 0 C cooler, ribbed at 18-21 hrs postmortem (PM) and evaluated. Five short loin steaks (2.5 cm) were removed after 60, 120, 180 and 240 hr PM aging periods for Warner-Bratzler shear (WBS) force and palatability (240 hr only) determinations. Carcasses from steers finished on forage were rated lower for lean color, lean firmness, lean texture, fat color, sensory flavor and sensory tenderness than grain finished steer carcasses. For comparisons between electrical stimulation (ES) and controls (combined feeding regimens, n = 59), ES improved ($P < .01$) lean color, firmness, texture scores and reduced heat-ring formation. ES sides from grain finished steers exhibited higher ($P < .10$) marbling scores (Small 30% vs Slight 90%) than control sides, however, ES did not significantly increase the marbling degree in forage finished or limit grain finished steer carcasses. ES steaks broiled to an internal temperature of 70 C for palatability determinations received higher ($P < .05$) tenderness ratings (5.1 vs 4.8) and had lower ($P < .01$) WBS force values at 60 hr (3.4 vs 4.1 kg), 120 hr (3.1 vs 3.8 kg), 180 hr (3.0 vs 3.4 kg) and 240 hr (2.8 vs 3.2 kg) PM aging periods. Aged (240 hr) steaks from

all ES sides were less ($P < .05$) variable (s.d. .79 vs .63 kg of WBS) in tenderness. These data indicate that ES coupled with 5 days cooler aging results in an equal level of tenderness than carcasses (forage of grain) aged 10 days.

Part II: Effects of Postmortem Aging on Fragmentation Index Values.

A total of 472 loin steaks were removed from short loins (n = 118) from electrically stimulated (ES) and non-electrically stimulated (NES) sides cooler aged for 60, 120, 180 and 240 hrs postmortem. Following each aging period, Warner-Bratzler shear (WBS) and Fragmentation Index (FI) samples were removed. Palatability, proximate analysis and histological samples were removed after the 240 hr aging period. FI of frozen longissimus muscle was recorded at two drying times (0 min and 10 min). No difference ($P < .01$) in correlation of FI residue to WBS force values for drying periods of 0 or 10 min was observed. Simple correlation coefficients ($P < .01$) of NES and ES muscle relating FI (0 min) of muscle at 60 hr postmortem to WBS force values were (.50 and .44), (.48 and .39), (38 and .36) and (.39 and .31) for steaks aged 60, 120, 180 and 240 hrs PM, respectively. FI of NES muscle accounted for approximately 23, 42, 38 and 15% of the observed variation in WBS force values not explained by selected carcass traits for steaks aged 60, 120, 180 and 240 hrs PM, respectively. USDA beef quality factors accounted for approximately 7% of the variation in shear force value, while FI (0 min drying time) accounted for an additional 10-37% of the variation in shear force for steaks aged 60-240 hours. By omitting the residue drying step, the FI procedure may be reduced by 10 min, thus creating a more time efficient procedure for tenderness evaluation using raw muscle

cooler aged for 60 hrs. These data indicate that this procedure has potential for commercial application.

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# PART I

# Effects of Electrical Stimulation on Carcass Characteristics and Palatability Attributes of Beef Produced From Three Feeding Regimens

# CHAPTER I

## INTRODUCTION

Since meat tenderness is the most important quality and palatability attribute of beef, considerable research has been conducted to enhance beef tenderness and reduce tenderness variability. Tenderization procedures should be practically acceptable for industrial use, nevertheless many of these procedures have been developed and accepted, some with undesirable characteristics. Presently, current tenderization procedures include advantages and disadvantages. Cooler aging, perhaps the most popular method of tenderization, involves cooler space, equipment and energy requirements. Bacterial spoilage on limited fat covered carcasses during aging has presented undesirable effects. Moreover, Culp et al., (1973) indicated little additional increase in tenderness beyond 11 days of cooler aging. High temperature-short time (HTST) aging has been shown to reduce the cold shortening effect (Smith et al., 1971; Stromer and Goll, 1967), and enhances a pH fall at a more rapid rate at warm temperatures, activating enzyme release, thus causing increased degredation of muscle tissue (Moeller et al., 1976). Bacterial spoilage continues to remain a problem with HTST aging. Obturator foramen suspension decreases toughness associated with the muscle fiber cold shortening effect (March and Leet, 1966), increased sarcomere length and tenderness (Hostetler et al., 1975), which is in agreement with Herring et al. (1965) that stretched sarcomeres resulted in increased tenderness.

Nevertheless, this method possesses carcass fabrication disadvantages (Smith et al., 1971). Blade tenderization has been shown to decrease toughness in forage-fed beef and increase cooking loss (Davis et al., 1975). Furthermore, other researchers Davis et al. (1977) and Savell et al. (1977a) indicated increases in tenderness coupled with increased cooking losses and lower juiciness scores. Tropical plant enzymes, often used to marinate meat, may often undesirably influence flavor and texture of the product (Henrickson, 1978). However, tenderness of bullocks has been elevated to more desirable levels by antemortem injection of plant enzymes (Smith et al., 1973).

Recently, electrical stimulation has achieved industrial acceptance and is becoming an economically desirable method of meat tenderization. Carcass electrical stimulation has been shown by Chrystall and Hagyard (1976) and Jambers (1977) to present no undesirable quality effects combined with increased tenderness, although safety is an important consideration with this technique. Results from electrical stimulation research conclude that improvements in tenderness, lean color, more rapid pH decline, reduction of the cold shortening effect and reduction of heat-ring formation are all beneficial effects from carcass electrical stimulation. Undisputed tenderness results in beef have been demonstrated, however early postmortem tenderness levels have not been elucidated. Therefore the objectives of this experiment were to: (1) determine the length of postmortem aging in which electrically stimulated sides possess tenderness levels similar to cooler aged beef; (2) compare early (18-21 hr) postmortem differences of quality indicators from electrically stimulated sides and non-stimulated sides; and (3) observe the effects

of electrical stimulation on carcasses from steers of three feeding regimens (forage-, limited grain- and full grain-finished).

# CHAPTER II

## REVIEW OF LITERATURE

Benjamin Franklin discovered that the first practical use for electricity was to kill turkeys, resulting in "uncommonly tender meat" (Lopez and Herbert, 1975). Electrical stimulation as a tenderization procedure was first commercially suggested by Harsham and Detherage (1951). Researchers later observed that electrical stimulation of lamb (Bendall, 1976; Carse, 1973; Chrystall and Hagyard, 1975, 1976; Savell et al., 1977b) and beef (Bendall et al., 1976; Bouton et al., 1978; Chrystall and Devine, 1978; Cross et al., 1979; Davey et al., 1976, 1977b, 1978a, b, c, 1979; Shaw and Walker, 1977; Smith et al., 1977) contributed to increases in tenderness and lower shear force values over non-stimulated controls, while Westervelt and Stouffer (1978) observed no additional increase in the tenderness of pork chops.

Locker and Hagyard (1963), Marsh and Leet (1966) and Marsh et al. (1968) concluded that the cold shortening effects resulting from low chill temperatures contributed to decreases in tenderness. In conjunction, Bowling et al. (1977) reported lower chilling temperatures attributed to increased shear force values. Electrical stimulation was found to reduce the cold shortening effect on muscle fibers and increase tenderness from carcasses subjected to low chill temperatures (Bendall et al., 1976; Chrystall and Devine, 1978; Chrystall and Hagyard, 1976; Davey et al., 1976; Gilbert and Davey, 1976). In addition, electrical stimulation was found to decrease adenine-tri-phosphate (ATP) levels, which may determine shortening (Bendall, 1976, 1978; Will et al., 1979), decrease

pH more rapidly and achieve identical pH endpoints as non-stimulated sides (Bendall et al., 1976; Bendall, 1976, 1978; Hallund and Bendall, 1965; Shaw and Walker, 1977; Smith et al., 1979; Chrystall and Hagyard, 1976; Bouton et al., 1978; Chrystall and Devine, 1978), increase glycolysis (Forrest et al., 1966, 1967; Carse, 1973; Chrystall and Devine, 1978; Chrystall and Hagyard, 1975; Smith et al., 1977; Davey et al., 1976), hasten rigor mortis onset (Gilbert and Davey, 1976), reduce heat-ring incidence (Savell et al., 1978b, c), improve longissimus color, firmness and USDA quality grades (Savell et al., 1976, 1978b, c), increase flavor scores (Savell et al., 1976, 1977b, 1978a), cause physical disruption of muscle fibers and the formation of contracture bands (Savell et al., 1978a), rupture lysosomes causing enzyme release (Nickle, 1977; Savell et al., 1977b), decrease conditioning time for lambs, permitting more rapid entry into freezers, with acceptable tenderness levels (Carse, 1973; Chrystall and Hagyard, 1975), lower variability in tenderness over non-stimulated carcasses (Chrystall and Hagyard, 1976; Davey et al., 1976), reduce microbial spoilage, permitting increased shelf life (Raccach and Hendrickson, 1978), is rapid and inexpensive (Smith et al., 1977) and electrical stimulation equipment can be installed at any point in the slaughter-dressing sequence where space is available and safety not compromised (McKeith et al., 1979).

Previous research establishes that electrical stimulation does increase meat quality and palatability attributes without creating undesirable characteristics. This tenderization method should be practically employed to enhance meat attributes, reduce cooler aging time and energy costs.

## CHAPTER III

## EXPERIMENTAL PROCEDURE

A total of fifty-nine steers were grouped into twenty trios on the basis of breed, weight and body type. All steers were wintered (October, 1977 to April, 1978) on a low energy hay ration. Subsequently, one steer from each trio was randomly assigned to one of three feeding regimens. Feeding regimen 1 contained 20 forage-finished steers (low energy, grass fed) allowed unlimited grazing of orchard grass (IRN 2-03-451), Kentucky 31 fescue (IRN 2-01-902) and Ladino clover (IRN 2-01-383). Feeding regimen 2 consisted of 20 limited grain-finished steers (low energy, grain-fed at 2% of body weight per day) fed in a dry lot to allow a weight gain similar to Feeding Regimen 1 steers. Feeding Regimen 3 included 19 steers ad libitum (full) grain-finished in a dry lot (high energy, grain-fed). The grain rations contained 59% shelled yellow corn, gr 2 (IRN 4-03-005), 10% soybean meal (44% protein, (IRN 5-04-604), 5% sugar-cane molasses (IRN 1-00-023), 2% animal fat (IRN 4-00-375), 20% cotton-seed hulls (IRN 1-01-600), .5% salt (IRN 6-04-152) and .5% ground limestone (IRN 6-02-632).

### Electrical Stimulation

At a commercial firm in August, 1978, the 59 steers were slaughtered, split longitudinally and within one hour post-exsanguination a randomly selected side from each carcass was electrically stimulated (ES). Two 4 m cables attached to a Best and Donovan (Type ES, Electro Sting) hog stunning unit and connected at the opposite end with two stainless steel probes (25 cm x 6 mm i.d.). These probes were

inserted into the heel of the round and between the scapula and thoracic vertebrae of the chuck. Electrically stimulated sides received 20 impulses, each with a one-second duration of 625 volts at 3-5 amps.

Carcass Evaluation

Following an 18-21 hour chill in a 1 C cooler with good air velocity, ES and non-electrically stimulated (NES) sides were ribbed and evaluated for carcass characteristics by two experienced selectors (University of Tennessee and USDA Meat Grader) for quality and yield grade factors. Subjective evaluations for the following quality indicators were performed: lean color; lean firmness; and lean texture using 8-point rating scales (8 = light grayish pink, very firm, very fine texture; 1 = black, very soft, very coarse texture). Heat-ring scores (5 = none; 1 = extremely severe) and fat color scores (5 = white; 1 = orange) were also evaluated.

Sample Preparation

Following shipment to The University of Tennessee Meat Laboratory, a 0.65 cm longissimus muscle sample (steak A) was immediately removed from the anterior end of the short loin for proximate analysis determination. Five steaks, 2.54 cm longissimus samples, were subsequently removed after 60 (steak B), 120 (steak C), 180 (steak D) and 240 (steaks E and F) hour postmortem aging periods for Warner-Bratzler shear (WBS) force measurements (steaks B, C, D and E) and palatability (steak F) determinations. Samples were trimmed of subcutaneous fat in excess of 0.65 cm, wrapped in polyethylene coated freezer paper, frozen at -31 C and stored at -18 C.

Cookery Procedures

Frozen steaks were removed from the freezer and stored in a 1-2 C cooler 24 hours prior to cookery. Each steak was broiled to an internal temperature of 70 C (monitored by a YSI Telethermometer thermo-couple device) on a pre-heated "Farberware" broiling unit at approximately 175 C. Degree of doneness was scored using an 8-point scale (1 = rare; 8 = very well done), cooking time and cooking losses were also recorded for each steak. After cooling to 25 C, four (2.5 x 1.3 cm i.d) cores were removed and sheared in duplicate (total of eight shear measurements per steak) on a Warner-Bratzler shear force machine. Palatability steaks, cooked by the same procedure as above, were weighed, boned and cut into 1.3 x 1.3 x 1.9 cm cubes with the use of a plexiglass grid (Cross et al., 1978). Two cubes were randomly selected and served hot to each of an eight member trained sensory evaluation panel. Panelists independently rated each sample and assigned scores on an 8-point descriptive scale for juiciness, tenderness and flavor intensity, and scored flavor desirability and overall satisfaction using 8-point desirability scales (8 = extremely juicy, extremely tender, extremely intense beef flavor and extremely desirable; 1 = extremely dry, extremely tough, extremely intense milky flavor and extremely undesirable, respectively).

Proximate Analysis

Proximate analysis samples (steak A) were trimmed of all epimyseal tissue, cubed, frozen in liquid nitrogen and powdered in a Waring blender at liquid nitrogen temperatures. Total moisture was determined by measuring the weight loss of duplicate 2 g samples after drying for 12-16 hr in a 100 C vacuum oven. Fat content was derived by measuring

the weight loss of the dried sample resulting from 8 hr of continuous extraction with anhydrous ether in a Soxhlet fat extraction unit. Percentage fat was calculated both on a whole tissue basis (WTB) and on a moisture-free basis (MFB). A.O.A.C. (1975) procedures were followed.

## Sarcomere Length

Sarcomere length was determined on longissimus muscle aged 240 hrs. Muscle was blended in an Osterizer Cycle-Blend for 2 min in a suspension medium of 4% formalin (25 ml) solution. A light microscope (1500X) and filar micrometer were employed to measure 10 sarcomeres on each of 12 myofibrils.

## Statistical Analysis

Statistical analysis was achieved by use of the Statistical Analysis System (Barr et al., 1976). Means, standard deviations, coefficients of variation, paired-t distribution, partial correlation coefficients and multiple regression analysis were employed using procedures outlined by Snedecor and Cochran (1967). The means separation technique of Tukey, (1953) was followed.

# CHAPTER IV

## RESULTS AND DISCUSSION

Data presented in Table 1 are means, standard deviations and coefficients of variation values for selected carcasses characteristics. Steers finished on full grain possessed significantly ($P < .05$) higher slaughter weights, higher dressing percentages, greater subcutaneous fat thickness, more internal fat, larger longissimus muscle and higher USDA yield grades than steers finished on all forage or limited grain. The populations of forage finished and limited grain finished cattle were not different ($P < .05$), with the exception of fat color scores. In agreement, Pearson, (1966) noted that the color of fat is influenced by carotene (Vitamin A) deposits dependent upon the type of feeding regimen.

Chemical measurements (Table 2) indicate forage- and limited grain-finished steer longissimus muscles were not different ($P < .05$) in percentages of moisture and fat, however samples from full grain-finished carcasses had higher ($P < .05$) levels of fat (WTB and MFB) and a lower moisture percentage. Sarcomere lengths were not affected by feeding regimen. This is in disagreement with Bowling et al. (1977) who reported that grain finished cattle exhibited longer sarcomere lengths (2.07 μm) than samples from forage finished (1.79 μm) steers.

Breidenstein et al. (1964) with pork and Brungardt and Bray (1963) with beef, observed no differences in right or left sides of carcasses, with the exception of kidney and pelvic fat. In conjunction, Covington et al. (1970) observed no differences in tenderness in right or left

Table 1 -- Mean, Standard Deviation and Coefficient of Variation Values for Certain Carcass Characteristics Subjectively Evaluated at 18-21 Hours Postmortem for Steer Carcasses From Three Feeding Regimens

| | Feeding Regimen | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Forage[1] Fed (n=20) | | | Limit[2] Fed (n=20) | | | Full[3] Fed (n=19) | | | Combined[c] (n=59) | | | Rank Order (highest to lowest) |
| Trait | Mean | S.D.[a] | C.V.[b] | Mean | S.D. | C.V. | Mean | S.D. | C.V. | Mean | S.D. | C.V. | Across Regimens[f] |
| Live Weight (kg) | 352.7 | 26.5 | 7.5 | 344.7 | 24.1 | 7.0 | 432.5 | 25.9 | 6.0 | 375.7 | 46.9 | 12.5 | 3 1 2 |
| Carcass Weight (kg) | 193.1 | 24.3 | 12.6 | 189.5 | 16.6 | 8.7 | 258.6 | 18.6 | 7.2 | 213.0 | 37.4 | 17.6 | 3 1 2 |
| Dressing Percentage | 54.6 | 3.8 | 6.9 | 54.9 | 2.1 | 3.8 | 59.8 | 2.2 | 3.8 | 56.4 | 3.6 | 6.4 | 3 2 1 |
| Skeletal Maturity[d] | $A^{50}$ | 0.0 | 0.0 | $A^{50}$ | 0.0 | 0.0 | $A^{51}$ | 0.5 | 3.0 | $A^{50}$ | 0.3 | 1.7 | 3 2 1 |
| Lean Maturity[d] | $A^{51}$ | 0.4 | 3.0 | $A^{60}$ | 4.1 | 25.1 | $A^{49}$ | 0.5 | 3.1 | $A^{54}$ | 2.4 | 15.8 | 2 1 3 |
| Overall Maturity[d] | $A^{50}$ | 0.2 | 1.5 | $A^{55}$ | 2.0 | 12.6 | $A^{50}$ | 0.3 | 2.2 | $A^{52}$ | 1.2 | 7.7 | 3 1 2 |
| Fat Color[e] | 3.1 | 1.4 | 36.8 | 4.0 | 0.3 | 8.1 | 4.8 | 0.4 | 7.7 | 4.0 | 0.8 | 20.9 | 3 2 1 |
| Fat Thickness (mm) | 3.8 | 1.4 | 36.8 | 3.3 | 1.6 | 48.8 | 12.0 | 4.9 | 41.1 | 6.2 | 5.0 | 79.8 | 3 1 2 |
| KPH (%) | 1.9 | 0.4 | 21.7 | 1.7 | 0.4 | 24.3 | 2.9 | 0.5 | 19.1 | 2.1 | 0.7 | 32.6 | 3 1 2 |
| Rib-eye Area ($cm^2$) | 62.3 | 6.8 | 10.9 | 62.8 | 6.8 | 10.8 | 72.3 | 9.1 | 12.6 | 65.7 | 8.8 | 13.3 | 3 2 1 |
| Final Yield Grade | 1.7 | 0.4 | 20.4 | 1.6 | 0.4 | 23.6 | 2.8 | 0.8 | 27.6 | 2.0 | 0.8 | 38.1 | 3 1 2 |

[a] S.D. = standard deviation.

[b] C.V. = coefficient of variation.

[c] Combined = combination of all feeding regimens.

[d] $A^{\bullet}$ = 9 months, $A^{100}$ = 30 months in age.

[e] 5 = white, 1 = orange.

[f] Means in the same row, underscored by a common line, do not differ ($P < .05$).

Table 2 -- Mean, Standard Deviation and Coefficient of Variation Values for Certain Laboratory Measurements of Longissimus Muscle

| Measurement | Feeding Regimen: Forage[1] Fed (n=20) Mean | S.D.[a] | C.V.[b] | Limit[2] Fed (n=20) Mean | S.D. | C.V. | Full[3] Fed (n=19) Mean | S.D. | C.V. | Combined (n=59) Mean | S.D. | C.V. | Rank Order (Highest to Lowest) Across Regimens[f] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentage Moisture (WTB)[d] | 75.3 | 1.0 | 1.3 | 75.8 | 1.2 | 1.5 | 72.4 | 1.2 | 1.6 | 74.6 | 1.9 | 2.5 | 2 1 3 |
| Percentage Fat (WTB)[d] | 1.8 | 0.6 | 32.1 | 1.8 | 0.8 | 46.0 | 4.8 | 1.5 | 31.2 | 2.7 | 1.7 | 62.8 | 3 2 1 |
| Percentage Fat (MFB)[e] | 7.7 | 3.2 | 41.2 | 7.3 | 3.2 | 43.4 | 17.9 | 5.5 | 30.8 | 10.8 | 6.3 | 58.2 | 3 1 2 |
| Sarcomere Length (μm) | 1.79 | 0.12 | 6.9 | 1.80 | 0.10 | 5.4 | 1.84 | 0.11 | 6.1 | 1.81 | 0.11 | 6.2 | 3 2 1 |

[a]S.D. = standard deviation.

[b]C.V. = coefficient of variation.

[c]Combined = combination of feeding regimens.

[d]WTB = whole tissue basis.

[e]MFB = moisture free basis.

[f]Means in the same row, underscored by a common line do not differ ($P < .05$).

beef sides. Therefore, bilateral symmetry of these beef carcasses is assumed for comparisons between paired ES and NES sides in this study.

ES sides, evaluated at 18-21 hrs postmortem, (Table 3) from full grain finished steers possessed significantly higher lean color, firmness, texture and marbling scores than full grain NES sides. ES sides produced from limited grain finished steer carcasses had higher ($P < .05$) lean color and firmness scores than NES sides. Generally, ES improved lean quality and prevented heat-ring formation of these carcasses, however forage-finished carcasses exhibited only slight lean quality differences. Heat-ring formation, a condition involving cold shortening of the longissimus muscle fibers, resulting in lean depression, dark color, course texture and lean separation from subcutaneous fat, was eliminated ($P < .01$) in ES sides, while NES sides evidenced slight heat-ring formation. Forage finished carcasses had increased ($P < .05$) heat-ring incidence, resulting in lower heat-ring scores than grain finished cattle. Subcutaneous fat thickness is associated with the cold shortening effect (Smith et al., 1976), and the limited amount of subcutaneous fat covering in forage-finished carcasses may have resulted in increased cold shortening, evidenced by heat-ring formation.

Carcasses which possess increased amounts of intramuscular fat (i.e. full grain-finished) have a greater potential for enhancement of marbling scores for evaluations at 18-21 hrs postmortem. Data in Table 3 support the above hypothesis. Among 19 full grain finished sides, 12 graded USDA Good, however, application of ES to the paired side improved 6 of these carcasses into the USDA Choice grade. These data are in agreement with Savell et al. (1976, 1978b, c), who reported that ES significantly increased marbling scores. Savell et al. (1978c)

Table 3 -- Mean Values for Longissimus Muscle Subjectively Evaluated at 18-21 Hours Postmortem For ES and NES Steer Carcasses From Different Feeding Regimens

| Muscle Characteristic[a] | Feeding Regimen | | | | | | | | Rank Order (Highest to Lowest) Across Regimens[e] |
|---|---|---|---|---|---|---|---|---|---|
| | 1 (Forage Fed) | | 2 (Limit Fed) | | 3 (Full Fed) | | (Combined) | | |
| | NES | ES | NES | ES | NES | ES | NES | ES | |
| Lean color[b] | 5.4 | 5.9 | 5.6 | 6.6 | 6.7 | 7.4 | 5.9 | 6.6 | |
| Significance of difference | (P < .10) | | (P < .05) | | (P < .05) | | (P < .01) | | 3 2 1 |
| Lean firmness[b] | 3.9 | 4.4 | 3.9 | 4.9 | 4.9 | 5.6 | 4.2 | 5.0 | |
| Significance of difference | (n.s.) | | (P < .05) | | (P < .10) | | (P < .01) | | 3 2 1 |
| Lean texture[b] | 5.4 | 5.9 | 6.1 | 6.8 | 6.4 | 7.3 | 6.0 | 6.6 | |
| Significance of difference | (n.s.) | | (n.s.) | | (P < .001) | | (P < .01) | | 3 2 1 |
| Marbling score[c] | $TR^{40}$ | $TR^{50}$ | $TR^{30}$ | $TR^{40}$ | $SL^{90}$ | $SM^{30}$ | $TR^{80}$ | $SL^{0}$ | |
| Significance of difference | (n.s.) | | (n.s.) | | (P < .10) | | (n.s.) | | 3 1 2 |
| Heatring score[d] | 4.6 | 5.0 | 4.9 | 5.0 | 4.9 | 5.0 | 4.8 | 5.0 | |
| Significance of difference | (P < .01) | | (n.s.) | | (n.s.) | | (P < .01) | | 3 2 1 |

[a]Evaluated at the 12-13th rib interface and statistical differences based on paired-t analysis (Snedecor and Cochran, 1967).

[b]8 = light grayish red (pink), very firm, very fine; 1 = black, very soft, very coarse, for lean color, lean firmness and lean texture, respectively.

[c]An A maturity carcass exhibiting a marbling score of SM (small), SL (slight) and TR (traces) will receive a USDA quality score of Choice, Good and Standard, respectively.

[d]Degree of "heat-ring" formation (5 = none, 1 = extremely severe).

[e]Means (NES sample only) in the same row, underscored by a common line do not differ (P < .05).

suggested that ES accelerated glycolysis, causing a "setting-up" of intramuscular fat at a rate faster than control (NES) carcasses, allowing earlier USDA quality grading (24 hrs postmortem). It was also reported that after a longer chill period (48 hrs), NES sides would also "set-up" and exhibit more marbling than at 24 hrs postmortem, resulting in higher USDA quality grades at 48 hrs rather than 24 hrs postmortem. Covington et al. (1970) reported that after longer chill periods, intramuscular fat whitens and solidifies, therefore becoming more visible. Results from these data (Table 3) indicate that ES influenced a "setting-up" of intramuscular fat and increased lean quality for USDA grading at 18-21 hrs postmortem over NES sides. In addition, full grain-finished sides exhibited higher ($P < .05$) lean quality characteristics than sides from the other feeding regimens.

ES significantly increased ($P < .05$) tenderness ratings of loin steaks from forage-finished steer carcasses (Table 4). Tenderness ratings of ES samples were judged to be significantly ($P < .05$) more tender than NES samples when feeding regimens were combined into ES and NES treatments. Mean ratings and characteristics for juiciness, flavor, overall palatability, degree of doneness, cooking time and cooking loss were not significantly affected by application of ES. These data are in disagreement with Savell et al. (1978a), who reported that ES decreased juiciness ratings, increased flavor ratings and increased cooking losses. The type of feeding regimen generally affected sensory evaluation ratings shown in Table 4. Steaks from forage finished steer carcasses were ($P < .05$) less juicy, scored higher in "milky" or forage flavor and were the least palatable in comparison to loin steaks from grain-finished

Table 4 -- Mean Scores of Palatability Attributes and Cookery Characteristics From ES and NES Longissimus Samples From Steer Carcasses of Three Feeding Regimens

| Palatability Attribute[a] | Feeding Regimen 1 Forage Fed NES | 1 Forage Fed ES | 2 Limit Fed NES | 2 Limit Fed ES | 3 Full Fed NES | 3 Full Fed ES | Combined[b] NES | Combined[b] ES | Rank Order (Highest to Lowest) Across Regimens[c] |
|---|---|---|---|---|---|---|---|---|---|
| Tenderness rating | 4.3 | 4.8* | 4.9 | 5.2 | 5.3 | 5.3 | 4.8 | 5.1* | 3 2 1 |
| Juiciness rating | 4.5 | 4.3 | 5.0 | 4.5 | 4.8 | 5.0 | 4.7 | 4.6 | 3 2 1 |
| Flavor intensity (n=46) | 3.1 | 3.3 | 4.7 | 4.8 | 5.3 | 5.5 | 4.4 | 4.6 | 3 2 1 |
| Overall palatability[d] | 2.9 | 3.1 | 4.2 | 4.0 | 4.6 | 4.7 | 3.9 | 3.9 | 3 2 1 |
| Degree of doneness[e] | 4.1 | 4.2 | 4.1 | 4.4 | 4.3 | 4.2 | 4.2 | 4.3 | 3 2 1 |
| Cooking time (min) | 26.1 | 27.3 | 25.2 | 25.5 | 25.5 | 25.3 | 25.6 | 26.0 | 1 3 2 |
| Cooking loss (%) | 28.6 | 28.5 | 29.2 | 29.0 | 30.6 | 29.4 | 29.5 | 29.0 | 3 2 1 |

[a]Palatability attributes scored on 240 hr aged samples statistically analyzed by paired-t test (Snedecor and Cochran, 1976).

[b]Combined = combination of feeding regimens.

[c]Means (ES and NES samples averaged within a regimen) in the same row, underscored by a common line do not differ ($P < .05$).

[d]8 = extremely tender, extremely juicy, extremely intense beef flavor, extremely desirable; 1 = extremely tough, extremely dry, extremely intense milky flavor, extremely undesirable, respectively.

[e]8 = very well done; 1 = rare.

*$P < .05$.

steers, which is in agreement with Bowling et al. (1977). In addition, no differences in degree of doneness, cooking time or cooking loss were observed between feeding regimens.

Simple correlation coefficients (Table 5) of sensory evaluation traits for ES and NES loin steaks indicate that tenderness, flavor intensity and overall satisfaction were significantly related to level of grain feeding. Increases in flavor intensity and overall palatability were significantly related to lean color, texture, marbling score, fat thickness, carcass weight, percentage KPH fat and yield grade. These relationships may be attributable to increases in grain feeding, inducing accumulation of increased quantities of adipose tissue, which desirably affected flavor and overall palatability scores. Low correlations with skeletal, lean and overall maturity to sensory variables were due to the limited variation in maturity scores for the carcasses evaluated in the present study. The degree of multi-colinearity between palatability attributes and correlations of WBS and cooking loss to palatability traits are presented in Table 6. Correlations between WBS and tenderness rating ($r = -0.51$, $P < .001$) of NES samples was lower than other researchers ($r = -0.67$, Hutsell, 1976; $r = -0.85$, Calkins, 1978). WBS and tenderness ratings of ES samples were significantly related ($r = -0.27$, $P < .05$), however this relationship was low. These data indicate that the panel was not as sensitive to changes in tenderness as the WBS machine. Segars et al. (1975) also observed a lower panel sensitivity than instrument sensitivity in tenderness differentiation. Among most sensory variables ($r = 0.50$ tenderness and flavor; $r = 0.36$ tenderness and juiciness; $r = 0.08$ juiciness and flavor), correlations

Table 5 -- Simple Correlation Coefficients for ES and NES Steer Carcasses Relating Sensory Evaluation Variables to Carcass Traits

| Carcass Traits | Sensory Evaluation Variables | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Tenderness Rating | | Juiciness Rating | | Flavor Intensity | | Overall Palatability | |
| | NES | ES | NES | ES | NES | ES | NES | ES |
| Feeding regimen | .47** | .31* | .21 | .32* | .80** | .83* | .71** | .74** |
| Skeletal maturity | .04 | -.10 | .02 | .04 | .04 | .03 | -.02 | -.05 |
| Lean maturity | .24 | .27* | .21 | .20 | -.18 | -.07 | -.06 | -.07 |
| Overall maturity | .25 | .27* | .26* | .21 | -.17 | -.07 | -.06 | -.07 |
| Lean color | .22 | .07 | -.13 | .17 | .47** | .36** | .36** | .38** |
| Lean firmness | .20 | .22 | .19 | .04 | .24 | .33* | .20 | .34** |
| Lean texture | .24 | .13 | -.10 | .13 | .48** | .44** | .36** | .43** |
| Marbling score | .30* | .28* | .13 | .30* | .50** | .60** | .38** | .59** |
| Fat thickness | .22 | .15 | .14 | .17 | .40** | .45** | .35** | .43** |
| Carcass weight | .35** | .19 | .10 | .42** | .41** | .60** | .45** | .57** |
| Percentage KPH | .31* | .12 | .06 | .28* | .47** | .49** | .40** | .50** |
| Rib-eye area | .14 | .06 | -.10 | .25 | .26 | .38** | .22 | .37** |
| Yield grade | .25* | .18 | .16 | .18 | .38** | .37** | .35** | .38** |

*P < .05.

**P < .01.

Table 6 -- Simple Correlation Coefficients for ES and NES Loin Steaks Relating Warner-Bratzler Shear, Palatability Attributes and Cookery Characteristics

| Characteristic | Warner-Bratzler Shear | | Juiciness | | Flavor Intensity | | Flavor Desirability | | Overall Palatability | | Cooking Loss | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NES | ES | NES | ES | NES | ES | NES | ES | NES | ES | NES | ES |
| Tenderness rating | -.51*** | -.27* | .36** | .55*** | .48*** | .33* | .50*** | .28* | .66*** | .47*** | .01 | -.42** |
| Warner-Bratzler shear | | | -.10 | -.15 | -.26 | -.07 | -.22 | -.13 | -.29* | -.15 | .23 | .20 |
| Juiciness rating | | | | | .13 | .41** | .08 | .31* | .08 | .53*** | -.55*** | -.71*** |
| Flavor intensity (n = 46) | | | | | | | .96*** | .97*** | .91*** | .94*** | .20 | .05 |
| Flavor desirability | | | | | | | | | .91*** | .93*** | .19 | .11 |
| Overall palatability | | | | | | | | | | | .04 | -.13 |
| Cooking loss | | | | | | | | | | | --- | --- |

*P < .05.

**P < .01.

***P < .001.

were generally lower than those ($r = 0.68$ tenderness and flavor; $r = 0.53$ tenderness and juiciness; $r = 0.47$ juiciness and flavor) reported by Romans et al. (1965).

Presented in Table 7 are correlation coefficients of sensory evaluation variables to laboratory measurements for ES and NES samples. Tenderness ratings, flavor intensity and overall palatability scores were generally significantly related to percentage moisture and percentage fat. These relationships may be attributable to the differences in chemical measurements (Table 2, page 13) between feeding regimens and the multi-colinearity of sensory evaluation variables. Juiciness ratings were not generally related to percentages of moisture and fat.

Mean WBS and standard deviation (SD) values are presented in Table 8. When feeding regimens were combined into ES and NES treatments, ES samples possessed significantly lower WBS force values after 60 ($P < .001$), 120 ($P < .01$), 180 ($P < .02$) and 240 ($P < .01$) hr postmortem aging periods. This is in agreement with Savell et al. (1978a; 1979), Bouton et al. (1978) and Jambers (1977) who observed increased tenderness of ES samples over controls after postmortem aging periods. Additional observations of SD values from cores subjected to the WBS indicate that ES samples were significantly less variable (evidenced by lower SD values for ES WBS values) after 60 ($P < .01$), 120 ($P < .02$) and 240 ($P < .05$) hr postmortem aging periods than NES samples. The variability of areas within loin steaks was decreased by ES and resulted in more uniform tenderness across ES steaks than in the more variable (higher SD values) NES samples. Covington et al. (1970) observed WBS cores from the periphery of the steak were tougher than inner cores. This difference may be explained by muscle fiber shortening from cold temperatures. The

Table 7 -- Simple Correlation Coefficients for ES and NES Steer Carcasses Relating Sensory Ratings to Chemical Measures

| | Sensory Evaluation Variables | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Tenderness Rating | | Juiciness Rating | | Flavor Intensity | | Overall Palatability | |
| Measurement | NES | ES | NES | ES | NES | ES | NES | ES |
| Percentage moisture | -.30* | -.25 | -.09 | -.20 | -.43** | -.49*** | .37** | -.50*** |
| Percentage fat (WTB) | .35** | .30* | .15 | .25 | .60*** | .57*** | .53*** | .58*** |
| Percentage fat (MFB) | .33** | .27* | .12 | .26* | .62*** | .54*** | .53*** | .56*** |
| Sarcomere length | .20 | .10 | .00 | .13 | .14 | .17 | .23 | .22 |

*P < .05.

**P < .01.

***P < .001.

Table 8 -- Mean Values for Warner-Bratzler Shear Force Values (WBSFV) Ranked From Lowest to Highest For ES and NES Aged Steer Carcasses From Three Feeding Regimens

| Hours Post-Mortem | Variable (kg) | Forage-Fed (n=20) NES | ES | Significance of Difference[a] | Limited Grain-Fed (n=20) NES | ES | Significance of Difference[a] | Full Grain-Fed (n=19) NES | ES | Significance of Difference[a] | Overall (n=59) NES | ES | Significance of Difference[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | WBSFV | 4.28 | 3.43 | P < .02 | 4.38 | 3.48 | P < .05 | 3.75 | 3.15 | P < .11 | 4.14 | 3.36 | P < .001 |
| | SDV | 1.03 | 0.83 | ns | 1.06 | 0.70 | P < .06 | 0.91 | 0.64 | P .03 | 1.00 | 0.73 | P < .01 |
| 120 | WBSFV | 4.00 | 3.05 | P < .01 | 4.17 | 3.24 | P < .02 | 3.15 | 2.86 | P < .20 | 3.79 | 3.05 | P < .01 |
| | SDV | 1.00 | 0.75 | P < .13 | 1.10 | 0.78 | P < .05 | 0.72 | 0.66 | ns | 0.94 | 0.73 | P < .02 |
| 180 | WBSFV | 3.57 | 3.00 | P < .04 | 3.76 | 3.16 | P < .13 | 2.96 | 2.78 | ns | 3.44 | 2.98 | P < .02 |
| | SDV | 0.91 | 0.73 | ns | 0.94 | 0.78 | ns | 0.68 | 0.73 | ns | 0.85 | 0.75 | ns |
| 240 | WBSFV | 3.28 | 2.72 | P < .01 | 3.42 | 2.97 | ns | 2.80 | 2.57 | ns | 3.17 | 2.76 | P < .01 |
| | SDV | 0.89 | 0.66 | P < .11 | 0.80 | 0.65 | ns | 0.67 | 0.59 | ns | 0.79 | 0.63 | P < .05 |

[a]Significance of difference between treatments based on paired t-test (Snedecor and Cochran, 1967).

cold shortening effect described by Marsh and Leet (1966) may have occured to a higher degree in NES carcasses than in ES carcasses. Bendall et al. (1976) observed that ES decreased ATP levels and accelerated glycolysis. These early reactions may have prevented shortening and the subsequent toughening of muscles from the cold chill temperatures. The inhibition of the cold shortening effect may explain the more uniform cores from ES samples.

Data presented in Table 9 are mean WBS values ranked from lowest to highest. Generally, full grain finished and ES samples possessed lower shear force values than NES steaks aged for shorter periods. Steaks from NES sides aged from 60-180 hrs generally exhibited higher shear values and were tougher than ES samples (Table 9). These data indicate that ES steaks aged for 60-180 hrs possessed tenderness levels similar to NES steaks aged for 240 hrs, therefore, application of ES to beef carcasses may reduce cooler aging periods over the period conventional carcasses (NES) are aged.

Data in Table 10 indicate that application of ES to beef carcasses produced from three feeding regimens results in cooked steaks which are significantly less variable in WBS force value.

Data in Table 11 were developed to identify the percentage of the observed variation in tenderness (shear and sensory) which could be accounted for by use of certain combinations of carcass traits. Regression equations for shear force value and sensory tenderness rating containing two variables accounted for 10.48 to 14.54%, respectively of the observed variability in tenderness for ES sides. Only 3 to 5% additional precision was obtained when eight, rather than two variables were used to predict tenderness of ES sides. Carcass traits accounted

Table 9 -- Mean Values for WBSFV Ranked From Lowest to Highest for ES and NES Aged Steer Carcasses From Three Feeding Regimens

| Feeding Regimen | Postmortem Aging (hrs) | Treatment | WBSFV (kg)[a] | Rank |
|---|---|---|---|---|
| Full grain-fed | 240 | ES | 2.57b | 1 |
| Forage-fed | 240 | ES | 2.72bc | 2 |
| Full grain-fed | 180 | ES | 2.78bcd | 3 |
| Full grain-fed | 240 | NES | 2.80bcd | 4 |
| Full grain-fed | 120 | ES | 2.86bcde | 5 |
| Full grain-fed | 180 | NES | 2.96bcde | 6 |
| Limited grain-fed | 240 | ES | 2.97bcde | 7 |
| Forage-fed | 180 | ES | 3.00bcde | 8 |
| Forage-fed | 120 | ES | 3.05bcdef | 9 |
| Full grain-fed | 120 | NES | 3.15bcdef | 10 |
| Full grain-fed | 60 | ES | 3.15bcdef | 11 |
| Limited grain-fed | 180 | ES | 3.16bcdef | 12 |
| Limited grain-fed | 120 | ES | 3.24bcdef | 13 |
| Forage-fed | 240 | NES | 3.28bcdefg | 14 |
| Limited grain-fed | 240 | NES | 3.42cdefg | 15 |
| Forage-fed | 60 | ES | 3.43cdefg | 16 |
| Limited grain-fed | 60 | ES | 3.48defgh | 17 |
| Forage-fed | 180 | NES | 3.57efghi | 18 |
| Full grain-fed | 60 | NES | 3.75fghij | 19 |
| Limited grain-fed | 180 | NES | 3.76fghij | 20 |
| Forage-fed | 120 | NES | 4.00ghij | 21 |
| Limited grain-fed | 120 | NES | 4.17hij | 22 |
| Forage-fed | 60 | NES | 4.28ij | 23 |
| Limited grain-fed | 60 | NES | 4.38j | 24 |

[a]Means bearing a common letter are not different ($P < .05$) based on Tukey (1953).

Table 10 -- Mean Standard Deviation Values (SDV) From WBS Cores Ranked From Lowest to Highest From Longissimus Muscle of ES and NES Aged Carcasses From Three Feeding Regimens

| Feeding Regimen | Postmortem Aging (Hrs) | Treatment | SDV[a] | Rank |
|---|---|---|---|---|
| Full grain-fed | 240 | ES | 0.59b | 1 |
| Full grain-fed | 60 | ES | 0.64bc | 2 |
| Limited grain-fed | 240 | ES | 0.65bcd | 3 |
| Forage-fed | 240 | ES | 0.66bcd | 4 |
| Full grain-fed | 120 | ES | 0.66bcd | 5 |
| Full grain-fed | 240 | NES | 0.67bcd | 6 |
| Full grain-fed | 180 | NES | 0.68bcd | 7 |
| Limited grain-fed | 60 | ES | 0.70bcde | 8 |
| Full grain-fed | 120 | NES | 0.72bcde | 9 |
| Forage-fed | 180 | ES | 0.73bcdef | 10 |
| Full grain-fed | 180 | ES | 0.73bcdef | 11 |
| Forage-fed | 120 | ES | 0.75bcdefg | 12 |
| Limited grain-fed | 180 | ES | 0.78bcdefg | 13 |
| Limited grain-fed | 120 | ES | 0.79bcdefg | 14 |
| Limited grain-fed | 240 | NES | 0.80bcdefgh | 15 |
| Forage-fed | 60 | ES | 0.83bcdefgh | 16 |
| Forage-fed | 240 | NES | 0.89bcdefgh | 17 |
| Forage-fed | 180 | NES | 0.91cdefgh | 18 |
| Full grain-fed | 60 | NES | 0.91cdefgh | 19 |
| Limited grain-fed | 180 | NES | 0.94cdefgh | 20 |
| Forage-fed | 120 | NES | 1.00efgh | 21 |
| Forage-fed | 60 | NES | 1.03fgh | 22 |
| Limited grain-fed | 60 | NES | 1.06gh | 23 |
| Limited grain-fed | 120 | NES | 1.10h | 24 |

[a]Means bearing a common letter are not different ($P < .05$) based on Tukey (1953).

Table 11 -- Coefficient of Determination for Multiple Regression Equations Predicting 240 Hour Aged Longissimus Muscle Shear Force Values and Sensory Tenderness Ratings for ES and NES Steer Sides Using Subsets of Selected Carcass Traits (n=57)

| Variables in Subset | Electrically Stimulated Sides | | | |
|---|---|---|---|---|
| | Shear Force Value | | Sensory Tenderness Rating | |
| | Variables[a] | $R^2$ X 100 | Variables[a] | $R^2$ X 100 |
| 8 | Full model | 15.88 | Full model | 17.85 |
| 5 | 2,3,6,7,8 | 15.36 | 1,2,4,5,6 | 16.83 |
| 4 | 2,6,7,8 | 14.27 | 1,2,4,5 | 15.93 |
| 3 | 2,6,8 | 12.28 | 2,4,5 | 15.42 |
| 2 | 2,6 | 10.48 | 2,5 | 14.54 |

| Variables in Subset | Non-Electrically Stimulated Sides | | | |
|---|---|---|---|---|
| | Shear Force Value | | Sensory Tenderness Rating | |
| | Variables[a] | $R^2$ X 100 | Variables[a] | $R^2$ X 100 |
| 8 | Full model | 26.67 | Full model | 35.45 |
| 5 | 1,3,4,7,8 | 24.43 | 4,5,6,7,8 | 34.10 |
| 4 | 1,3,7,8 | 22.32 | 4,5,7,8 | 33.66 |
| 3 | 3,7,8 | 19.93 | 4,7,8 | 32.81 |
| 2 | 2,3 | 17.44 | 4,7 | 31.37 |

[a]Variable code for carcass traits: 1 = Overall maturity 2 = Marbling degree 3 = Lean color 4 = Lean texture 5 = Lean firmness 6 = Fat thickness 7 = Carcass weight 8 = Ribeye area.

for a higher percentage of the variation in tenderness for NES side in comparison to ES sides. Regression equations containing two variables accounted for 17.44 to 31.37% of the observed variation in shear force value and sensory tenderness rating, respectively. Upon addition of six more variables, precision was increased only by 4 to 9%. These data suggest that more variation in tenderness may be explained in NES than in ES sides by using selected carcass traits.

Data in Table 12 identify the percentage of the observed variability in tenderness which could be accounted for by five selected laboratory measurements. Regression equations for shear force value and sensory tenderness rating containing two variables accounted for 16.74 to 30.07%, respectively, of the variability in tenderness for ES sides. Upon addition of the other variables, the full regression model accounted for only a 0.33 to 3.53% increase in the observed variation in tenderness in ES sides. Regression equations of two variables (NES sides) accounted for 14.05 to 14.21% of the variation in sensory tenderness rating and shear force value, respectively, while addition of all other variables only accounted for a 0.88 to 2.77% increase in tenderness variability. These data indicate that little additional precision can be attained when three, four or five variables are included in the regression model using laboratory measurements. In addition, laboratory measurements accounted for more (15.53%) of the observed tenderness variation in ES sides than NES sides in sensory tenderness rating.

Results of multiple regression analysis using selected carcass traits and laboratory measurements for predictional 240 hr postmortem aged longissimus muscle tenderness (shear and sensory) from ES and NES sides are presented in Table 13. Regression equations of shear force

Table 12 -- Coefficients of Determination For Multiple Regression Equations Predicting 240 Hour Aged Longissimus Muscle Shear Force Values and Sensory Tenderness Ratings of ES and NES Steer Sides Using Subsets of Selected Laboratory Measurements (n=59)

| Variables in Subset | Electrically Stimulated Steer Sides | | | |
|---|---|---|---|---|
| | Shear Force Value | | Sensory Tenderness Rating | |
| | Variables[a] | $R^2$ X 100 | Variables | $R^2$ X 100 |
| 5 | Full model | 20.27 | Full model | 30.40 |
| 4 | 1,3,4,5 | 20.27 | 2,3,4,5 | 30.40 |
| 3 | 3,4,5 | 18.89 | 2,3,5 | 30.34 |
| 2 | 3,4 | 16.74 | 2,5 | 30.07 |

| Variables in Subset | Non-Electrically Stimulated Steer Sides | | | |
|---|---|---|---|---|
| | Shear Force Value | | Sensory Tenderness Rating | |
| | Variables[a] | $R^2$ X 100 | Variables | $R^2$ X 100 |
| 5 | Full model | 16.98 | Full model | 14.93 |
| 4 | 1,2,4,5 | 16.95 | 2,3,4,5 | 14.93 |
| 3 | 2,4,5 | 16.25 | 2,4,5 | 14.93 |
| 2 | 2,5 | 14.21 | 2,4 | 14.05 |

[a]Variable code for laboratory measurements: 1 = Percentage moisture
2 = Percentage fat (Whole tissue basis) 3 = Percentage fat (Moisture free basis)
4 = Sarcomere length 5 = Cooking loss.

Table 13 -- Coefficients of Determination for Multiple Regression Equations Predicting 240 Hour Longissimus Muscle Shear Force Values and Sensory Tenderness Ratings for ES and NES Steer Sides Using Selected Carcass Traits and Laboratory Measurements (n=57)

| Variables in Subset | Electrically Stimulated Steer Sides | | | |
|---|---|---|---|---|
| | Shear Force Value | | Sensory Tenderness Rating | |
| | Variables[a] | $R^2$ X 100 | Variables[a] | $R^2$ X 100 |
| 12 | Full model | 27.45 | Full model | 31.51 |
| 5 | 6,8,10,11,12 | 24.42 | 5,6,8,10,12 | 30.70 |
| 4 | 6,10,11,12 | 21.63 | 5,8,10,12 | 30.09 |
| 3 | 10,11,12 | 18.13 | 5,10,12 | 29.36 |
| 2 | 6,10 | 14.79 | 10,12 | 28.12 |

| Variables in Subset | Non-Electrically Stimulated Steer Sides | | | |
|---|---|---|---|---|
| | Shear Force Value | | Sensory Tenderness Rating | |
| | Variables[a] | $R^2$ X 100 | Variables[a] | $R^2$ X 100 |
| 12 | Full model | 32.19 | Full model | 38.96 |
| 5 | 1,4,5,8,10 | 27.24 | 4,6,7,8,10 | 35.74 |
| 4 | 4,5,8,10 | 25.20 | 4,5,7,8 | 33.66 |
| 3 | 4,5,10 | 22.59 | 4,7,8 | 32.81 |
| 2 | 4,10 | 20.21 | 4,7 | 31,37 |

[a]Variable code for carcass traits and laboratory measurements: 1 = Overall maturity
2 = Marbling degree 3 = Lean color 4 = Lean texture 5 = Lean firmness
6 = Fat thickness 7 = Carcass weight 8 = Ribeye area 9 = Percentage moisture
10 = Percentage fat (whole tissue basis) 11 = Sarcomere length 12 = Cooking loss

value and sensory tenderness ratings from ES sides using the best 2-variable equation accounted for 14.79 to 28.12% of the observed tenderness variability, respectively. Equations containing all variables accounted for 12.66 and 3.39% additional precision in predicting the variability of shear force value and sensory tenderness rating of ES sides, respectively. Measures of fat thickness, fat WTB and cooking loss explained considerable tenderness variability in ES sides and combinations of these variables were observed in the best 2-variable models. This observation is apparently a result of the multi-colinearity from adipose tissue measures. Regression equations of NES sides using two variables accounted for 20.21 and 31.37% of the variation in shear force value and sensory tenderness rating, respectively. Upon addition of all other variables to the full regression model, precision was increased to 32.19 and 38.96% of the observed variation in tenderness rating and shear force value, respectively. These data indicate that combinations of carcass traits and laboratory measures can be employed to predict variability in tenderness (shear and sensory) in ES and NES sides, while combinations of percentage fat (WTB), fat thickness, cooking loss, lean texture and carcass weight were observed in the best 2-variable model regression equations. The variation in the lighter forage- and limited grain-finished carcasses compared to the heavier full grain-finished carcasses was undoubtedly responsible for the presence of carcass weight in the equations for sensory tenderness.

# CHAPTER V

## CONCLUSIONS

The conclusion of the present study are as follows: (a) carcasses from steers finished on forage or limited grain are likely to (1) be USDA yield grade 1, (2) have a USDA quality grade of Standard, (3) have a dressing percentage of less than 55, (4) possess a slight yellow fat color, (5) have longissimus moisture percentages of 75-76 and percentage fat (WTB) of less than two and (6) likely to be slightly tough to slightly tender, slightly dry to slightly juicy and have a moderately intense "milky" flavor (forage finished) or slightly intense beef flavor (limited grain finished); (b) carcasses from steers finished in four months on full grain are likely to (1) be USDA yield grade 2, (2) have a USDA quality grade of Good, (3) have a dressing percentage of 60, (4) possess white fat, (5) have longissimus moisture percentage of 72 and percentage fat (WTB) of less than five and (6) likely to be slightly tender, slightly juicy and have a slightly intense beef flavor; (c) application of ES to steer carcasses generally resulted in higher lean color, firmness, texture and marbling scores with less "heat-ring" formation for evaluations at 18-21 hrs postmortem, more tender loin steaks and lower shear force values with less variability in tenderness levels; (d) ES samples aged for 120 hrs possessed similar tenderness levels as NES samples aged 240 hrs, therefore ES sides require 50 % less postmortem aging as NES carcasses; (e) carcass traits and common laboratory measurements may not predict tenderness of ES sides as accurately as with NES sides; (f) no undesirable quality or palatability effects were observed from electrical stimulation.

# LIST OF REFERENCES

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# APPENDIX

Table A-1 -- Coefficients of Determination for Multiple Regression Equations Predicting 240 Hour Aged Longissimus Muscle Shear Force Values and Sensory Tenderness Ratings for ES and NES Steer Sides Using Subsets of Selected Carcass Traits (n=59)

| Variables in Subset | Electrically Stimulated Sides | | | |
|---|---|---|---|---|
| | Shear Force Value | | Sensory Tenderness Rating | |
| | Variables[a] | $R^2$ X 100 | Variables[a] | $R^2$ X 100 |
| 8 | Full model | 15.87 | Full model | 25.80 |
| 5 | 2,3,6,7,8 | 15.29 | 1,2,4,5,6 | 24.43 |
| 4 | 2,6,7,8 | 14.23 | 1,2,4,6 | 24.04 |
| 3 | 2,6,8 | 12.06 | 1,2,4 | 22.73 |
| 2 | 2,6 | 10.22 | 1,2 | 18.49 |

| Variables in Subset | Non-Electrically Stimulated Sides | | | |
|---|---|---|---|---|
| | Shear Force Value | | Sensory Tenderness Rating | |
| | Variables[a] | $R^2$ X 100 | Variables[a] | $R^2$ X 100 |
| 8 | Full model | 22.45 | Full model | 39.65 |
| 5 | 1,3,5,7,8 | 19.43 | 1,4,6,7,8 | 38.02 |
| 4 | 1,3,7,8 | 17.72 | 1,4,7,8 | 37.02 |
| 3 | 1,2,3 | 15.35 | 1,4,7 | 35.83 |
| 2 | 1,3 | 13.62 | 1,3 | 22.42 |

[a]Variable code for carcass traits: 1 = Overall maturity 2 = Marbling degree 3 = Lean color 4 = Lean texture 5 = Lean firmness 6 = Fat thickness 7 = Carcass weight 8 = Ribeye area.

Table A-2 -- Coefficient of Determination for Multiple Regression Equations Predicting 240 Hour Aged Longissimus Muscle Shear Force Values and Sensory Tenderness Ratings for ES and NES Steer Sides Using Subsets of Selected Carcass Traits and Laboratory Measures (n=59)

| Variables in Subset | Electrically Stimulated Steer Sides | | | |
|---|---|---|---|---|
| | Shear Force Values | | Sensory Tenderness Ratings | |
| | Variables[a] | $R^2$ X 100 | Variables[a] | $R^2$ X 100 |
| 12 | Full model | 25.91 | Full model | 38.77 |
| 5 | 3,6,8,10,12 | 23.33 | 1,5,8,10,12 | 36.94 |
| 4 | 6,8,10,12 | 20.24 | 1,5,10,12 | 36.14 |
| 3 | 6,10,11 | 18.07 | 1,10,12 | 34.78 |
| 2 | 6,10 | 10.30 | 10,12 | 30.07 |

| Variables in Subset | Non-Electrically Stimulated Steer Sides | | | |
|---|---|---|---|---|
| | Shear Force Values | | Sensory Tenderness Ratings | |
| | Variables[a] | $R^2$ X 100 | Variables[a] | $R^2$ X 100 |
| 12 | Full model | 33.56 | Full model | 43.63 |
| 5 | 1,3,8,10,12 | 26.98 | 1,4,6,7,8 | 38.86 |
| 4 | 1,3,10,12 | 23.41 | 1,4,7,8 | 37.02 |
| 3 | 1,3,12 | 20.16 | 1,4,7 | 35.83 |
| 2 | 3,12 | 15.25 | 1,3 | 22.42 |

[a]Variable code for carcass traits and laboratory measurements: 1 = Overall maturity
2 = Marbling degree 3 = Lean color 4 = Lean texture 5 = Lean firmness
6 = Fat thickness 7 = Carcass weight 8 = Ribeye area 9 = Percentage moisture
10 = Percentage fat (whole tissue basis) 11 = Sarcomere length 12 = Cooking loss.

Table A-3 -- Mean Values of Cookery Characteristics for Warner-Bratzler Shear Force Analysis

| Hours Postmortem | Variable | Forage-Fed NES | Forage-Fed ES | Limited-Fed NES | Limited-Fed ES | Full-Fed NES | Full-Fed ES | Combined NES | Combined ES |
|---|---|---|---|---|---|---|---|---|---|
| 60 | Cooking time (min) | 28.6 | 27.2 | 26.2 | 27.8 | 27.8 | 26.1 | 27.5 | 27.0 |
| | Cooking loss (%) | 26.7 | 26.6 | 25.6 | 26.3 | 27.7 | 27.8 | 26.6 | 26.9 |
| | D.D.[a] | 4.2 | 4.2 | 4.0 | 4.0 | 4.1 | 4.1 | 4.1 | 4.1 |
| 120 | Cooking time (min) | 27.8 | 27.2 | 27.1 | 27.6 | 25.9 | 28.0 | 26.9 | 27.6 |
| | Cooking loss (%) | 29.5 | 28.6 | 28.1 | 29.1 | 29.4 | 30.6 | 29.0 | 29.4 |
| | D.D. | 4.0 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 |
| 180 | Cooking time (min) | 27.9 | 28.3 | 26.8 | 25.1 | 25.3 | 27.0 | 26.7 | 26.8 |
| | Cooking loss (%) | 28.3 | 29.1 | 28.3 | 27.0 | 27.6 | 28.1 | 28.1 | 28.1 |
| | D.D. | 4.1 | 4.2 | 4.3 | 4.1 | 4.1 | 4.2 | 4.2 | 4.2 |
| 240 | Cooking time (min) | 26.9 | 27.3 | 26.0 | 25.4 | 26.3 | 23.5 | 26.4 | 25.4 |
| | Cooking loss (%) | 27.6 | 27.0 | 26.7 | 26.9 | 26.7 | 26.0 | 27.0 | 26.6 |
| | D.D. | 4.1 | 4.0 | 4.2 | 4.1 | 4.3 | 4.3 | 4.2 | 4.1 |

[d] D.D. = Degree of doneness (8 = very well done; 1 = raw).

* $P < .05$.

# PART II

# EFFECTS OF POSTMORTEM AGING ON FRAGMENTATION INDEX VALUES

# CHAPTER I

## INTRODUCTION

The USDA beef quality grades segment carcasses into expected palatability groups based on marbling and maturity. These beef quality grades account for approximately 15 % or less of the variation in palatability (Jeremiah et al., 1970). Research indicated considerable tenderness variability exists within these quality grades. Field et al. (1970) observed that when antemortem and postmortem factors are held constant, beef from similar carcasses often varies in tenderness. Some research efforts have been directed to identify this variability. For instance, Reagan et al. (1975) emphasized the need to relate beef quality attributes to methods for carcass classification by objective measures of raw tissues.

It is well known that tenderness increases with aging (Davey et al., 1967). The physical and chemical changes of myofibrils, such as Z-line disintegration and a weakening of actin and myosin bonds, are associated with aging and tenderness. Davey and Graafhuis (1976) concluded that myofibril components were closely related to tenderness. In addition, other research by Davey and Gilbert (1967, 1969) and Moller et al. (1973) deduced: (1) the weakening of Z-lines on myofibrils was related to aging; (2) aged muscle had more myofibril Z-line disruption; and, (3) myofibril Z-line disintegration allows myofibrils to cleave into smaller fragments upon homogenization.

Current research indicated the number or amount of myofibril fragments is related to tenderness through objective tests such as

Myofibril Fragmentation Index (Davey and Gilbert, 1969; Olson et al., 1976) and the Fragmentation Index (FI) of Reagan et al. (1975) modified by Davis et al. (1980a). The FI of Davis et al. (1980a) improved by Calkins et al. (1980) was selected in this study for its accuracy and speed. However, a need exists to reduce the time postmortem a raw muscle sample may be assessed by FI and to reduce the time of the FI procedure for increased research and future industrial acceptance. Therefore, the objectives of this study were to: (1) determine the earliest time postmortem the FI is significantly related to tenderness and (2) determine the minimum drying time for the FI.

# CHAPTER II

## REVIEW OF LITERATURE

Presently, most meat tenderness evaluation methods require removal of fresh muscle from a carcass, cookery of the muscle and then objective and/or subjective appraisal of the cooked sample. The Warner-Bratzler shear machine (Bratzler, 1949) is the most common device used for tenderness measurement of cooked samples. In addition, other less popular methods also require considerable time and are costly.

Pearson (1963) noted that subjective tenderness is complicated to evaluate because the shearing, squeezing, tearing, cutting and grinding processes are measured by nerves and interpreted in the brain. Reagan et al. (1975) emphasized the need to develop a quick and accurate method for tenderness evaluation using raw muscle. Kapsalis and Szczesniak (1976) suggested that tenderness predictions using raw meat could be very useful, however raw meat tenderness predictions may be difficult because of biochemical changes and the alteration of the material upon cooking.

Mechanical tenderness prediction devices which use raw muscle include: The Armour Tenderometer (Dikeman et al., 1972; Campion et al., 1975; Parrish et al., 1973a); Warner-Bratzler shear and Nip Tenderometer (Smith and Carpenter, 1973; Davis et al., 1975). These researchers observed that these devices were not highly related to tenderness, consequently they are not used with raw muscle.

Raw tenderness prediction procedures have recently been developed: The Poisson's Ratio Device (Segars et al., 1974); Myofibril Fragmentation Index (MFI) (Davey and Gilbert, 1969; Olson et al., 1976; Culler et al., 1978); and Fragmentation Index (Reagan et al., 1975; Davis et al., 1980a; Calkins and Davis, 1978). In general, these procedures were significantly related to cooked tenderness, and present promise as tenderness prediction procedures.

Recently, research interests in raw muscle tenderness prediction procedures have been concentrated on the degredation of Z-lines and the influence of this phenomenon on myofbril fragments after blending and homogenization. Stromer and Goll (1967) observed differences in myofibrillar fragmentation with postmortem aged bovine muscles using different suspension and isolation media. Subsequent studies have related Z-line degradation and/or a weakening of Z-line attachments as follows: meat tenderness and numbers of myofibril fragments increase with aging (Davey and Gilbert, 1967, 1969; Davey and Graafhuis, 1976; Berry et al., 1974); chicken pectoral muscle Z-line degradation results in greater ease of fragmentation and smaller fragments with aging (Takahshi et al., 1967; Fukazawa et al., 1969); more tender muscles have more fragmentation at the Z-disk I-band junction than tougher samples (Gann and Merkel, 1978; Goll et al., 1970; Parrish et al., 1973b); Z-line degradation and cellular changes contribute to the amount of fiber fragmentation (Jeremiah and Martin, 1978); higher temperature aged muscle exhibits smaller fragments from cell proteolysis (Moeller et al., 1977); early postmortem (unaged) homogenized myofibrils are longer than later postmortem (aged) homogenized myofibrils (Moller et al., 1973); and light absorption of myofibrils is related to

tenderness (Moller et al., 1973; Olson et al., 1976). However, Sayre (1970) concluded that fragmentation of chicken muscle from different glycolytic rates was not an accurate index for tenderness.

These researchers conclude that fragmentation is an objective test of raw muscle, and highly related to cooked tenderness and aging. This procedure may lead to a rapid and accurate method to segment carcasses into homogeneous tenderness groups (Davis et al., 1980b).

CHAPTER III

# EXPERIMENTAL PROCEDURE

Procedures for basic carcass design, evaluation, cookery and statistical analysis are outlined in Chapter III of Part I, page 7.

## Sample Preparation

Following shipment to The University of Tennessee Meat Laboratory, a 0.65 cm longissimus muscle sample (steak A) was immediately removed from the anterior end of the short loin for determination of proximate analysis. Nine steaks were subsequently removed after 60 (steaks B and BB), 120 (steaks C and CC), 180 (steaks D and DD) and 240 (steaks E, EE and F) hour postmortem aging periods for Warner-Bratzler shear (WBS) force determination (steaks BB, CC, DD and EE, 2.54 cm thickness), Fragmentation Index value (steaks B, C, D and E, 0.65 cm thickness) and palatability (steak F, 2.54 cm thickness) determination. Samples were trimmed of subcutaneous fat in excess of 0.65 cm, wrapped in polyethylene-coated freezer paper, frozen at -31 C and stored at -18 C.

## Fragmentation Index

Fragmentation Index was determined according to the Davis et al. (1980a) procedure. The Fragmentation Index (FI) was obtained by adding 10 g of frozen 7 mm cubed longissimus muscle (steaks B, C, D and E) to 50 ml of a cold sucrose (0.25M) and potassium chloride (0.02M) solution in a 150 ml fluted, stainless steel homogenization cup. After 5 min in the solution, each sample was blended for 40 seconds at maximum speed with a Virtis Macro-Model "45" homogenizer. The blades were set in

reverse position and parallel to each other. The dorsal blade of the homogenizer was adjusted to 1 mm below the surface of the solution (Calkins and Davis, 1978). The homogenate was filtered through a pre-weighed "Nitex" screen (250 μm pore size) in a modified 115 "Nalgene filter unit" with the aid of a plastic stirring rod. Screen and residue were blotted on Whatman No. 3 filter paper and immediately weighed. Following a 10 min air drying period at 22 C on filter paper, weights were again recorded. FI = residue weight in g X 100.

# CHAPTER IV

## RESULTS AND DISCUSSION

Mean FI values for ES and NES longissimus muscle during different postmortem aging periods are shown in Table 14. Significant differences in FI values were observed in comparisons between ES and NES samples during the 60, 120 and 240 hr aging periods. However, the FI was higher for NES samples in comparisons to ES samples for beef aged 120 hrs postmortem. These results indicate that a need exists to further study the effect of ES on FI at various times postmortem before conclusions or recommendations can be made.

Frozen longissimus samples were assessed based on work by Davis et al. (1980a) modified by Calkins et al. (1980), however, the drying step was eliminated (samples were weighed immediately after blotting on filter paper) therefore, FI values reported here are generally higher than those reported by these researchers. With the exception of the 60 hr postmortem aging period, FI values generally decreased with postmortem aging, reflecting increases in muscle tenderness with aging.

Simple correlation coefficients relating FI of different aging periods to carcass characteristics and laboratory measurements are presented in Table 15. FI of longissimus muscle was often related to certain measures of adipose tissue (Table 15). Marbling degree, fat thickness, KPH fat, and fat (%, WTB and MFB), indicate that FI may be related to the bulk density effect of tenderness. This is in agreement with Calkins et al. (1980). Significant relationships between FI and fat thickness range from $r = 0.31$ to $r = 0.51$ for ES samples, however

Table 14 -- Mean Fragmentation Index (FI) Values for ES and NES Longissimus Muscle During Four Postmortem Aging Periods

| Hours Postmortem | Variable | Forage-fed NES | Forage-fed ES | Limited-fed NES | Limited-fed ES | Full-fed NES | Full-fed ES | Combined[a] NES | Combined[a] ES |
|---|---|---|---|---|---|---|---|---|---|
| 60 | FI[b] | 536 | 666 | 672 | 632 | 502 | 752 | 571 | 682 |
| | Sig. of diff.[c] | ($P < .05$) | | (n.s.) | | ($P < .001$) | | ($P < .01$) | |
| 120 | FI | 721 | 572 | 717 | 613 | 751 | 677 | 730 | 620 |
| | Sig. of diff. | ($P < .01$) | | ($P < .05$) | | (n.s.) | | ($P < .001$) | |
| 180 | FI | 569 | 415 | 532 | 536 | 569 | 724 | 557 | 548 |
| | Sig. of diff. | ($P < .05$) | | (n.s.) | | (n.s.) | | (n.s.) | |
| 240 | FI | 355 | 422 | 455 | 503 | 396 | 607 | 402 | 509 |
| | Sig. of diff. | (n.s.) | | (n.s.) | | ($P < .01$) | | ($P < .01$) | |

[a]Combined - combination of feeding regimens.

[b]FI = fragmentation index (100 X weight (g) after blotting on filter paper).

[c]Sig. of diff. = significance of difference based on paired t-test, Snedecor and Cochran (1967).

Table 15 -- Simple Correlation Coefficients Relating FI of ES and NES Steer Sides After Postmortem Aging to Carcass Characteristics and Chemical Measurements

| Variable | FI[a] at Different Hours of Postmortem Aging | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 60 | | 120 | | 180 | | 240 | |
| | NES | ES | NES | ES | NES | ES | NES | ES |
| Lean color | -.06 | .12 | .01 | .13 | -.20 | .15 | -.20 | .33** |
| Lean firmness | -.01 | .07 | .01 | .06 | .13 | .22 | -.11 | .19 |
| Lean texture | -.01 | .09 | -.03 | .06 | -.22 | .15 | -.13 | .19 |
| Marbling degree | -.29* | .17 | .05 | .15 | .05 | .37* | -.09 | .27* |
| Carcass weight | -.12 | .19 | .12 | .14 | .11 | .34* | .10 | .24 |
| Fat thickness | -.11 | .31* | .11 | .37** | .11 | .51** | -.12 | .39** |
| KPH fat | -.12 | .23 | .07 | .33* | .02 | .40* | -.06 | .40** |
| Rib-eye area | -.12 | .26* | .18 | -.05 | .17 | .21 | .26* | .19 |
| Fat color | .06 | .23 | .11 | .31* | .09 | .42** | .19 | .46** |
| Percentage moisture | .16 | -.25* | .00 | -.20 | .05 | -.30 | .18 | -.27* |
| Fat (%, WTB) | -.19 | .15 | .00 | .12 | .01 | .40* | -.21 | .23 |
| Fat (%, MFB) | -.27* | .08 | -.07 | .13 | .04 | .39* | -.21 | .20 |
| Sarcomere length | -.06 | -.01 | -.07 | .13 | -.14 | -.02 | -.12 | -.13 |

[a]FI = 100 X weight (g) after blotting on filter paper (0 min drying time).

*P < .05.

**P < .01.

low, non-significant relationships of FI to fat thickness for NES muscle was observed. No significant associations between FI and sarcomere length were observed.

FI drying periods of NES samples at 0 and 10 min (Table 16) were both significantly related to WBS values during most aging periods. Because of only slight differences in 0 and 10 min drying periods, these data substantiate the use of the 0 min drying period compared to the 10 min period, thereby reducing the time required to perform the FI procedure. FI for all NES samples was highly associated with WBS values during all aging periods, however the FI of ES samples was only highly related to WBS values when the fragmentation procedure was conducted using 60 hr postmortem aged samples. The relationships of the control (NES) 240 hr FI samples to shear force values ($r = 0.36$) were lower than those observed by others ($r = 0.81$, Davis et al., 1980; $r = 0.91$, Calkins and Davis, 1978; $r = 0.71$, Calkins et al., 1980; $r = -0.79$, Reagan et al., 1975), and to MFI ($r = -0.58$, Parrish et al., 1979; $r = -0.75$, Olson and Parrish, 1977; $r = -0.77$, MacBride and Parrish, 1977), however this relationship was higher than Hutsell (1979) who reported $r = 0.28$ for FI to WBS. The FI of ES samples was generally not related to WBS values. These data are not in agreement with Stiffer and Ray (1979) who reported that FI of raw ES samples was related to WBS ($r = 0.70$). FI was not highly related to tenderness rating (TR) in ES or NES treatments, except the 180 hr postmortem NES samples. These data indicate that FI of 60 hr aged NES samples is a significantly related to WBS values of steaks from 60, 120, 180 and 240 hr aged beef. Olson and Parrish (1977) also using early postmortem aged (24 hrs) muscle observed high correlations with MFI ($r = -0.65$) to WBS values. Electrically stimulated samples

Table 16 -- Simple Correlation Coefficients Relating FI From Different Drying Periods to WBS and Tenderness Ratings (TR) From ES and NES Steer Sides During Four Postmortem Aging Periods

| Measure | Hours Postmortem | Treatment | Fragmentation Index at Hours of Postmortem Aging | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 60 | | 120 | | 180 | | 240 | |
| | | | 0 Min | 10 Min | 0 Min | 10 Min | 0 Min | 10 Min | 0 Min | 10 Min |
| WBS | 60 | NES | .50*** | .48*** | .42*** | .51*** | .53*** | .44*** | .32* | .31* |
| | | ES | .44*** | .37** | .27* | .23 | .20 | .19 | -.08 | -.08 |
| WBS | 120 | NES | .48*** | .47*** | .55*** | .63*** | .52*** | .50*** | .45*** | .44*** |
| | | ES | .39** | .33** | .21 | .18 | .12 | .12 | -.13 | -.16 |
| WBS | 180 | NES | .38** | .37** | .53*** | .61*** | .53*** | .53*** | .36** | .32* |
| | | ES | .36** | .31** | .33 | .30 | .22 | .22 | -.04 | -.06 |
| WBS | 240 | NES | .39** | .40** | .48*** | .61*** | .60*** | .62*** | .36** | .30* |
| | | ES | .31** | .23 | .28* | .29* | .22 | .17 | -.03 | .00 |
| TR | 240 | NES | -.20 | -.16 | -.21 | -.31* | -.41*** | -.42*** | -.12 | -.11 |
| | | ES | -.15 | -.16 | -.26* | -.19 | -.19 | -.17 | .05 | -.01 |

*P < .05.

**P < .01.

***P < .001.

assessed by FI were only slightly related to WBS values, with the exception of the 60 hr aging period. Through disruption of muscle fibers and formation of myofibrillar contracture bands (Savell et al., 1978), ES may decrease the effectiveness of FI to assess ES muscle accurately.

Table 17 indicated simple correlation coefficients relating FI to TR and overall palatability (OP). WBS, regardless of aging period, was significantly ($P < .01$) related to TR and ($P < .05$) to OP for NES samples. The 180 hr postmortem FI sample was the only FI period related to TR of NES samples, however it was not related to TR or OP during other aging periods. The relationship of FI at 240 hrs postmortem to TR ($r = -0.12$) was lower than others ($r = -0.23$, Hutsell, 1979; $r = -0.68$, Calkins, (1978); $r = -0.83$, Davis et al., 1980). These data indicate that WBS was a better predictor of TR or OP and FI of 180 hrs was the most optimum FI period for predictions of TR.

Simple correlation coefficients (Table 18) relating 240 hr TR and WBS values to FI of samples from different feeding regimens indicate that the highest r-values were observed for samples from the limited fed steer carcasses. Values for 180 hr aged FI samples provided the highest r-values, which was also shown in Table 16. Forage- and full grain-finished steer samples evidenced low r-values, except for the 180 hr postmortem aging period. When feeding regimens were combined into ES and NES treatments, TR was significantly associated with the 180 hr FI of NES samples. In contrast, the FI was related ($P < .01$) to WBS values of NES samples, however only significant relationships were observed associating FI to WBS at 60 and 120 hrs postmortem for ES samples. These data do not support the use of the FI on ES muscle, but do provide high relations of FI with WBS using conventional (NES) muscle.

Table 17 -- Simple Correlation Coefficients Relating FI and WBS Measures to Certain Sensory Evaluation Variables From ES and NES Aged Steer Carcasses

| Sensory Evaluation Variables | Treatment | 60 | | 120 | | 180 | | 240 | |
|---|---|---|---|---|---|---|---|---|---|
| | | FI | WBS | FI | WBS | FI | WBS | FI | WBS |
| Tenderness rating | NES | -.20 | -.51** | -.21 | -.57** | -.41** | -.51** | -.12 | -.51*** |
| | ES | -.15 | -.41** | -.26* | -.35** | -.19 | -.39** | .05 | -.27* |
| Overall palatability | NES | -.03 | -.32* | -.04 | -.39** | -.17 | -.38** | -.05 | -.29* |
| | ES | -.03 | -.17 | .12 | -.08 | .25 | -.14 | .37 | -.15 |

*P < .05.

**P < .01.

Table 18 -- Simple Correlation Coefficients Relating 240 Hour Postmortem Aged Longissimus Muscle TR and WBS Force Values to FI of ES and NES Steer Sides From Three Feeding Regimens

| FI[a] at hrs Postmortem | Treatment | Forage-Fed (n=20) | | Limited-Fed (n=20) | | Full-Fed (n=19) | | Combined (n=59) | |
|---|---|---|---|---|---|---|---|---|---|
| | | TR | WBS | TR | WBS | TR | WBS | TR | WBS |
| 60 | NES | -.35 | .29 | -.44* | .49* | .05 | .28 | -.20 | .39** |
| | ES | -.14 | .41 | -.35 | .51* | -.15 | .25 | -.15 | .31* |
| 120 | NES | -.09 | .52* | -.45* | .63** | -.25 | .33 | -.21 | .50** |
| | ES | -.43 | .38 | -.55** | .28 | -.22 | .46* | -.26* | .28* |
| 180 | NES | -.25 | .44** | -.50* | .79** | -.59** | .55* | -.41** | .60** |
| | ES | -.37 | -.06 | -.50* | .29 | -.38 | .86** | -.19 | .22 |
| 240 | NES | -.41 | .15 | -.24 | .57** | -.02 | .22 | -.12 | .36** |
| | ES | -.20 | -.03 | .08 | -.28 | -.08 | .52* | .05 | .03 |

[a]FI = 100 X weight (g) after blotting on filter paper (0 min drying time).

*P < .05.

**P < .01.

Six carcass trait variables (marbling degree, lean color, fat thickness, lean firmness and carcass weight) based on the variable's influence on the final USDA quality and yield grade, three fragmentation measures (FI of 0 and 10 min drying periods and filtrate volume) and five objective laboratory measurements (sarcomere length, percentage fat (WTB), percentage fat (MFB), percentage moisture and percentage cook loss) were selected as variables to develop prediction models for beef tenderness (Table 19). The six carcass traits were chosen to be included first into the regression model followed by fragmentation and laboratory measurements, based on their ease of evaluation. Each post-mortem aging period contained the fragmentation indexes measured during that period to predict tenderness (shear and sensory) of 240 hr aged samples. Partial coefficients of determination accounting for variation in shear force value and sensory tenderness explained by carcass traits ranged from 9.78 to 10.28%, and 16.02 to 16.30% of the variation, respectively. Partial coefficients of determination accounting for variation in shear force value and sensory tenderness (not previously explained by the carcass trait variables) for fragmentation indexes ranged from 14.63 to 41.65% and 6.81 to 19.93%, respectively. These values are lower than those reported by Calkins et al. (1980) who reported 58 to 61% of tenderness variation was accounted for by FI. In addition, Olson and Parrish (1977) and Culler et al. (1978) who accounted for approximately 50% of the variation in tenderness with MFI. Laboratory measurements accounted for a lower percentage of shear force value and tenderness variation (5.37 to 12.79 and 2.57 to 6.14), respectively. These data indicate that FI measures predicted a higher

Table 19 -- Coefficients of Determination and Partial Coefficients of Determination Predicting TR and Shear Force Value of 240 Hour Postmortem Aged Loin Steaks From NES Sides Using Subsets of Certain Carcass, Fragmentation and Laboratory Measures

| Model | Shear Force Value ($R^2$ X 100) | | | | Tenderness Rating ($R^2$ X 100) | | | |
|---|---|---|---|---|---|---|---|---|
| | 60[a] | 120[a] | 180[a] | 240[a] | 60 | 120 | 180 | 240 |
| Carcass[b], fragmentation[c], laboratory[d] | 46.05 | 57.78 | 53.48 | 33.26 | 34.56 | 32.88 | 38.79 | 25.75 |
| Carcass | 10.28 | 9.78 | 10.28 | 10.28 | 16.30 | 16.02 | 16.29 | 16.29 |
| Fragmentation/carcass[e] | 22.98 | 41.65 | 37.83 | 14.63 | 12.12 | 14.00 | 19.93 | 6.81 |
| Laboratory/carcass, fragmentation[f] | 12.79 | 6.35 | 5.37 | 8.35 | 6.14 | 2.86 | 2.57 | 2.65 |

[a]Postmortem aging period (hrs).

[b]Carcass traits include marbling degree, lean color, fat thickness, lean firmness and carcass weight.

[c]Fragmentation measures include frozen indexes at 0 min, 10 min drying periods and volume of filtrate.

[d]Laboratory measurements include sarcomere length, percentage fat (whole tissue basis), percentage fat (moisture free basis), percentage moisture and percentage cook loss.

[e]Partial coefficients of determination accounting for variation in WBS force value and sensory tenderness rating which was not previously explained by the carcass trait variables.

[f]Partial coefficients of determination accounting for variation in WBS force value and sensory tenderness rating which was not previously explained by the carcass trait and fragmentation variables.

percentage of the loin steak tenderness variation and were more highly related to tenderness than carcass traits or laboratory measurements.

Coefficients of determination and partial coefficients of determination predicting tenderness ratings and shear force value of 240 hr aged loin samples using USDA beef quality grading factors and fragmentation index (0 min drying time) are presented in Table 20. USDA factors, marbling degree and overall carcass maturity, were included in the regression model first because of their ease of evaluation. Approximately 6.67 and 18.6% of the variation in shear force value and tenderness rating, respectively, was explained by the USDA grading factors. One measure of FI (0 min drying time) explained from 10.34 to 36.96% and 0.56 to 16.26% of the observed variation in shear force value and tenderness rating, respectively. The high relationship between marbling degree and sensory panel ratings (Table 5, page 19) partially explain the tenderness to USDA factor relationships reported in the present study. These data indicate that FI is of more value in predicting the objective shear force values than certain USDA factors.

Table 20 -- Coefficients of Determination and Partial Coefficients of Determination Predicting TR and Shear Force Value of 240 Hour Postmortem Aged Loin Steaks From NES Sides Using USDA Beef Quality Grading Factors and FI

| Model | Shear Force Value ($R^2$ X 100) | | | | Tenderness Rating ($R^2$ X 100) | | | |
|---|---|---|---|---|---|---|---|---|
| | 60[a] | 120[a] | 180[a] | 240[a] | 60 | 120 | 180 | 240 |
| USDA factors[b], fragmentation[c] | 17.01 | 29.32 | 43.63 | 18.52 | 19.23 | 21.36 | 34.94 | 19.77 |
| USDA factors | 6.67 | 6.67 | 6.67 | 6.67 | 18.67 | 18.67 | 18.67 | 18.67 |
| Fragmentation/USDA factors[d] | 10.34 | 22.65 | 36.96 | 11.85 | 00.56 | 2.69 | 16.27 | 1.10 |

[a]Postmortem aging period (hrs).

[b]USDA factors include marbling degree and overall maturity.

[c]Fragmentation measure is the fragmentation index after blotting on filter paper (0 min drying time).

[d]Partial coefficients of determination accounting for variation in WBS force value and sensory tenderness rating which was not previously explained by the USDA factors.

# CHAPTER V

## CONCLUSIONS

The conclusions of the present study were as follows: (a) FI values generally decreased with postmortem aging; (b) FI is slightly influenced by the "bulk density effect" component of tenderness; (c) from omission of the drying step, the requirement for the FI may be reduced by 10 min; (d) FI of ES samples was generally not related to WBS or sensory tenderness, except for the 60 hr samples; (e) FI of 60 hr postmortem aged muscle was significantly correlated to WBS in either NES or ES samples; (f) measures of FI explained more variation in shear force value than carcass traits, laboratory measurements or USDA beef quality grading factors for NES samples; (g) USDA factors explained a larger percentage of the variation in tenderness rating than FI.

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# VITA

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