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Fragmentation of loin steaks from U.S. commercial and U.S. utility beef carcasses

Chris Richard Calkins

To the Graduate Council:

I am submitting herewith a thesis written by Chris Richard Calkins entitled "Fragmentation of loin steaks from U.S. commercial and U.S. utility beef carcasses." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science and Technology.

Gordon W. Davis, Major Professor

We have read this thesis and recommend its acceptance:

C. C. Melton, S. D. Cunningham, H. O. Jaynes

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Gordon W. Davis, Major Professor

We have read this thesis
and recommend its acceptance:

Curtis C. Melton

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

FRAGMENTATION OF LOIN STEAKS FROM U. S. COMMERCIAL AND U. S. UTILITY BEEF CARCASSES

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Chris Richard Calkins

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DEDICATION

This thesis is affectionately dedicated to the author's parents Mrs. Anna L. Calkins and Mr. Richard A. Calkins whose support, encouragement, love, understanding and guidance have made this endeavor both possible and rewarding.

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ABSTRACT

Short loin steaks were removed from U. S. Commercial (n=38) and U. S. Utility (n=42) beef carcasses to facilitate study of cooked meat tenderness as related to certain raw muscle fragmentation measures, carcass traits and laboratory procedures. Carcass traits explained 14.1 percent of the variation in shear force value while all fragmentation measures accounted for 61.1 percent. Frozen fragmentation measures (R^2 X 100 = 58.1 percent) were superior to fresh fragmentation measures (R^2 X 100 = 37.3 percent). Results indicate that fresh or frozen fragmentation index of raw muscle is superior to selected carcass traits and/or laboratory assays. The best regression model (two fragmentation measures) accounted for 56.6 percent of the variation in tenderness.

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CHAPTER I

INTRODUCTION

Szczesniak and Torgenson (1965) emphasized the need to provide a sound scientific basis for the development of reliable measures of meat tenderness while Smith et al. (1969) stressed the importance of methodology. These conditions are of paramount importance because tenderness has been shown to be the most important palatability attribute influencing the acceptability of beef (McFadyen et al., 1973; Dunsing, 1959; VanSyckle and Brough, 1958).

While characterization of factors which influence tenderness is widespread, the specific mechanism associated with the post-mortem increase in tenderness is still unresolved. The common belief is that aging causes structural and chemical alterations between the myofibrillar component of muscle proteins (Locker, 1960; Goll et al., 1974) and a degradation of the z lines within a sarcomere. Recently, the recognized existance of gap filaments has stimulated new theories on meat aging (Davey and Graafhuis, 1976). Davis et al. (1978) suggested that fragmentation index may be the best single, objective measure of tenderness using raw muscle.

The objectives of the present study were as follows:

1. To determine the relationship between meat tenderness and fragmentation index in comparison with the relationship of tenderness to selected carcass traits and laboratory procedures.
2. To compare results of fragmentation with use of fresh versus frozen *longissimus* muscle.

CHAPTER II

REVIEW OF LITERATURE

Meat tenderness is difficult to assess because the sensation includes cutting, grinding, squeezing, shearing and tearing in vertical and lateral motions (Pearson, 1963). Much effort has been extended to identify physiological factors which affect or relate to tenderness. The following carcass traits and physical, chemical and histological characteristics have been related to bovine muscle tenderness: marbling degree (Crouse and Smith, 1978; Goll _et al_., 1965; Campion _et al_., 1975b; Breidenstein _et al_., 1968), carcass maturity (Berry _et al_., 1974 a, b; Goll _et al_., 1965; Kropf and Graf, 1959), sarcomere length (Berry _et al_., 1974b; Cooper _et al_., 1968; Herring _et al_., 1965), percentage fat (Covington _et al_., 1970; Cover _et al_., 1956; Palmer _et al_., 1958), connective tissue amount (Ritchey and Hostetler, 1964; Cover _et al_., 1962), fiber diameter (Gillis and Henrickson, 1967; Tuma _et al_., 1962; Hiner _et al_., 1953) and water binding capacity (Covington _et al_., 1970; Breidenstein _et al_., 1968; Wierbicki and Deatherage, 1958). Results of these studies have been equivocal but, in general, the relationships found were not highly correlated with tenderness.

Extensive reviews have also been published concerning objective methods available for assessment of bovine muscle tenderness (Szczesniak and Torgeson, 1965; Pearson, 1963; Schultz, 1957; Heim, 1954). The Warner-Bratzler shear machine is the most common device presently used for objective tenderness measurement of cooked samples. A technique or method which employs raw muscle as the sample has obvious advantages. Several mechanical devices have been applied to raw muscle with limited or no success. These include: the Armour tenderometer (Campion et al., 1975a; Parrish et al., 1973; Dikeman et al., 1972), Warner-Bratzler shear and Nip tenderometer (Smith and Carpenter, 1973; Davis et al., 1975).

Recently, fragmentation of raw muscle has gained interest as a possible index to tenderness of the cooked product. Stromer and Goll (1967) reported differences in the degree of myofibrillar fragmentation during their studies on post-mortem muscle. Subsequent papers by Takahashi et al. (1967) and Fukazawa et al. (1969) relating fragmentation index to tenderness of chicken pectoral muscle suggested: (a) that fragmentation may be related to physical and chemical post-mortem changes in muscle, specifically, z line degradation, (b) some substance involved in the glycolytic pathway may influence the degree of fragmentation, and (c) a relationship does exist between muscle tenderness and degree of fragmentation. However, data presented by Sayre (1970) on differing glycolytic rates of chicken muscle related to fragmentation did not support mechanical fragmentation as an index to tenderness.

Davey and Gilbert (1969) used a different fragmentation procedure to study post-mortem aging. A version of their procedure was applied to bovine muscle by Møller et al. (1973), who used protein content as an index and reported favorable results in the prediction of tenderness. Olson et al. (1976) utilized the Davey and Gilbert (1969) procedure and developed the Myofibrillar Fragmentation Index (M. F. I.) which was successful in prediction of bovine muscle tenderness.

Berry et al. (1974b) reported that shorter myofibril fragments were associated with higher sensory tenderness ratings of beef.

Reagan et al. (1975) reported another fragmentation technique for application to bovine semimembranous muscles with significant results. Davis (1977) successfully refined the Reagan et al. (1975) procedure and accounted for much of the variation in tenderness from beef carcasses of the same U.S.D.A. grade.

Thus, the concept of fragmentation has been applied by use of protein amount, muscle fragment length and weight of residue as an index. The Davis et al. (1978) procedure was selected for study because of the speed, ease and application to industry that the technique provides.

CHAPTER III

EXPERIMENTAL PROCEDURE

Beef carcasses (n=80) were selected at two commercial firms, evaluated for U.S.D.A. (1976) grade factors and certain other quality indicators. shipped to the University of Tennessee meat laboratory and aged for 10-14 days in a 2° C cooler. Six steaks (A and B, 1.3 cm thickness; C and D, 0.65 cm thickness; E and F, 3.2 cm thickness) were removed from the anterior end of the short loin for subsequent chemical (steak A), physical (steaks B, C, D), histological (steak B) and palatability (steaks E, F) analysis.

Sample Selection

There were 60 C maturity carcasses and 20 D maturity carcasses utilized in the present study. Marbling and maturity qualifications for the U. S. Commercial grade were met by 38 carcasses while the remaining 42 carcasses were graded U. S. Utility. At time of selection, the following maturity indicators were evaluated: loin thoracic ossification; skeletal maturity; lean maturity; and overall maturity. U.S.D.A. yield grading factors were measured and the appropriate grades were assigned. In addition, these quality indicators were subjectively assessed by use of 8-point rating scales: lean color; lean firmness; lean texture; marbling texture; marbling distribution; and, marbling size variability (8= light grayish red, very firm, very fine texture, very even distribution and very uniform size, 4= moderately dark red, slightly soft, slightly coarse texture, slightly uneven distribution and slightly variable in size). Fat color (5= white, 1= yellow) and sex class (determined by anatomical differences among carcasses) were also recorded.

Means, ranges and coefficients of variation for carcass selection criteria are presented in Table 1. Variation in maturity scores were designed to be low. However, variation in muscle quality traits and especially in marbling degree suggest a population was selected with sufficient magnitude in expected tenderness difference to allow adequate study of the relationship between tenderness and fragmentation index.

Proximate Analysis

Proximate analysis samples (steak A) were frozen in liquid nitrogen and powdered in a Waring blender. Percentage moisture was determined by use of a 100° C vacuum oven. Samples were dried 8-12 hours and then extracted with anhydrous ether in a Goldfish fat extraction apparatus. Percentage fat was calculated on a moisture free and whole tissue basis. A.O.A.C. (1975) procedures were followed.

Fragmentation Index

The procedure outlined by Davis *et al*. (1978) was followed. Fragmentation index was derived by adding 10g of 7mm cubed *longissimus* muscle (fresh, steak C or frozen, steak D) to 50 ml of cold sucrose (0.25M) and potassium chloride (0.02M) solution in a 150 ml stainless steel homogenization cup. After 5 minutes, each sample was blended for 40 seconds at full speed in a Virtis Macro-Model "45" homogenizer. The blades were in reverse position and parallel with the dorsal blade positioned at the surface of the solution. The resulting homogenate was filtered through a "Nitex" screen (250 μm pore size) by use of a 115 ml "Nalgene Filter Unit" and a plastic stirring rod. Screens were blotted on Whatman No. 3 filter paper and the residue was allowed to air dry at 22° C.

Table 1. Means, ranges and coefficients of variation for carcass selection criteria

Trait	Mean	Minimum Value	Maximum Value	C.V.[a]
Loin thoracic percent ossification	57.4	30	90	27.0
Skeletal maturity[b]	36.8	30	50	12.2
Lean maturity[b]	36.9	14	56	28.3
Overall maturity[b]	37.5	30	50	14.4
Lean color[c]	4.2	2	7	25.5
Lean firmness[c]	6.3	1	8	27.6
Lean texture[c]	4.3	1	8	38.3
Marbling texture[c]	5.4	1	8	31.3
Marbling distribution[c]	6.4	2	8	26.3
Marbling size variability[c]	5.1	1	8	41.2
Marbling degree[d]	45.1	20	90	37.4
Carcass weight (kg)	226	143	327	15.5
Adjusted fat thickness (mm)	9.9	1	41	72.0
Percent Kidney, pelvic and heart fat	2.4	0.5	4.5	42.1
Ribeye area (in^2)	9.4	5.4	12.3	14.1
Yield grade	2.8	1.2	5.9	31.9
Fat color[e]	3.2	1	5	27.9

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

[b]Mean based on 50-unit scale (40 = D°°, 30 = C°°).

[c]Mean based on 8-point rating scales (8 = light grayish red, very firm, very fine texture, very uniform distribution and very uniform size; 4 = moderately dark red, slightly soft, slightly coarse texture, slightly uneven distribution and slightly variable size).

[d]Mean based on 100-unit scale (70 = slightly abundant°°, 30 = slight°°).

[e]Mean based on 5-unit scale (5 = white, 1 = yellow).

Weights were taken at 10 minutes, 40 minutes and after a 22 hour oven drying (35° C) period (Fragmentation index = 100 X weight (g)). Volume of filtrate remaining following filtration was also recorded.

Expressible Juice

Duplicate, 500 mg samples of frozen longissimus muscle (steak B) were subjected to the press-filter paper absorption technique of Grau and Hamm (1953) as modified by Briskey et al. (1959). A Carver laboratory press was used to apply 4000 psi to each sample for 5 minutes. Percentage expressible juice was calculated using the Carpenter (1962) formula:

$$\text{Percent expressible juice} = 100 \left\{ \frac{\text{total juice area - meat film area}}{\text{total moisture (mg) in original muscle sample}} \times 44.07 \right\}$$

Sarcomere Length

Samples for sarcomere length (steak B) were blended in an Osterizer Cycle-Blend for 90 seconds. The suspension medium was 4 percent formalin (25 ml). A light microscope (1500 X) and filar micrometer were used to measure 10 sarcomeres on each of 12 myofibrils.

Meat Cookery

Sensory evaluation and shear force value were determined on steaks cooked, using thermocouples, to a final internal temperature of 70° C on individual, preheated broiling units. Steaks E and F (wrapped in polyethylene coated freezer paper, frozen at -23° C and stored at -4° C) were thawed for 24 hours in a 5-7° C cooler and weighed prior to cookery to facilitate calculation of percentage cook loss. A trained, eight-member sensory panel evaluated tenderness, juiciness, flavor desirability, connective tissue amount and overall satisfaction for each sample using 8-point rating scales (8 = extremely tender, extremely juicy, extremely desirable flavor, no connective tissue or extremely desirable overall; 1 = extremely tough, extremely dry, extremely undesirable flavor, abundant amount of connective tissue or extremely undesirable overall). Four 1.3 cm cores were removed from corresponding steaks (cooled to 25° C) and sheared twice on a Warner-Bratzler shear machine.

Statistical Analysis

Statistical analysis included estimates of coefficients of determination, simple correlation coefficients, multiple and stepwise regression and discriminate analysis using the Statistical Analysis System (SAS) of Barr and Goodnight (1972).

CHAPTER IV

RESULTS AND DISCUSSION

Presented in Table 2 are means and coefficient of variation values for selected laboratory measurements. These values are in general agreement with those reported in the literature, although the coefficient of variation for percentage fat is higher than data reported by other investigators. The coefficients of variation were also relatively high for shear force value and tenderness rating. These data indicate that the population selected for this study did vary widely in tenderness (both shear and sensory rating) and suggest that sufficient magnitude of tenderness difference is present to allow a reliable estimation of the relationship between selected chemical, physical and histological traits to tenderness (Table 3).

Means and coefficients of variation for fragmentation index utilizing fresh and frozen longissimus muscle are presented in Table 4. These results show frozen fragmentation values (with the exception of filtrate volume) to be slightly less variable than fragmentation values for fresh muscle. It should be noted that repeatability between duplicate samples fragmented in the laboratory was superior for fresh in comparison to frozen muscle samples.

Frozen longissimus samples lost approximately 50 percent more weight between weighing times (10 minutes, 40 minutes and 22 hours) than fresh samples (Table 4). In addition, frozen sample residue weights were 73.6 percent larger (22 hours) and, correspondingly, filtrate volumes were lower. A possible explanation for these observations may be the physical and chemical changes which occur when meat is frozen. Deatherage and

Table 2. Means and coefficients of variation for laboratory measurements

Measurement	Mean	C.V.[a]
Sarcomere length (μm)	1.82	7.0
Percentage fat (WTB)[b]	3.9	53.2
Percentage fat (MFB)[c]	14.2	46.9
Percentage moisture	73.3	2.7
Percentage expressible juice	52.2	9.9
Percentage cook loss	30.0	9.4

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

[b]WTB = whole tissue basis.

[c]MFB = moisture free basis.

Table 3. Means and coefficients of variation for shear force value and sensory palatability ratings

Trait	Mean	C.V.[a]
Shear force value (kg)	4.4	32.5
Sensory palatability ratings[b]		
tenderness	5.2	25.5
juiciness	5.2	11.3
connective tissue	7.0	11.0
flavor desirability	5.4	15.5
overall satisfaction	5.0	18.2

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

[b]Means based on 8-point rating scales (8 = extremely tender, extremely juicy, no connective tissue, extremely desirable flavor and extremely desirable overall satisfaction; 4 = slightly tough, slightly dry, moderate connective tissue amount, slightly undesirable flavor and slightly undesirable overall satisfaction).

Table 4. Means and coefficients of variation for fragmentation variables

Variable	Mean[a]	C.V.[b]
Fresh (10 min)	201.7	46.9
Fresh (40 min)	175.1	47.4
Fresh (22 hrs)	48.0	45.4
Fresh (filtrate volume, mls)	54.0	3.5
Frozen (10 min)	325.9	40.9
Frozen (40 min)	289.9	43.0
Frozen (22 hrs)	83.3	43.0
Frozen (filtrate volume, mls)	51.6	4.9

[a]Fragmentation index = 100 X weight (g) after air drying at 22° C (10 min and 40 min) and oven drying at 35° C (22 hrs).

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

Hamm (1960) have postulated that increased water holding capacity of frozen muscle is a result of small ice crystals which loosen the protein structure and thus increase the number of charged, water binding groups. Hiner et al. (1945) interpreted an increase in tenderness of frozen muscle as a rupturing of fibers and intestitial connective tissue by intrafibrillar ice formation. These seemingly conflicting results (freezing increases tenderness and fragmentation index) can be applied to fragmentation with little problem. Since freezing causes a decrease in the solubility of the sarcoplasmic proteins (Sizov, 1956; Kronman and Winterbottom, 1960), any observed increase in tenderness would be masked by the increased weight of the additional water bound. The overall residue weight (22 hours) would increase as the sarcoplasmic proteins remain with the salt-soluble proteins. This increased residue volume would logically decrease the filtrate volume by retaining more free water (solution) as a physical phenomenon. This "free" water would be lost during drying and therefore result in the greater weight loss observed for frozen samples (Table 4).

Simple correlation coefficients relating fragmentation index (fresh and frozen longissimus), shear force value and sensory tenderness rating to selected carcass traits are presented in Table 5. Fragmentation index of fresh muscle is significantly related to overall maturity, lean texture and fat color while frozen samples appear related to carcass weight and fat color. It is interesting to note that fat color correlates significantly ($P < .05$, $r = .23$) to skeletal maturity. While no significant relationships were found between shear force value and these carcass traits, the magnitude of the correlations using marbling

Table 5. Simple correlation coefficients relating measures of tenderness (fragmentation index,[a] shear force value and sensory tenderness rating) to selected carcass traits

Trait	Fresh fragmentation index				Frozen fragmentation index					
	10 min	40 min	22 hrs	filtrate volume (mls)	10 min	40 min	22 hrs	filtrate volume (mls)	Shear force value	Sensory tenderness rating
Marbling degree	.00	.01	.19	-.09	-.07	-.07	.09	.05	-.20	.22
Overall maturity	.24*	.26*	.21	-.29**	.13	.13	.06	-.16	.15	-.22
Carcass weight	-.18	-.17	-.04	.11	-.27*	-.27*	-.15	.27*	-.16	.26*
Adjusted fat thickness	.03	.05	.22*	-.13	.04	.03	.15	-.05	.00	.11
Lean texture	-.27*	-.26*	-.15	.31**	-.17	-.16	-.07	.20	-.21	.26*
Lean color	-.07	-.07	.03	.18	.02	.02	.13	.04	-.05	.07
Lean firmness	.02	.02	.17	.01	-.08	-.08	.03	.12	-.05	.01
Fat color	-.27*	-.27*	-.22*	.25*	-.21	-.22*	-.19	.26*	-.14	.17

[a]Fragmentation index = 100 X weight (g) after air drying at 22°C (10 min and 40 min) and oven drying at 35°C (22 hrs).

*$P < .05$.

**$P < .01$.

degree, adjusted fat thickness, lean color, lean firmness and lean color, lean firmness and lean texture are in agreement with similar data reported by Campion et al. (1975b). Correlation coefficients presented by Kroph and Graf (1959) are much higher in all comparisons in Table 5 except carcass weight. In this study, sensory tenderness rating and shear force value were similarily related to the various carcass traits. These data suggest that measures of tenderness and carcass traits of U. S. Commercial and U. S. Utility carcasses are generally not related.

Simple correlation coefficients relating measures of tenderness (fragmentation index, shear force value and sensory tenderness rating) to laboratory measurements are presented in Table 6. Correlation results shown in Table 6 suggest fresh and frozen fragmentation index are related to different attributes. Sarcomere length is significantly related to frozen fragmentation index, shear force value and sensory tenderness rating. Conversely, percentage fat and moisture are significantly related to the 22 hour fresh fragmentation index. Correlations of sacrcomere length and percentage fat to shear force value are in agreement with Berry et al. (1974b) while percentage expressible juice was more highly related to shear in the present study.

Simple correlation coefficients relating measures of tenderness (fragmentation index, shear force value and sensory tenderness rating) to shear force value and sensory palatability ratings are displayed in Table 7. In every case except connective tissue amount, correlation coefficients are higher for fragmentation index of frozen muscle than for fresh muscle. Fragmentation of fresh *longissimus* muscle was more highly related to lean texture (Table 5). This would indicate that

Table 6. Simple correlation coefficients relating measures of tenderness (fragmentation index,[a] shear force value and sensory tenderness rating) to laboratory measurements

	Fresh fragmentation index				Frozen fragmentation index					
Trait	10 min	40 min	22 hrs	filtrate volume (mls)	10 min	40 min	22 hrs	filtrate volume (mls)	Shear force value	Sensory tenderness rating
Sarcomere length	-.16	-.17	-.13	.27*	-.26*	-.26*	-.21	.34**	-.30**	.30**
Percentage fat (WTB)[b]	.09	.12	.32**	-.14	-.02	-.02	.17	.03	-.19	.20
Percentage fat (MFB)[c]	.09	.12	.32**	-.14	-.04	-.04	.15	.05	-.20	.21
Percentage moisture	-.04	-.06	-.28*	.09	.05	.05	-.15	-.07	.22*	-.19
Percentage expressible juice	.06	.06	.12	.14	.13	.14	.18	.01	.17	-.22
Percentage cook loss	.08	.08	.20	-.03	.18	.20	.30**	-.09	.11	-.06

[a]Fragmentation index = 100 X weight (g) after air drying at 22°C (10 min and 40 min) and oven drying at 35°C (22 Hrs).

[b]WTB = whole tissue basis.

[c]MFB = moisture free basis.

$*P < .05$.

$**P < .01$.

Table 7. Simple correlation coefficients relating measures of tenderness (fragmentation index,[a] shear force value and sensory tenderness rating) to shear force value and sensory palatability ratings

	Fresh fragmentation index				Frozen fragmentation index					
Trait	10 min	40 min	22 hrs	filtrate volume (mls)	10 min	40 min	22 hrs	filtrate volume (mls)	Shear force value	Sensory tenderness rating
Shear force value	.60**	.60**	.53**	-.48**	.71**	.73**	.68**	-.72**	--	-.85**
Sensory palatability rating										
tenderness	-.60**	-.60**	-.52**	.43**	-.68**	-.69**	-.63**	.68**	-.85**	--
juiciness	-.08	-.07	-.04	.00	-.09	-.10	-.10	.04	-.17	.25*
connective tissue	-.44**	-.44**	-.35**	.31**	-.39**	-.39**	-.31**	.38**	-.42**	.66**
flavor desirability	-.36**	-.35**	-.18	.31**	-.39**	-.38**	-.20	.38**	-.44**	.52**
overall satisfaction	-.56**	-.55**	-.42**	.41**	-.60**	-.60**	-.47**	.60**	-.73**	.90**

[a]Fragmentation index = 100 X weight (g) after air drying at 22°C (10 min and 40 min) and oven drying at 35°C (22 hrs).

*P < .05.

**P < .01.

lean texture was significantly related to sensory connective tissue rating (P <.01, r = .29) and that fresh fragmentation more accurately measures this component of tenderness than does frozen fragmentation.

Fragmentation index, regardless of sample preparation, has a higher relationship to shear force value than to sensory tenderness rating. Any single fragmentation measure accounts for approximately 23 (fresh filtrate volume) to 53 percent (frozen 40 minute index) of the variation in shear force value in comparison with 18 (fresh filtrate volume) to 48 percent (frozen 40 minute index) for sensory tenderness rating. Nevertheless, a correlation coefficient of 0.85 between shear force value and sensory tenderness rating is higher than correlations reported by Campion et al. (1975b), Breidenstein et al. (1968) and Goll et al. (1965).

Juiciness was the only palatability attribute not significantly correlated to any fragmentation measure. All other palatability attributes were highly related to fragmentation.

From the data presented in Tables 5, 6 and 7, it can be concluded that fragmentation primarily measures an aspect of tenderness that cannot be completely explained by various carcass traits and certain laboratory measurements. Moreover, it is evident that fresh fragmentation and frozen fragmentation do not measure identical characteristics. Data presented in Table 8 show the degree of multi-colinearity between all fragmentation measures. The relationships between fresh fragmentation variables to frozen fragmentation variables range from -.58 to 0.72 (Table 8). In general, the relationships reported in Table 8 were high, which was expected.

Table 8. Simple correlation coefficients for fresh and frozen fragmentation index[a]

Index	Variable code	Variable Code						
		2	3	4	5	6	7	8
Fresh (10 min)	1	.99**	.94**	-.86**	.71**	.72**	.68**	-.70**
Fresh (40 min)	2		.95**	-.87**	.71**	.72**	.68**	-.70**
Fresh (22 hrs)	3			-.81**	.68**	.69**	.72**	-.64**
Fresh (filtrate volume)	4				-.62**	-.62**	-.58**	.70**
Frozen (10 min)	5					.99**	.95**	-.93**
Frozen (50 min)	6						.96**	-.93**
Frozen (22 hrs)	7							-.88**
Frozen (filtrate volume)	8							--

[a]Fragmentation index = 100 X weight (g) after air drying at 22°C (10 min and 40 min) and oven drying at 35°C (22 hrs).

**$P < .01$.

Coefficients of determination for multiple regression equations predicting shear force value and sensory tenderness rating using subsets of carcass traits are presented in Table 9. While lean texture and marbling degree comprise the best two-variable model for predicting shear force value, the best two-variable model for predicting sensory tenderness rating contains skeletal maturity and lean texture. Equations for predicting tenderness rating all contain skeletal maturity while no maturity variable is included in shear force equations. This may be due to the correlation between skeletal maturity and connective tissue amount ($P < .01$, $r = -.47$) which some believe is a component of tenderness that the Warner-Bratzler shear does not effectively measure. In addition, marbling degree is included in all shear force prediction equations, but does not appear in tenderness rating equations except the five-variable model.

The full model of carcass traits accounts for 13.2 percent more of the variation in shear force value than does the best five-variable model. Conversely, the best five-variable equation for predicting tenderness rating accounts for as much of the variation in sensory tenderness (32.05 percent) as the full model accounts for in shear force value.

These date indicate that greater variation may be explained in tenderness rating than in shear force value when a limited number of carcass traits are included in the regression equation.

Coefficients of determination for multiple regression equations predicting shear force value and sensory tenderness rating using subsets of laboratory measurements are displayed in Table 10. Optimum, two-

Table 9. Coefficients of determination (R^2 X 100) for multiple regression equations predicting shear force value and sensory tenderness rating using subsets of carcass traits

Variables in Subset	Dependent variable					
	Shear force value			Sensory tenderness rating		
	Variables[a]	C.D.[b]	S.E.E.[c]	Variables[a]	C.D.[b]	S.E.E.[c]
15	Full model	32.05	2.87	Full model	38.97	1.10
5	6, 7, 11, 12, 15	18.85	2.86	1, 2, 7, 11, 13	32.05	1.06
4	7, 11, 12, 15	17.62	2.86	1, 2, 7, 13	29.80	1.07
3	7, 11, 15	13.59	2.90	1, 2, 13	25.70	1.09
2	7, 11	10.60	2.93	2, 7	18.96	1.13

[a]Variable code for carcass traits:

1 = Loin thoracic percent ossification	6 = Lean firmness	11 = Marbling degree
2 = Skeletal maturity	7 = Lean texture	12 = Fat color
3 = Lean maturity	8 = Marbling texture	13 = Carcass weight
4 = Overall maturity	9 = Marbling distribution	14 = Ribeye area
5 = Lean Color	10 = Marbling size variability	15 = Adjusted fat thickness

[b]C.D. = coefficient of determination.

[c]S.E.E. = standard error of the estimate.

Table 10. Coefficients of determination (R^2 X 100) for multiple regression equations predicting shear force value and sensory tenderness rating using subsets of laboratory measurements

Variables in Subset	Dependent variable					
	Shear force value			Sensory tenderness rating		
	Variables[a]	C.D.[b]	S.E.E.[c]	Variables[a]	C.D.[b]	S.E.E.[c]
6	Full model	20.38	2.95	Full model	18.64	1.23
5	1, 3, 4, 5, 6	19.39	2.95	2, 3, 4, 5, 6	18.28	1.23
4	3, 4, 5, 6	19.33	2.93	3, 4, 5, 6	18.13	1.22
3	3, 4, 5	16.77	2.96	3, 4, 6	17.20	1.22
2	4, 6	12.60	3.01	4, 6	14.52	1.23

[a]Variable code for laboratory measurements:

1 = Percentage fat (whole tissue basis)
2 = Percentage fat (moisture free basis)
3 = Percentage moisture
4 = Sarcomere length
5 = Percentage cook loss
6 = Percentage expressible juice

[b]C.D. = coefficient of determination.

[c]S.E.E. = standard error of the estimate.

variable equations for predicting tenderness (shear or sensory rating) contain identical variables (sarcomere length, percentage expressible juice), both of which require the least amount of time and sample to complete. The best four-variable models also contain similar measures and differ in the amount of variation explained by 1.05 percent. However, the amount of variation explained by the full model is relatively low (20.4 percent shear; 18.6 percent sensory tenderness).

These data suggest that limited benefit may be gained from use of various physical, chemical and histological measures in accounting for the observed variation in tenderness (Table 10).

Table 11 displays coefficients of determination for regression equations predicting tenderness (shear and sensory rating) using subsets of selected carcass traits, fragmentation measures (fresh and frozen) and laboratory measurements. All two, three and four variable equations contain one laboratory measurement while the remaining variables are fragmentation measures. These date emphasize the high percentage of tenderness variation which may be explained by fragmentation measures and underscore the limited benefit gained by use of carcass traits.

The optimum prediction equation for shear force value contains three variables (two fragmentation measures and percentage moisture) and accounts for approximately 60 percent of the observed variation. Equivalent coefficients of determination are shown for tenderness rating by use of a four-variable equation (Table 11).

Six carcass traits (marbling degree, overall maturity, carcass weight, adjusted fat thickness, lean texture and lean color), six

Table 11. Coefficients of determination (R^2 X 100) for multiple regressions equations predicting shear force value and sensory tenderness rating using subsets of selected carcass traits, fresh and frozen fragmentation measures and laboratory measurements

Variables in Subset	Dependent variable					
	Shear force value			Sensory tenderness rating		
	Variables[a]	C.D.[b]	S.E.E.[c]	Variables[a]	C.D.[b]	S.E.E.[c]
10	3, 4, 7, 8, 9, 10, 12, 13, 15, 17	68.06	1.92	2, 5, 7, 9, 11, 12 13, 15, 17, 19	65.30	0.83
5	4, 7, 10, 11, 14	62.61	2.01	7, 9, 13, 15, 17	62.41	0.83
4	6, 10, 11, 16	61.28	2.03	7, 9, 13, 15	60.77	0.84
3	10, 11, 16	60.06	2.05	7, 11, 14	54.44	0.90
2	11, 16	57.11	2.11	11, 14	51.09	0.93

[a]Variable code for selected carcass traits, fresh and frozen fragmentation measures and laboratory measurements:

1 = Marbling degree	7 = Fresh (40 min) index	13 = Frozen (filtrate volume)
2 = Overall maturity	8 = Fresh (22 hrs) index	14 = Percentage fat (whole tissue basis)
3 = Carcass weight	9 = Fresh (filtrate volume)	15 = Percentage fat (moisture free basis)
4 = Adjusted fat thickness	10 = Frozen (10 min) index	16 = Percentage moisture
5 = Lean texture	11 = Frozen (40 min) index	17 = Sarcomere length
6 = Fresh (10 min) index	12 = Frozen (22 hrs) index	18 = Percentage cook loss
		19 = Percentage expressible juice

[b]C.D. = coefficient of determination.

[c]S.E.E. = standard error of the estimate.

fragmentation measures (fresh and frozen index at 10 minutes and 40 minutes and filtrate volume) and six laboratory assays (sarcomere length and percentage fat, moisture, expressible juice and cook loss) were selected as candidate variables to develop prediction models for beef tenderness. The decisions regarding variable selection for this model were based on importance of carcass traits to final USDA grade (all quality and yield factors were considered), the simplicity and speed of the various fragmentation measures and increased precision and objectivity of certain laboratory assays which have been shown to be related to tenderness. Since six beef carcass traits can be evaluated rapidly, they were chosen to be included first in the regression model. Simultaneous consideration of these indicators accounted for approximately 14 percent and 21 percent of the variation in tenderness for shear force and tenderness rating, respectively (Table 12).

Because measures of fragmentation do not necessitate the time and skill required for completion of the laboratory assays, the six fragmentation variables were next added to the model. Partial coefficients of determination accounting for variation in shear force values and sensory tenderness (not previously explained by the carcass variables) were approximately 51 percent and 41 percent, respectively. The third major addition to the regression model was laboratory assays which increased the C.D. (R^2 X 100) by approximately 3 to 4 percent (Table 12). The magnitude of these increases were not significantly different from zero. Also, none of the partial regression coefficients from either the carcass traits or laboratory assays were significantly different from zero. Clearly, the fragmentation variables were more

Table 12. Coefficients of determination and partial coefficients of determination between dependent variables (shear force value and sensory tenderness rating) and selected independent variables (carcass traits, fragmentation index and laboratory assays)

	Dependent variable	
Model	Shear force value R^2 X 100	Sensory tenderness rating R^2 X 100
Carcass[a], fragmentation[b], laboratory[c]	68.05	65.76
Carcass	14.10	21.38
Fragmentation/carcass	50.56	40.72
Laboratory/carcass, fragmentation	3.40	3.66

[a]Carcass traits include marbling degree, overall maturity, carcass weight, adjusted fat thickness, lean texture and lean color.

[b]Fragmentation includes fresh and frozen measures of filtrate volume (mls) and indexes at 10 min and 40 min drying times.

[c]Laboratory assays include sarcomere length, percentage fat (whole tissue basis), percentage fat (moisture free basis), percentage moisture, percentage expressible juice and percentage cook loss.

highly related to beef tenderness than either the selected carcass traits or laboratory variables.

To further simplify and define a usable prediction equation for beef tenderness subsequent analyses were conducted from use of fresh and frozen fragmentation measures. It is realized that these measures are multicollinear. Due to ease of application, fresh fragmentation measures were included first in the predictive model and resulted in coefficients of determination of approximately 37 percent (shear) and 40 percent (sensory tenderness) (Table 13). Frozen fragmentation variables increased the explained variation in tenderness by 23.81 percent (shear) and 18.63 percent (sensory tenderness). These data suggest that fragmentation of frozen longissimus muscle may contain sufficient information to be utilized independently. Thus, a model containing frozen fragmentation measures accounted for approximately 58 percent to 49 percent of the variation in shear force value and sensory tenderness, respectively (Table 13). It appears the increased time required to freeze raw longissimus muscle prior to performance of the fragmentation procedure can be justified.

Following the logic of simplicity, speed and magnitude of relationship, Table 14 presents regression equations for predition of shear force value with use of fresh and frozen fragmentation measures. The best fresh fragmentation model contains one variable (10 minute index) with a coefficient of determination of 36.50 percent. Addition of a second variable contributed 0.71 percent to the model. Conversely, the best frozen fragmentation model contains two variables (10 minute and

Table 13. Coefficients of determination and partial coefficients of determination between dependent variables (shear force value and sensory tenderness rating) and selected models containing fresh and frozen fragmentation measures

Model	Dependent variable: Shear force value R^2 X 100	Dependent variable: Sensory tenderness rating R^2 X 100
Fresh fragmentation[a], frozen fragmentation[a]	61.06	58.14
Fresh fragmentation	37.25	39.51
Frozen fragmentation/fresh fragmentation	23.81	18.63
Frozen fragmentation	58.09	49.36

[a]Fresh fragmentation and frozen fragmentation includes measures of filtrate volume (mls) and indexes at 10 min and 40 min drying times.

Table 14. Regression equations (Y-intercept and beta coefficients) for predicting shear force value using fresh and frozen fragmentation measures

		Independent variables					
		Fresh fragmentation index[a]		Frozen fragmentation index[b]			
		beta coefficients					
Equation	Intercept	10 min	Filtrate volume (mls)	10 min	40 min	C.D.[b]	S.E.E.[c]
1	-10.3979	.0251	.2800			37.21	2.55
2	5.6886	.0203				36.50	2.55
3	5.1863			-.0478	.0696	56.57	2.12
4	4.3701				.0187	53.57	2.18

[a]Fragmentation index = 100 X weight (g) after air drying at 22°C (10 min and 40 min) and oven drying at 35°C (22hrs).

[b]C.D. = coefficient of determination (R^2 X 100).

[c]S.E.E. = standard error of the estimate.

40 minute index) and accounts for 56.57 percent of the variation in shear force value while the one variable subset reduces this value by 3.0 percent.

Identification of carcass traits which are related to sensory palatability ratings is the purpose of Table 15. These data indicate that skeletal maturity, lean texture and carcass weight are significantly related to sensory tenderness. These three carcass traits were included in a multiple regression equation (Table 9, page 22) and were contained in the best 4-variable predictive model. In addition, quality grade, percent kidney, pelvic and heart fat and ribeye area correlated significantly to tenderness rating, flavor desirability and overall satisfaction. None of the carcass traits evaluated were related to juiciness ratings.

All carcass traits significantly correlated to connective tissue amount were also related to overall satisfaction with the exception of fat color. These traits notably include all measures of maturity and lean texture.

Flavor desirability was significantly correlated to 12 of the 19 carcass traits. This would suggest that a multiple regression model containing these variables could be used to predict flavor desirability rating.

The distribution of short loin steaks (n = 65) in tenderness classes as determined by sensory panel ratings and all carcass traits are presented in Table 16. Among the 28 loin steaks which were rated "tough" (< 5.0 sensory rating), all 28 were classed as "tough" by a statistical model consisting of 19 carcass traits. Correspondingly, the

Table 15. Simple correlation coefficients relating sensory palatability ratings[a] to carcass traits

Carcass trait	Sensory palatability rating: Tenderness	Juiciness	Connective Tissue	Flavor Desirability	Overall Satisfaction
Loin thoracic percent ossification	-.20	.09	-.42**	-.19	-.25*
Skeletal maturity	-.29**	.09	-.47**	-.20	-.31**
Lean maturity	-.17	.08	-.24*	-.27*	-.27*
Overall maturity	-.22	.08	-.37**	-.28*	-.30**
Lean color	.07	-.05	.20	.28*	.20
Lean firmness	.01	-.11	.10	.37**	.19
Lean texture	.26*	.12	.29**	.39**	.39**
Marbling texture	.00	.09	-.01	-.04	-.01
Marbling distribution	.09	.09	.06	.13	.17
Marbling size variability	.00	-.07	.02	-.06	-.01
Marbling degree	.22	.15	.10	.39**	-.38**
Quality grade	.26*	.10	.19	.42**	.41**
Fat color	.17	-.01	.30**	.15	.20
Carcass weight	.26*	.05	.17	.45**	.35**
Fat thickness	.03	-.07	.04	.22	.13
Adjusted fat thickness	.11	.10	.19	.31**	.25*
Percent kidney, pelvic, heart fat	.36**	-.02	.35**	.40**	.43**
Ribeye area	.26*	.07	.27*	.36**	.36**
Yield grade	.13	.05	.15	.30**	.24*

[a]Scored on 8-point rating scales (8 = extremely tender, extremely juicy, no connective tissue, extremely desirable flavor and extremely desirable overall satisfaction; 4 = slightly tough, slightly dry, moderate amount of connective tissue, slightly undesirable flavor and slightly undesirable overall satisfaction).

*P < .05.

**P < .01.

Table 16. Distribution of short loin steaks (n=65) in tenderness classes[a] as determined by sensory panel ratings and all carcass traits[b]

Tenderness class	Total number of observations	Tenderness class by model: Tough number of observations	Tender number of observations
Tough	28	28	0
Tender	37	0	37
Total by model		28	37

[a]Tough <5.0 on 8-point sensory evaluation rating scale, tender $\geq$ 5.0.

[b]Carcass traits include loin thoracic ossification percent, skeletal maturity, lean maturity, overall maturity, lean color, lean firmness, lean texture, marbling distribution, marbling size variability, marbling degree, quality grade, fat color, carcass weight, fat thickness, adjusted fat thickness, percent kidney, pelvic and heart fat, ribeye area and yield grade.

same model classified all 37 "tender" samples as tender. These data suggest that use of all carcass traits can successfully segment carcasses into two tenderness groups. Since it is not practical to utilize 19 carcass traits to stratify carcasses according to tenderness level, a discriminate analysis was performed via use of a five-variable model (Table 17). Pooled variance was used in reducing these data. Use of skeletal maturity, overall maturity, lean texture, marbling degree and carcass weight in the discriminate model resulted in misclassification of 25 of 80 samples in comparison to panel tenderness rating. This included the misclassification of 16 "tough" samples as "tender" and 9 "tender" samples as "tough" (Table 17). Nevertheless, these results imply that a limited number of carcass traits may be useful in identification of carcasses which may be unacceptable in tenderness.

Results of a discriminate analysis using all carcass traits in a model to classify samples by their flavor desirability ratings are presented in Table 18. Within class variation was not significant, resulting in use of the pooled variance for this analysis. While identical results were not attained when compared to sensory flavor desirability ratings (undesirable < 5.0 on an 8-point rating scale), only 11 of 65 samples were misclassified (16.9 percent). Six of 48 desirably flavored steaks were misclassified, whereas 5 of 17 undesirably flavored samples were incorrectly segmented by use of the 19 variable model (Table 18). These data suggest that simultaneous consideration of 19 carcass traits could aid in the correct disposition of carcasses which are undesirable in flavor. Furthermore, these data indicate that approximately one-fourth of all U. S. Commercial and U. S. Utility

Table 17. Distribution of short loin steaks (n=80) in tenderness classes[a] as determined by sensory panel ratings and selected carcass traits[b]

Tenderness class	Total number of observations	Tenderness class by model: Tough number of observations	Tenderness class by model: Tender number of observations
Tough	34	18	16
Tender	46	9	37
Total by model		27	53

[a]Tough < 5.0 on 8-point sensory evaluation rating scale, tender ≥ 5.0.

[b]Carcass traits include skeletal maturity, overall maturity, lean texture, marbling degree and carcass weight.

Table 18. Distribution of short loin steaks (n=65) in flavor classes[a] as determined by sensory panel ratings and all carcass traits[b]

Flavor class	Total number of observations	Flavor class by model: Desirable number of observations	Flavor class by model: Undesirable number of observations
Desirable	48	42	6
Undesirable	17	5	12

[a]Desirable $\geq$ 5.0 on 8-point sensory evaluation rating scale, undesirable < 5.0.

[b]Carcass traits include loin thoracic ossification percent, skeletal maturity, lean maturity, overall maturity, lean color, lean firmness, lean texture, marbling texture, marbling distribution, marbling size variability, marbling degree, quality grade, fat color, carcass weight, fat thickness, adjusted fat thickness, percent kidney, pelvic and heart fat, ribeye area and yield grade.

carcasses utilized in the present study possessed unacceptable flavor. Identification of these carcasses would be of interest to certain steak operations which utilize steaks from U. S. Commercial and U. S. Utility carcasses.

CHAPTER V

CONCLUSIONS

The conclusions of the present study are as follows: (a) fresh or frozen fragmentation index of raw muscle is superior to certain carcass traits and/or laboratory assays in prediction of tenderness; (b) frozen fragmentation index accounts for approximately 20 percent more of the variability in tenderness than fresh fragmentations index; (c) the best regression model (considering C. D. and laboratory time) accounted for 56.6 percent of the variation in cooked product tenderness. Fragmentations, from use of this model, can be conducted in 40 minutes from use of frozen *longissimus* muscle; (d) carcass characteristics are successful in identifying carcasses which are unacceptable in tenderness and undesirable in flavor.

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