I. SOME MEASUREMENTS OF FIRMNESS OF BEEF MUSCLE

II. SOME RELATIONSHIPS OF FIRMNESS TO COMPOSITION AND CERTAIN PALATABILITY TRAITS IN BEEF MUSCLE

By

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INTRODUCTION

In meat terminology, quality is a collective term used to describe the character of the lean, fat and maturity of the carcass or cut. The quality of carcass beef, therefore, is a composite evaluation of the color, texture, firmness and marbling in the longissimus dorsi (ribeye) muscle. At the present time, these quality factors are evaluated visually. The United States Department of Agriculture grading standards for carcass beef (1956) placed great emphasis upon these quality attributes in determining Federal carcass grade. An example of the emphasis placed on one of the quality factors, namely firmness, is found in the official U.S.D.A. standards for carcass beef which sets forth the minimum requirements for U.S. Choice as follows: "Regardless of the extent to which other factors may exceed the minimum requirements for the grade, carcasses whose flesh is moderately soft and slightly watery are not eligible for the Choice grade".

Today, this nation is enjoying the highest standard of living in its history. Associated with this standard of living is an all-time high in the per capita consumption of beef. Furthermore, accompanying this standard of living and high per capita consumption of beef is a tendency for the consuming public to associate quality as determined by carcass grade with certain palatability characteristics in the beef they buy. The U.S.D.A. standards for carcass beef tend to minimize the variation in conformation, quality and finish of certain age beef carcasses within a grade. However, Cover and co-workers (1958) reported that a wide variation still exists in tenderness, flavor and juiciness of meat from beef carcasses in the same grade. Because of the wide variation in the palatability characteristics of beef within a grade, questions have arisen as to the justification for placing a great deal of emphasis on color, texture, firmness and marbling in beef grading.

Studies have been conducted in an effort to determine the relationship of marbling to the palatability traits of beef (Sartorius and Child, 1938; Cover et al., 1957; and Simone et al., 1959). The results of these and similar studies suggested that marbling is to a limited extent associated with tenderness. However, its primary effect appears to be the enhancement of flavor and juiciness of the cooked product.

Brady (1937) and Ramsbottom et al. (1945) have studied the relationship between the texture of beef lean and tenderness. The results of these studies indicated that "finer textured" beef lean is more tender than "coarse textured" lean.

Many studies have dealt with factors affecting the color of beef. However, there are few studies pertaining to the effect of the color of beef lean on the palatability of the cooked product.

Similarly, a limited amount of data is available which elucidates the relationship between the firmness, and tenderness, flavor and juiciness of beef lean.

REVIEW OF LITERATURE

The problem of measuring the firmness or softness of food products has perplexed researchers for many years. Some phases of the food industry have related the chemical properties of the product to firmness. An example of this procedure is the use of the iodine number and refractive index as they relate to the firmness of pork fat (Hiner and Hankins, 1941).

Black, *et al.* (1931) observed that a desirable piece of beef lean was smooth, fine grained and firm while the coarse grained, soft, rather wet beef was undesirable. However, no research data was presented to substantiate this claim.

The Tressler, Birdseye and Murray (1932) penetrometer method of measuring tenderness and the modified techniques employed by Tressler and Murray (1932) and Noble, *et al.* (1934) are considered by Doty (1959) to be essentially beef firmness studies.

Tressler, Birdseye and Murray (1932) reported a penetrometer technique for measuring the tenderness of beef. These workers used the depth of penetration by a needle into a 3/8 inch core of meat as a measure of tenderness. The needle, 1 3/8 inches long and 0.15 inches in diameter, was forced into the cylinder of meat under 255 grams of pressure. An eight hole box was used in place of the cylinder by Tressler and Murray (1932) to allow for more penetrometer readings from a single sample of meat. Their results with this modified method were more closely associated with organoleptic tenderness scores than with the Warner shear values or the tenderness values from their own devised cutting gage.

Noble, et al. (1934) modified the Tressler and Murray technique for measuring the tenderness of cooked beef. The modifications included a slightly smaller needle and a 205 grams weight.

Hiner and Hankins (1941) used the Tressler and Murray procedure to study the firmness of pork fat samples. These workers obtained a simple correlation coefficient of 0.90 between panel scores for firmness and penetrometer readings. Standards were then developed for measuring the firmness of pork fat by using the average of six penetrometer readings.

Gannaway (1955) used a ball with the penetrometer to measure the firmness of the lean in the face of fresh hams. He reported a simple correlation coefficient of 0.82 between panel firmness scores and penetrometer readings. In addition, the results indicated that the soft hams had a higher weight loss than the firm hams during the curing and smoking process. However, it was concluded that the amount of marbling in the ham face was as reliable an indicator of shrinkage during the curing process as was firmness.

Murphy (1959) observed that cuts with a comparable amount of marbling differed in firmness. He attributed the difference in firmness to the presence of microscopic fat.

Kropf and Graf (1959) reported the results of a beef quality study in which 334 beef carcasses were used. These workers reported simple correlation coefficients of 0.79 and 0.90 between a visual estimate of fat content and Warner-Bratzler Shear values and the visual firmness of the ribeye, respectively.

EXPERIMENTAL OBJECTIVES

The objectives of this study were:

1. to develop an objective measure of firmness in beef
2. to determine the relationship of firmness to certain palatability characteristics of cooked beef.

EXPERIMENT I

This experiment was conducted to study the relationship between objective and subjective measures of firmness in beef rib steaks.

Description of Objective Measure

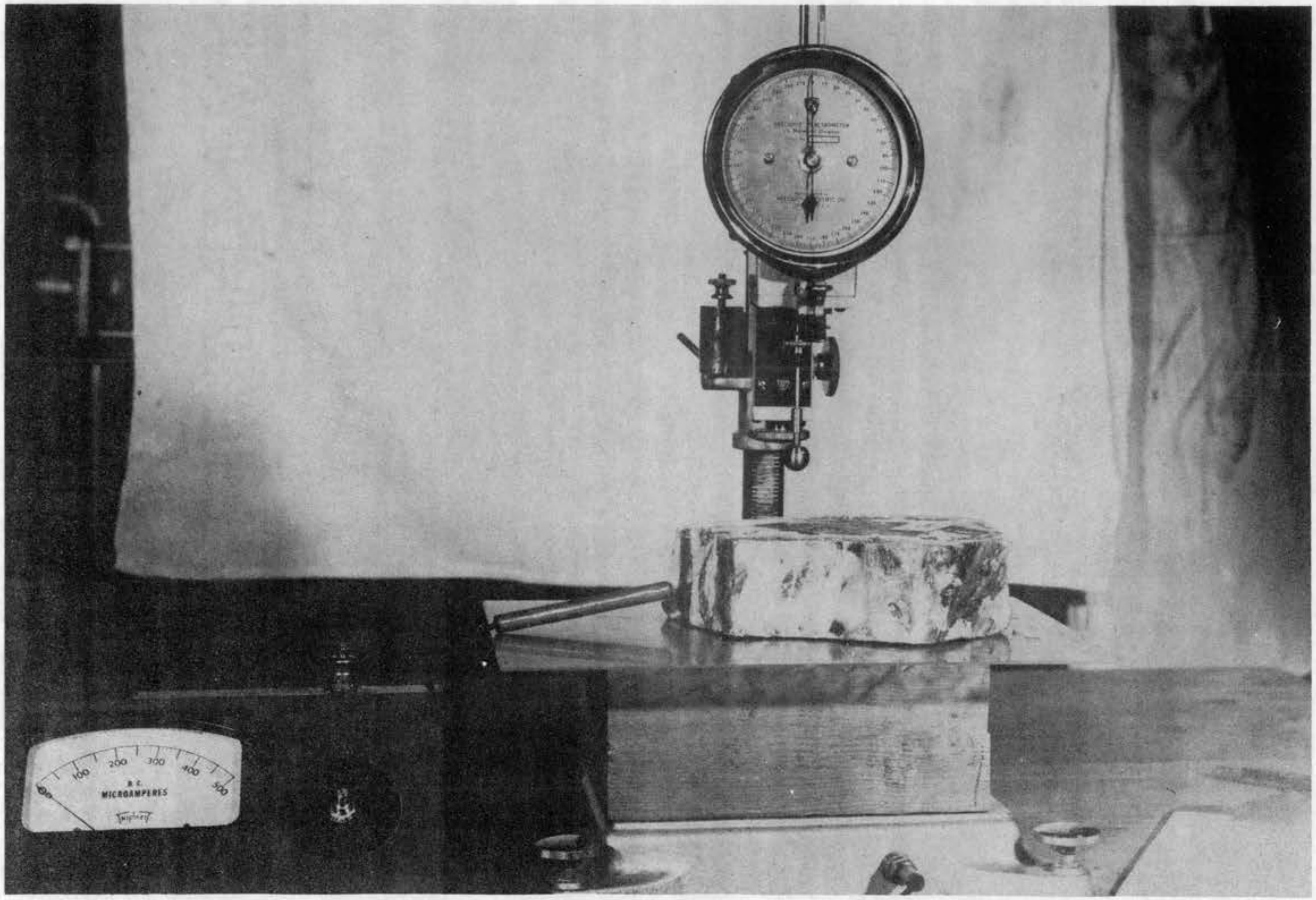
The "Precision" penetrometer (Plate I) was modified and used in these studies as an objective measure of firmness. Figure 1 illustrates the modified pressure heads used with the penetrometer. Table I presents dimensions of the modified pressure heads. The tips and balls used on the spike and ball pressure heads were made of steel. However, the extension on the single spike and the mounting plates for the multiple pressure heads were made of aluminum.

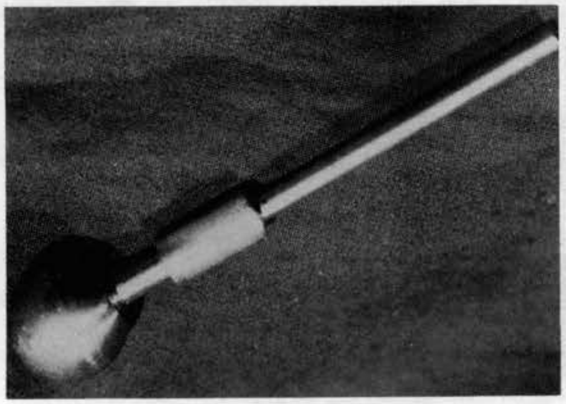
Depth of penetration in 1/10 millimeters for a standard time and pressure was used as the measure of firmness (i.e. resistance to pressure). A stop watch was used to determine the length of time for penetration.

To standardize the point of zero penetration for each measurement, the penetrometer was equipped with a microampmeter, powered by a 1½ volt battery. One electrode from the ampmeter was connected to the penetrometer and the other electrode was placed in the meat. When the pressure head came in contact with the meat, a complete electrical circuit was formed and a deflection was noted on the ampmeter. This point of contact was then used as the zero point of penetration.

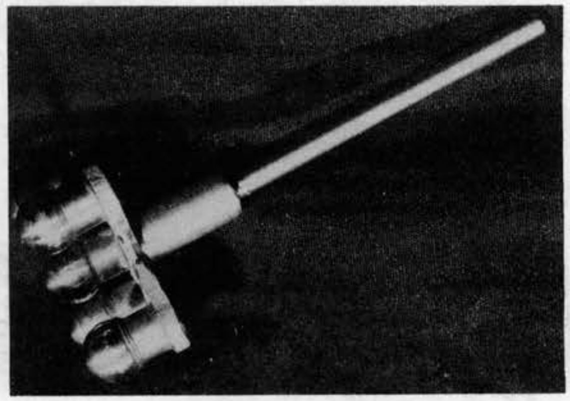
PLATE I

MODIFIED PRECISION PENETROMETER

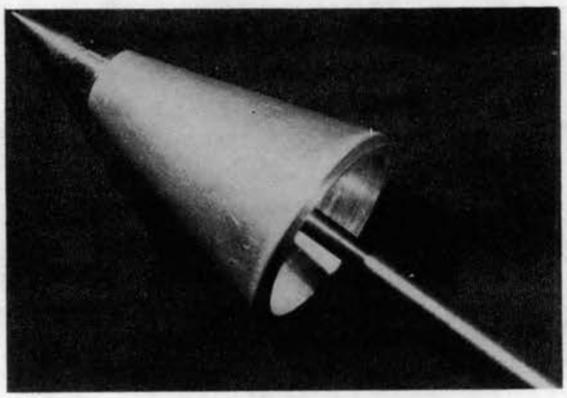




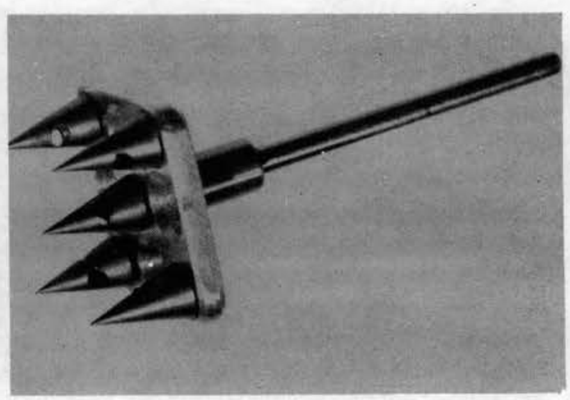
A (Single Ball)



B (Multiple Ball)



C (Single Spike)



D (Multiple Spike)

Figure 1. Modified Pressure Heads Used with the Precision Penetrometer

TABLE I

DIMENSIONS OF THE PRESSURE HEADS USED AS MODIFICATIONS OF THE PRECISION PENETROMETER

Ball Pressure Heads	Diameter mm.	Weight gms.	Size of Plate mm.
A	15.0	14.05	
B	7.0	14.38	2 X 23

Spike Pressure Heads	Diameter Top of Cone mm.	Length Tip mm.	Length Cone mm.	Weight gms.	Size of Plate mm.
C	25	15	32	12.84	
D	7	7		10.18	3 X 23

Experimental Procedures

I. Materials

Experimental materials used in this trial were one and one-half inch steaks from the seventh and eighth rib sections from the right and left sides of three U.S. Choice and seven U.S. Good, twenty-four month old beef carcasses.

II. Methods

The anterior surface of the eighth rib steaks was used for the measurement of firmness with the single and multiple ball pressure heads. Firmness measurements with the single and multiple spike pressure heads were obtained from the posterior surface of the seventh rib steaks.

A pilot study, using the single ball and single spike and time intervals of one, two, three, four, and five seconds, was conducted to determine the time for penetration. Results of this study indicated: 1. that the two second penetrometer readings had the highest simple correlation coefficient with visual firmness (0.70); and 2. that the average of the penetrometer readings for the lateral and dorsal ends of each steak was as highly associated with visual firmness as an average of the penetrometer readings of the dorsal, medial and lateral areas of the ribeye. From these results, it was concluded that penetrometer firmness readings would be obtained from the lateral and dorsal ends of the steaks using a penetration time of two seconds.

Penetrometer readings using the multiple ball and multiple spike were made in the medial portion of each steak.

Prior to the time at which subjective and objective measurements of firmness were obtained, the steaks were stored in a 34°F. cooler for twenty-four hours to allow them to reach a uniform internal temperature. To prevent moisture loss during this period, the steaks were covered with oxygenated paper and cover cloths.

For visual scoring of firmness by a panel, the seventh and eighth rib steaks were numbered from one to forty and placed on separate tables. A six member panel, consisting of graduate students and members of the staff, was used to visually estimate the firmness of the steaks. Before entering the cooler, each panel member was given a starting number between one and forty in order to partially compensate for variance in firmness of the ribeyes due to handling. Each panel member scored the steaks using the following seven point rank and word description scale: 1. very firm, 2. firm, 3. moderately firm, 4. slightly firm, 5. moderately soft, 6. soft, and 7. very soft.

Approximately one hour elapsed between visual scoring by the panel and the taking of penetrometer readings.

Results and Discussion

An analysis of variance was computed for each series of observations made in this experiment and is presented in Table II. The results of this analysis indicated statistically significant differences in firmness between the ribeyes as measured by the panel, and the single ball, single spike and multiple spike penetrometer readings. However, the multiple ball pressure head reading measured little difference in firmness between the ribeyes. In addition, the single ball data indicated that there were differences in firmness between the lateral and dorsal

TABLE II

ANALYSES OF VARIANCE FOR FIRMNESS MEASUREMENTS

Source	d.f.	Single Ball M.S.	Single Spike M.S.
Total	39		
Carcass	9	178.74**	596.40*
Position (dorsal and lateral)	1	616.23**	14.40
Side	1	7.29	302.50
S X C	9	32.66	156.61
P X C	9	28.34	89.84
Remainder	10	28.63	159.10

Source	d.f.	Multiple Ball M.S.	Multiple Spike M.S.
Total	19		
Carcass	9	20.31	87.24*
Side	1	3.2	16.20
Remainder	9	19.53	17.76

Source	d.f.	Panel Estimate M.S.
Total	39	
Carcass	9	134.97**
Steak	1	21.03
Side	1	0.23
C X Side	9	15.39
C X Steak	9	4.52
Remainder	10	10.98

**P $< .01$
*P $< .05$

ends of the same steak.

Since there were statistically significant differences in firmness as measured subjectively and objectively by three of the pressure heads, correlations were computed between these various measurements. The simple correlations obtained between the subjective scores and the three objective measures were as follows: 1. single ball, 0.90 (d.f. 18); 2. single spike, 0.71 (d.f. 18); and 3. multiple spike, 0.61 (d.f. 18). Also, the simple correlations between the single ball pressure head and the multiple and single spike pressure heads were 0.65 and 0.71 (d.f. 18), respectively.

Summary

Results of this experiment indicated different degrees of firmness in the ribeyes from the carcasses of ten two-year old beef animals. The degree of firmness was measured visually or by the single ball, single spike and multiple spike penetrometer pressure heads. The single ball pressure head measured differences in firmness between the lateral and dorsal ends of the steaks. The simple correlations between the panel estimate and the objective measures of firmness ranged from 0.60 to 0.90 (d.f. 18).

EXPERIMENT II

The purpose of this experiment was to determine the repeatability of the single ball and multiple spike pressure head measurements by using the adjacent surfaces of steaks from the same rib.

Experimental Procedures

I. Materials

Experimental material for this study consisted of one and one-half inch seventh and eighth rib steaks from the right ribs of twenty-four yearling steer carcasses. The carcasses were from four lots of cattle with similar breeding. However, part of the steers had been fed a high concentrate ration and a part fed a low concentrate ration. These cattle yielded carcasses ranging in weight from 399.0 to 634.0 pounds which graded from U.S. Standard to U.S. Choice.

II. Methods

The adjacent surfaces of the seventh and eighth rib steaks were used for duplicate readings for the visual and penetrometer firmness measurements. Procedures used in handling and obtaining the panel firmness scores, the single ball measurements and the multiple spike measurements were the same as those used in Experiment I. The data were analyzed (1) to determine if there were differences in firmness between the anterior surface of the eighth rib steak and the posterior surface of the seventh rib steak, and (2) to determine the precision of the penetrometer firmness measurements. Two basic assumptions were made in studying the precision of the firmness measurements: (1) that there was no difference in firmness between the adjacent surfaces of the two steaks, and (2) that the standard measure of firmness was the average panel firmness score. These data were statistically analyzed according to tests outlined by Snedecor (1956).

Results and Discussion

The analyses of variance for the firmness measurements obtained in this study are presented in Table III. These results indicated that there were differences in the firmness of the longissimus dorsi muscle among the different carcasses. Differences in firmness between the lateral and dorsal ends of the same steak were also measured by the single ball. No significant difference in firmness ($P > .05$) was found between the adjacent surfaces of the seventh and eighth rib steaks. The single ball results also suggested that there was an interaction between the steak (seventh and eighth) and the location (dorsal and lateral) at which the measurement was taken (Table III).

Simple correlations were computed between the panel firmness scores and the penetrometer measurements. These correlations were slightly lower than those found between the same measurements in Experiment I, panel firmness score and single ball, (0.82, d.f. 46) and panel firmness score and multiple spike, (0.40, d.f. 46). A Z transformation (Snedecor, 1956) was used to test the difference between these correlations. The results of this test indicated that the single ball was more highly correlated with the panel firmness scores than the multiple spike ($P < .025$).

TABLE III

ANALYSES OF VARIANCE FOR THE FIRMNESS MEASUREMENTS IN EXPERIMENT II

Source	d.f.	Single Ball M.S.	
Total	95		
Carcass	23	394.90**	
Position	1	4,830.84***	
Steak	1	11.34	
C X P	23	85.19	
C X S	23	55.34	
P X S	1	373.10**	
Error	23	45.44	
Source	**d.f.**	**Panel Estimate M.S.**	**Multiple Spike M.S.**
Total	47		
Carcass	23	127.46***	135.55***
Steak	1	4.08	0.19
Error	23	18.39	23.62

$^{**}P < .01$
$^{***}P < .001$

The repeatability of each firmness measurement was studied by computing simple correlation coefficients between the same measurements on the seventh and eighth rib steaks. The resulting correlations are presented in Table IV. Also, coefficients of determination were computed to study the percent of the variation in firmness in one of the steaks that was associated with the variation in firmness of the other steak (Table IV). These results indicated that these measurements of firmness (single ball, multiple spike and panel firmness scores) were accounting for approximately 55.0 percent of the variation in firmness in one steak with the variation of firmness in the other steak. Thus, the firmness variation in one of the steaks does not account for approximately 45.0 percent of the variation in firmness of the other steak.

This unaccountable variation could be due to (1) a low precision in the firmness measurements, and/or (2) an erroneous assumption that there was no difference in the firmness of the adjacent surfaces of the two steaks.

TABLE IV

REPEATABILITY OF THE FIRMNESS MEASUREMENTS

Observations	Single Ball	Multiple Spike	Panel Firmness Scores
Correlation Between 7th and 8th Rib Steak Measurements	0.76**	0.71**	0.75**
Coefficient of Determination (r^2)	0.58	0.50	0.56
Variation Not Accounted for ($1-r^2$)	0.42	0.50	0.44

**$P < .01$ (d.f. 22)

Simple correlations were also computed between the single ball measurements on the same steak and between the measurements taken in similar areas of the seventh and eighth rib steaks. The purpose of these correlations was to study the repeatability of the individual single ball measurements and to study the relationship of the lateral and dorsal measurements on each steak. Table V presents the results of these correlations. The correlations between the lateral and dorsal readings indicated that the firmness variation in one location accounted for 25.0 to 42.0 percent of the variation in firmness of the other location. However, the dorsal measurements were more repeatable than the lateral measurements ($P < .06$) as determined by a Z transformation to test the difference between correlation coefficients (Snedecor, 1956).

Furthermore, simple correlations were computed to study the relationship between the single ball and multiple spike readings (Table VI). A significant correlation ($P < .01$) was found between the multiple spike measurements and the single ball measurements taken on the eighth rib steaks. However, the relationship between the multiple spike and the single ball measurements on the seventh rib steaks was not significant ($P > .05$).

TABLE V

RELATIONSHIP BETWEEN THE SINGLE BALL DORSAL AND/OR LATERAL MEASUREMENTS ON THE SEVENTH AND/OR EIGHTH RIB STEAKS

Observations	Correlations	Coefficient of Determination (r^2)	Variation Not Accounted For ($1-r^2$)
Eighth Rib Steak			
Dorsal and Lateral	0.65**	0.42	0.68
Seventh Rib Steak			
Dorsal and Lateral	0.50**	0.25	0.75
Seventh and Eighth Rib Steaks			
1. Lateral Measurements	0.65**	0.42	0.68
2. Dorsal Measurements	0.88**	0.77	0.23

**$P < .01$ (d.f. 22)

TABLE VI

SIMPLE CORRELATIONS BETWEEN THE SEVENTH AND EIGHTH RIB STEAK MEASUREMENTS FOR THE SINGLE BALL AND MULTIPLE SPIKE READINGS

Observations	Correlations	Coefficient of Determination (r^2)	Variation Not Accounted For ($1-r^2$)
Lateral (S. Ball) & M. Spike			
Seventh Rib Steaks	0.25	0.06	0.94
Eighth Rib Steaks	0.64**	0.41	0.59
Dorsal (S. Ball) & M. Spike			
Seventh Rib Steaks	0.26	0.07	0.93
Eighth Rib Steaks	0.62**	0.38	0.62

**$P < 0.01$ (d.f. 22)

Summary

Experimental materials for this study consisted of the seventh and eighth rib steaks from twenty-four yearling steer carcasses. Differences in firmness were found between the carcasses when the firmness was measured by the single ball, multiple spike and panel firmness scores. No significant difference in firmness was observed between the adjacent surfaces of the seventh and eighth rib steaks.

Slightly lower correlations than in Experiment I were found between the panel firmness scores and the penetrometer firmness measurements. Using the panel firmness scores as the standard measurement of firmness, these results indicated that the single ball pressure head was more highly correlated with the standard measure of firmness than the multiple spike.

The repeatability of the different measures of firmness were found not to be high when the average of the single ball readings, average panel firmness scores and the multiple spike reading was studied. In addition, the correlations between the dorsal and lateral single ball readings indicated that the firmness reading at one location could not be used with accuracy to predict the firmness reading at the other location. Furthermore, the repeatability of the single ball dorsal readings was found to be significantly higher than the lateral readings. These data also suggested that the multiple spike reading was significantly correlated with the individual single ball measurements on the eighth rib steaks, but not with the single ball measurements on the seventh rib steaks.

EXPERIMENT III

The purpose of this experiment was to study the relationship between the firmness of the ribeye of beef and the palatability characteristics of beef rib steaks.

Experimental Procedures

I. Materials

Four separate trials were conducted in this study in which ten ribs per trial were studied. The ribs were chosen from the right sides of beef carcasses weighing from 627.0 to 681.0 pounds and visually estimated to be from two-year old cattle. All of the cattle had received stilbestrol, with the majority of them receiving it in the feed.

In each trial, five wholesale ribs were visually selected to be firm and five to be soft. Each wholesale rib was selected to fit into one of the above groups, regardless of the color, texture or degree of marbling in the ribeye.

II. Methods

Three days post slaughter, the wholesale ribs were cut into steaks. Table VII lists the thickness of cut and the observations made on each rib steak.

Immediately following cutting, the bone and excess fat covering were removed from the tenth rib steaks. These steaks were then quick

TABLE VII

THICKNESS AND OBSERVATIONS OBTAINED FROM EACH STEAK IN EXPERIMENT III

	12th Rib Steak	11th Rib Steak	10th Rib Steak	9th Rib Steak
Thickness (in.)	2	2	1½	2
Observations	(1) Panel Firmness Score	(1) Panel Firmness Score	Taste Panel Scores	Shelf-Life
	(2) Single Ball	(2) Single Ball	a. Tenderness	a. Weight Loss
	(3) Multiple Spike	(3) Multiple Spike	b. Flavor	b. Change in pH
	(4) Chemical Analysis a. Moisture b. Ether Extract	(4) Warner-Bratzler Shear	c. Juiciness	
	(5) Panel Marbling Scores	(5) Cooking Time		
		(6) Cooking Loss		

frozen and stored at $0^{o}F.$ for later analysis. The ninth rib steaks were prepared for the shelf-life study. However, the eleventh and twelfth rib steaks were handled the same as the steaks used for firmness measurements in the previous experiments, except that they were frozen for further studies after the subjective and objective measures were obtained.

Subjective and objective measures of firmness for each trial were obtained as previously described in Experiment I.

The degree of marbling was determined visually with the aid of the U.S.D.A. picture standards for the twelve degrees of marbling. For statistical analysis, numerical scores from one to twelve were assigned to the degrees of marbling, with one being devoid and twelve being extremely abundant.

Before freezing, the twelfth rib steaks were partially prepared for chemical analysis by removing the external fat, the bone and epimysium surrounding the longissimus dorsi muscle. A homogenous sample for chemical determination of fat and moisture was obtained by cutting the frozen ribeyes into strips with a power saw and running the strips through a hand grinder in a $28^{o}F.$ cooler. From this ground meat sample, a more homogenous sample was prepared by the use of a "Waring Blender". Aliquots from this sample were used for ether extract and moisture determinations with slight modifications to the A.O.A.C. methods (1945).

Similar thawing and cooking procedures were used in preparing the tenth and eleventh rib steaks for the taste panel testing and the Warner-Bratzler shear values. Approximately eighteen hours prior to cooking, the steaks were removed from $0^{o}F.$ storage and placed in a $45^{o}F.$ cooler for thawing. In following this procedure, the internal temperature of the steaks was 40 to 50°F. when placed in the broiler.

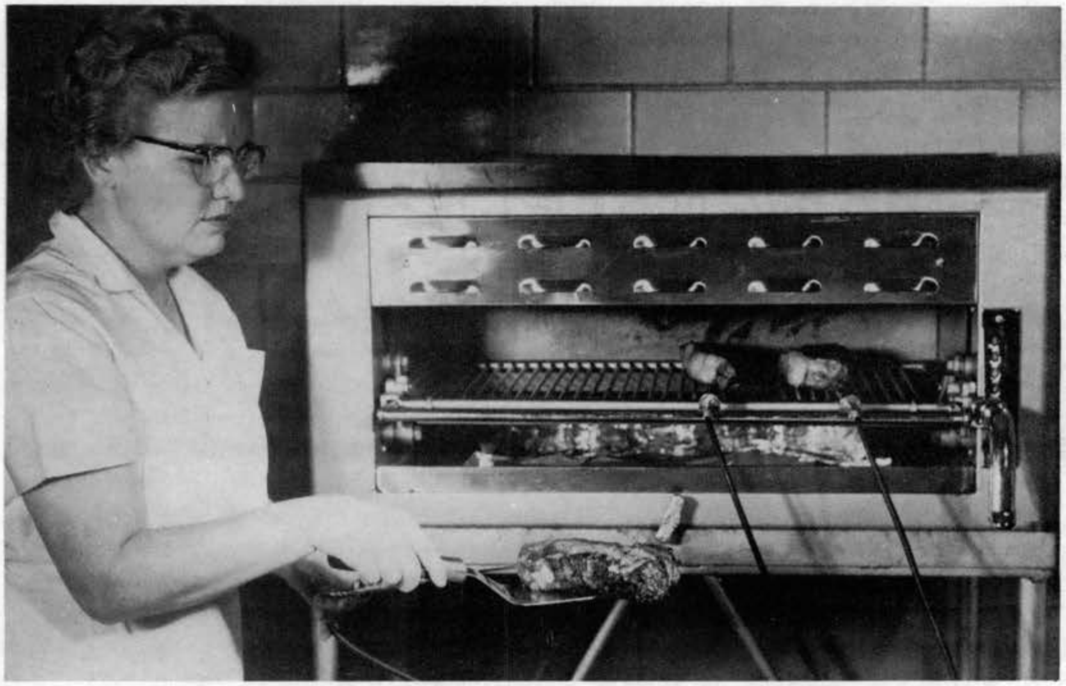
All the steaks were cooked in an open-faced, gas, griddle-broiler preheated to approximately 400°F. The broiler rack was adjusted so the top surface of the steaks was approximately three inches from the overhead flame (Plate II).

Before the steaks were placed in the broiler, thermocouples from a recording "Micromax" were placed as near the center of the steak as possible (Plate II). To obtain a uniform pink color in the center of the steaks, they were turned at an internal temperature of 90°F. and then cooked to an internal temperature of 150°F. as recommended by Sartorius and Child (1938).

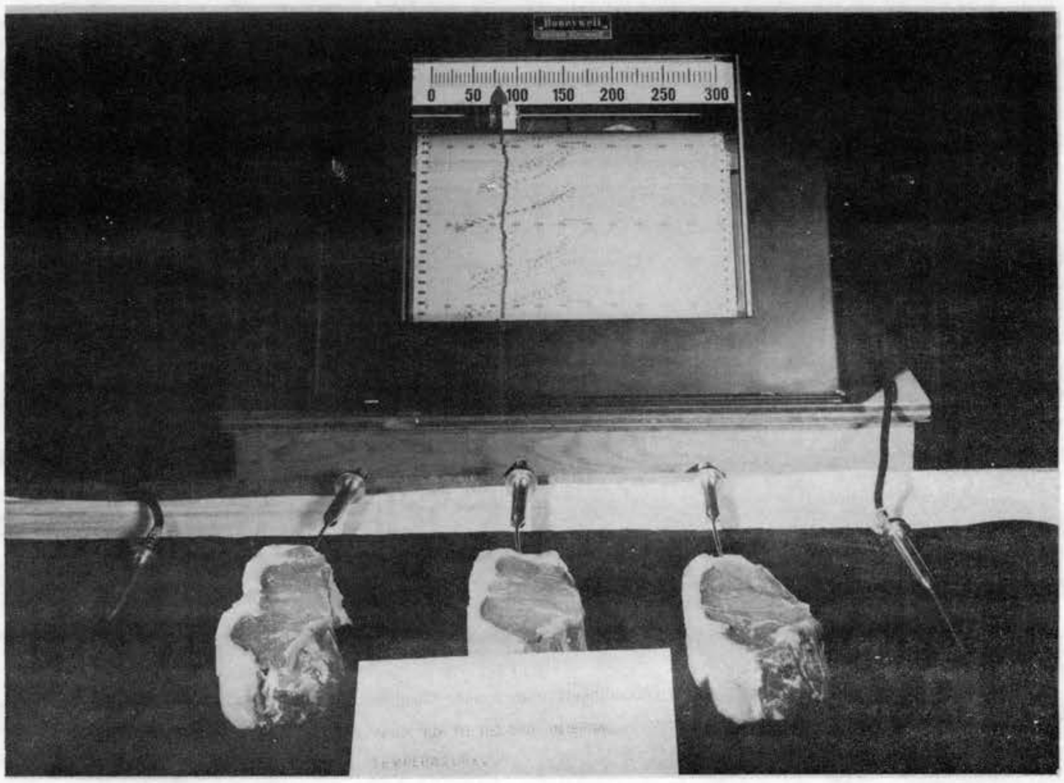
To more accurately estimate the weight loss during cooking which might be attributed to the firmness or softness of the ribeye all fat and bone were removed from the <u>longissimus dorsi</u> muscle. Cooking loss was determined by weighing the steaks to the nearest gram on a dial gram scale immediately before and after cooking. Cooking time to the nearest minute was determined from the time the steak went into the broiler until the internal temperature reached 150°F.

Steaks from Trials 1 & 2, and 3 & 4 to be used for Warner-Bratzler shear values were cooked on the same days. One inch cores from the dorsal, medial and lateral portions of each steak were used for shearing (Figure 2). The cores were removed parallel to the predominating muscle fiber direction in the meat as recommended by Cover <u>et al</u>. (1958). Three shear readings (recorded in pounds) were obtained from each core, with the average of the nine readings used as the objective tenderness measure for each steak.

PLATE II



1 - Steaks in an open-faced, gas, griddle-broiler



2 - Thermocouples inserted into steaks

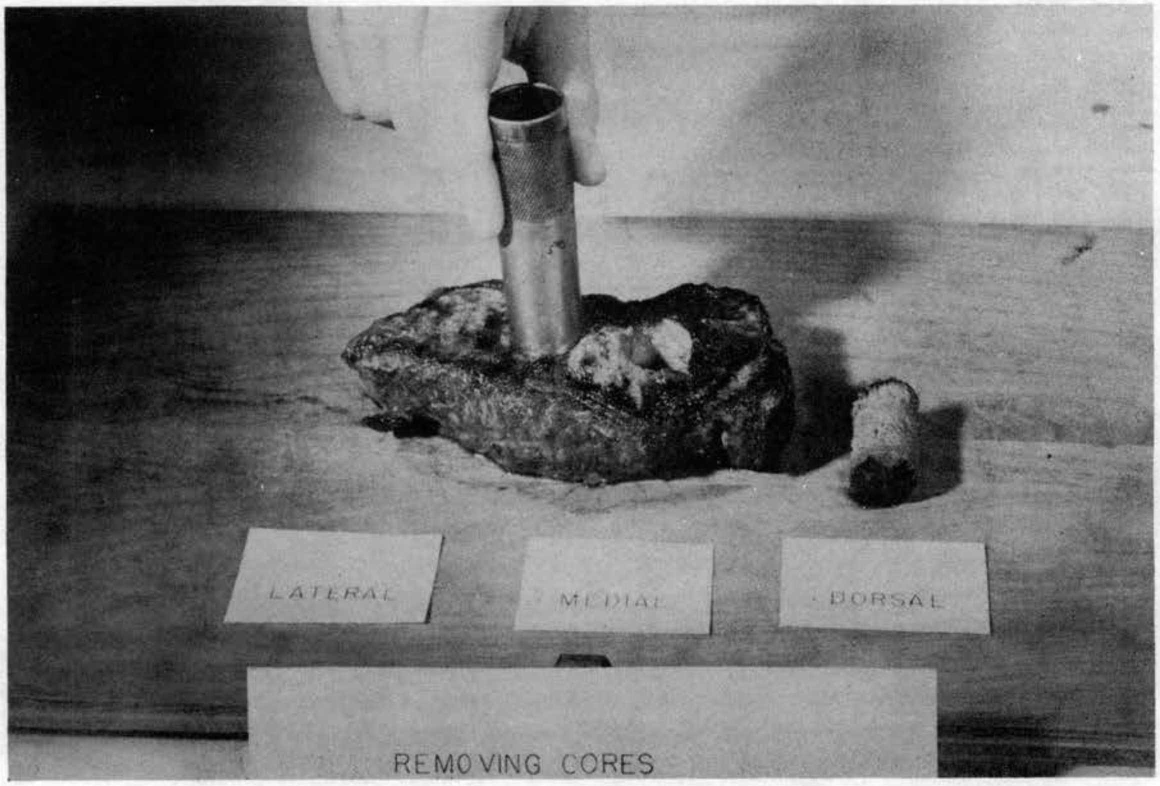


Figure 2. Position of Shear Cores

All the tenth rib steaks from one trial were sampled by a taste panel at two different sittings on the same day, 11:00 a.m. and 1:00 p.m., as recommended by Mitchell (1957).

A six member panel (staff and graduate students) experienced in determining the tenderness, flavor and juiciness of cooked beef were used in this study. Each panel member received a five-eighths inch core of meat from the lateral or dorsal end of each steak. During each sitting, a panel member received cores from the same portion of each steak. However, he did not receive cores from the same end of the steak at both sittings. Alternating the location of the core was done to compensate for any bias due to panel members. Between samples, bread and tepid water were served to remove tastes and sensations as a result of the previous sample.

Each panel member rated the palatability factors from one to eight, using the score sheet shown in Figure 3. The average of the panel members' estimate for each factor was used for statistical analysis.

The shelf-life phase of this experiment was conducted to study the relationship of firmness and the keeping quality of ribeyes under simulated meat market conditions. Approximately one hour after the steaks were cut, the pH of each steak was measured. The pH was determined by placing the electrodes from a "Beckman Zeromatic pH Meter" in the center of the ribeye, allowing a 60 second equilibration period, and then recording the pH. After each pH determination, the electrodes were rinsed with distilled water. To standardize the surface area and weight of each shelf-life sample, a 38 mm. X 50 mm. X 50 mm. section was removed from the center of each ribeye (Plate III). These sections were then cut in half (Plate III), placed in a 5 inch X 8 inch tared meat packaging tray and weighed to the nearest gram. The package was wrapped in M.S.A.T. 80 cellophane, heat sealed, and placed under 37 foot-candles of florescent light in a 45^{o}F. cooler. After five days, the packages were weighed and the pH determined. However, the final pH was the average reading from the two pieces of ribeye from each rib.

The statistical analysis of this experiment was computed according to Snedecor (1956).

Results

I. Analysis of Variance

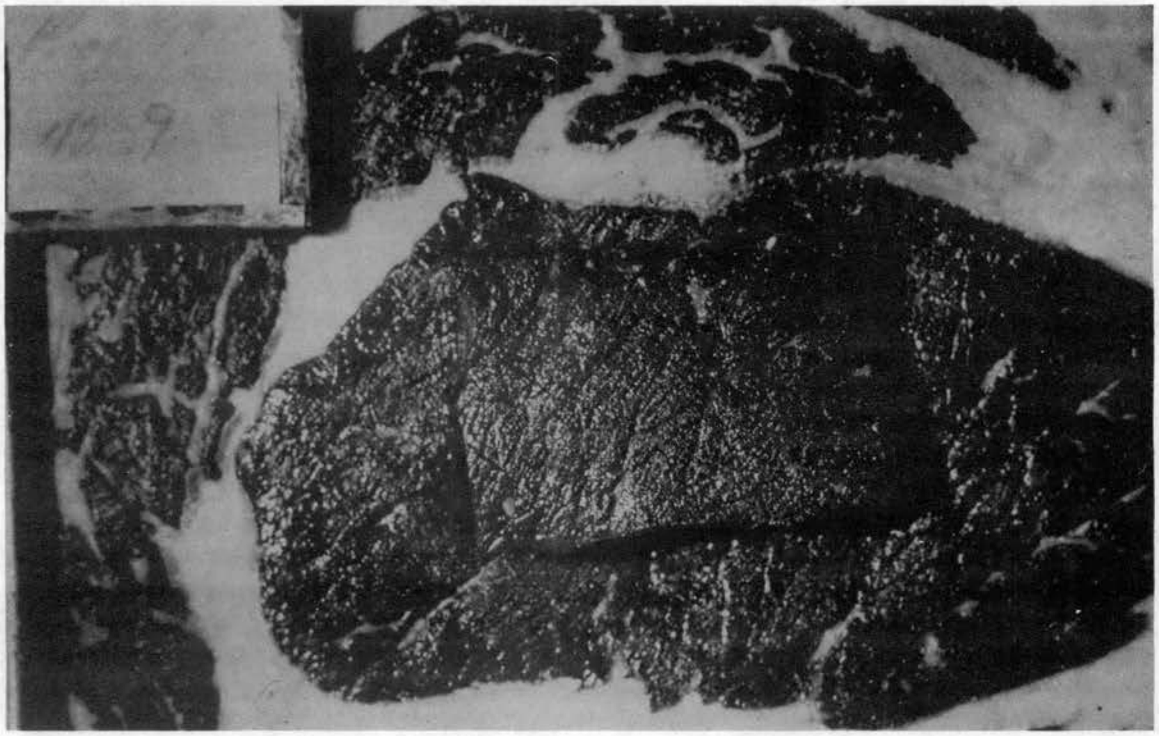
The analysis of variance for each series of observations was designed to study the differences between the measurements made on the soft and firm

SCORE SHEET
FOR
QUALITY FACTORS

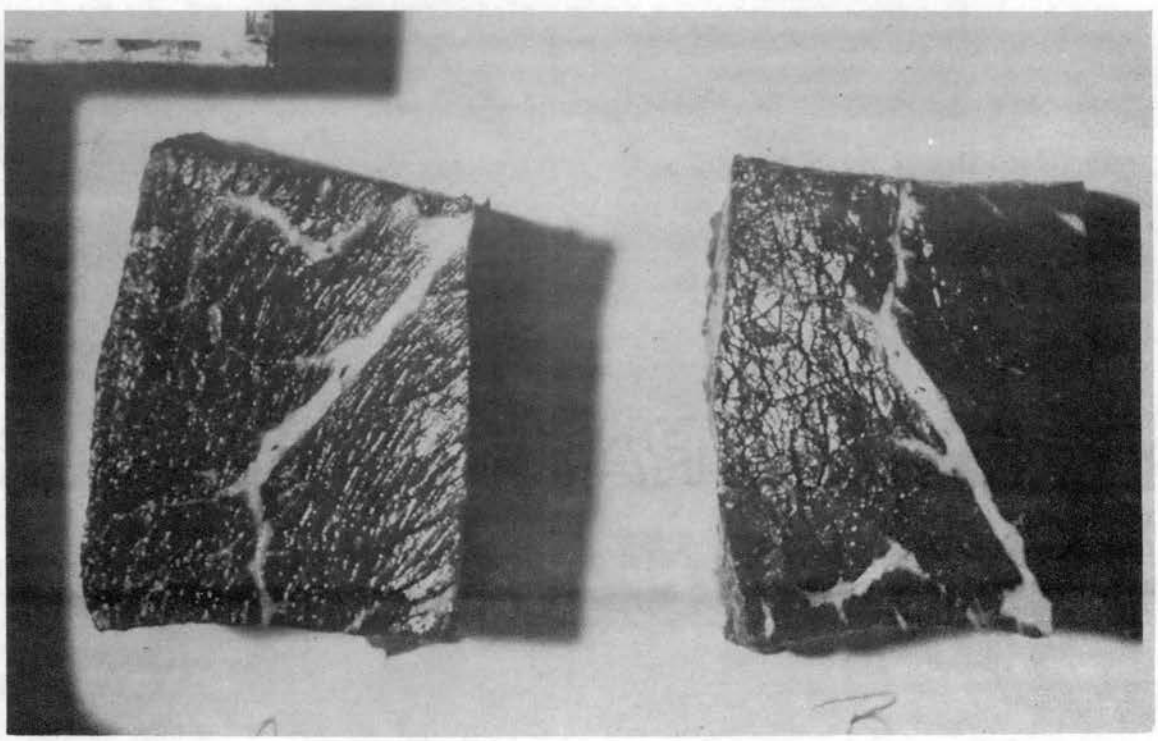
	TENDERNESS		FLAVOR		JUICINESS
8. Extremely Tender		Extremely Desirable		Extremely Juicy	
7. Very Tender		Very Desirable		Very Juicy	
6. Moderately Tender		Moderately Desirable		Moderately Juicy	
5. Slightly Tender		Slightly Desirable		Slightly Juicy	
4. Slightly Tough		Slightly Undesirable		Slightly Dry	
3. Moderately Tough		Moderately Undesirable		Moderately Dry	
2. Very Tough		Very Undesirable		Very Dry	
1. Extremely Tough		Extremely Undesirable		Extremely Dry	

Figure 3. Taste Panel Score Sheet

PLATE III



1 - Location of shelf-life sample



2 - A representative shelf-life sample

ribeyes. Therefore, the measurements obtained from each series of observations were divided into two groups. One group included the measurements obtained from the firm ribeyes and the other group included the measurements obtained from the soft ribeyes. These two firmness groups were established at the time the wholesale rib selections were made at the packing plant. Difference in firmness between the adjacent surfaces of the eleventh and twelfth rib steaks was also studied in this experiment. Inasmuch as the four trials were conducted over a period of three month's time, the wholesale ribs were selected from the carcasses of cattle which had been under different breeding and management practices. The effect of the time interval between trials was therefore removed from the error term in the analysis.

Results of the analysis of variance for the single ball measurements are given in Table VIII. These results indicated that the single ball pressure head measured differences in firmness between ribeyes from wholesale ribs intentionally selected for extremes in firmness and/or softness. Differences in firmness between the lateral and dorsal areas of the same steak were also measured by the single ball. No significant differences in firmness ($P > .05$) were measured by the single ball between the adjacent surfaces of the eleventh and twelfth rib steaks. However, an interaction was found between position (lateral or dorsal measurement) and steak (eleventh or twelfth). This indicated that differences in firmness were measured by the single ball between similar areas on the adjacent surfaces of the eleventh and twelfth rib steaks.

The two-way table for position and steak is presented in Table IX. These results indicated that the dorsal end of the steaks was generally firmer than the lateral end. However, the difference in the degree of firmness between the two ends of the steaks was larger for the twelfth than for the eleventh rib steaks.

TABLE VIII

ANALYSIS OF VARIANCE FOR THE SINGLE BALL MEASUREMENT

Source	d.f.	M.S.
Total	159	
Trial	3	286.27
Softness (firm vs. soft)	1	10112.40***
S X T	3	140.17
Between Carcasses[1]	32	135.28
Within Carcasses	120	36.01
Position (dorsal vs. lateral)	1	846.40***
Steaks (eleventh vs. twelfth rib)	1	34.22
St X P	1	119.03*
C X St X P[2]	117	28.39

***$P < .001$
*$P < .05$
[1]Estimate of σ^2 for testing the above observations between carcasses
[2]Estimate of σ^2 for testing the above observations within carcasses

TABLE IX

SINGLE BALL STEAK X POSITION TWO-WAY TABLE

Steak	Position[1,2]		Total
	Dorsal	Lateral	
Twelfth	1427.0	1680.0	3107.0
Eleventh	1459.0	1574.0	3033.0
Total	2886.0	3254.0	

[1]Depth of penetration in mm. (sum of 20 measurements)
[2]Deeper the penetration the softer the ribeye

Table X presents the analyses of variance for the panel firmness scores and the multiple spike measurements. These data indicated that there were differences in firmness between the longissimus dorsi muscles from the different wholesale ribs. Differences in firmness were also measured between the eleventh and twelfth rib steaks by the panel and the multiple spike. The data in Table XI suggested that the multiple spike measured the twelfth rib steaks to be firmer than the eleventh rib steaks. However, the panel firmness scores indicated that the eleventh rib steaks were firmest (Table XI).

TABLE X

ANALYSES OF VARIANCE FOR THE MULTIPLE SPIKE PRESSURE HEAD AND PANEL ESTIMATES OF FIRMNESS

Source	d.f.	Multiple Spike M.S.	Panel Firmness Scores M.S.
Total	79		
Trial	3	14.11	0.45
Softness	1	5968.51***	113.10***
T X S	3	28.95	0.85
Between Carcass[1]	32	94.25	0.75
Between Steaks	1	812.81***	1.62***
Within Carcass[2]	39	48.27	0.11

***$p < 0.001$

[1]Estimate of σ^2 for testing the above observations between carcasses
[2]Estimate of σ^2 for testing the above observation within carcasses

TABLE XI

AVERAGE MULTIPLE SPIKE MEASUREMENTS AND PANEL FIRMNESS SCORES FOR THE ELEVENTH AND TWELFTH RIB STEAKS

Firmness Measurement	Eleventh Rib Steak	Twelfth Rib Steak
Multiple Spike[1] (mm)	54.90	48.50
Panel Firmness Score[2]	3.14	3.42

[1]Deeper the penetration the softer the meat
[2]3.0 = Moderately firm, 4.0 = slightly firm

TABLE XII

ANALYSIS OF VARIANCE FOR SOME OBSERVATIONS IN EXPERIMENT III

Source	d.f.	Marbling Score M.S.	Percent Ether Extract M.S.	Percent Moisture M.S.	Percent Cooking Loss M.S.	Cooking Time M.S.	Wt.Loss M.S.	pH Change M.S.
Total	39							
Trial	3	0.23	4.77	0.31	14.11	119.69***	10.65	1.464***
Softness	1	119.03***	159.84***	93.79***	0.07	30.63**	2.69	0.002
T X S	3	4.49	5.41	1.77	1.13	5.56	1.55	0.011
Error	32	1.99	2.86	1.02	5.11	6.31	24.63	0.029

Source	d.f.	Warner-Bratzler Shear M.S.	Taste Panel Tenderness M.S.	Taste Panel Flavor M.S.	Taste Panel Juiciness M.S.
Total	79				
Trial	3	72.80**	0.84	0.23	0.27
Softness	1	85.34*	19.67***	2.81***	4.51***
S X T	3	69.17**	1.46	0.15	0.15
Between Carcasses	32	15.31	1.20	0.25	0.35
L X D	1	63.88***	2.33***	0.11	0.23
Within Carcass	39	4.38	0.22	0.075	0.23

***P < .001
**P < .01
*P < .05

The results of the analyses of variance for the remainder of the observations made in this experiment are presented in Table XII. A statistically significant difference in the fat content, both visually estimated marbling and percent ether extract, was found between the firm and soft ribs. The average marbling scores for the firm and the soft ribs were 5.6 (small to modest amount) and 9.05 (moderately abundant), respectively. Average percent ether extract was 5.05 for the soft ribeyes and 9.05 for the firm ribeyes.

Moisture content of the ribeye also appeared to be associated with firmness of the <u>longissimus</u> <u>dorsi</u> muscle. Soft ribeyes had an average of 71.56 percent moisture, while the firm ribeyes had slightly less moisture, 68.50 percent.

Tenderness, as measured by the Warner-Bratzler shear machine and a taste panel, appeared to be associated with firmness (Table XII). These tenderness measures indicated that the firm rib steaks were generally more tender than the soft rib steaks (Table XIII). However, the average of the Warner-Bratzler shear values for the soft and firm ribeyes in each trial indicated that the soft steaks were as tender or more tender than the firm steaks in Trials 1 and 4.

TABLE XIII

THE AVERAGE SCORE OR MEASUREMENT FOR PALATABILITY CHARACTERISTICS FROM SOFT AND FIRM RIB STEAKS

Wholesale Rib Group	Warner-Bratzler Shear Values[1]	Taste Panel Scores[2]		
		Tenderness	Flavor	Juiciness
Soft Rib Steaks	16.33	5.15	5.97	5.43
Firm Rib Steaks	14.24	6.14	6.34	5.90

[1]Pounds of force required to shear a one inch core of meat

[2]These values are based on the scoring sheet illustrated in Figure 3

The Warner-Bratzler shear values and the taste panel tenderness scores measured differences in tenderness between the lateral and dorsal ends of the rib steaks in this study (Table XII). However, these two tenderness measurements did not agree as to which end was the most tender. When tenderness was measured by the Warner-Bratzler shear machine, the results indicated that the dorsal end was the more tender. However, taste panel results suggested that the lateral end was more tender.

Flavor and juiciness, as evaluated by a taste panel, appeared to be influenced by the firmness and softness of the ribeyes (Table XII). Not only were the firmer ribs juicier, but they were more desirable in flavor (Table XIII).

Firmness of the ribeye appeared to have little relationship to cooking loss (Table XII). However, the steaks with the firmer ribeyes required approximately two minutes longer, on the average, to reach 150^{o}F. internal temperature.

The analysis of weight loss and changes in pH during the shelf-life period indicated that the firmness of the ribeye was not highly associated with these measures of storage change in rib steaks (Table XII). Trial appeared to have some effect upon the change in pH during the five day storage period.

II. Simple Correlations

Simple correlation coefficients were computed to study the degree of association between the firmness measurements and the observations that the analyses of variance indicated were associated with the firmness of the longissimus dorsi muscle of the wholesale rib. Also, simple correlation coefficients were obtained between each of the observations to study their degree of relationship. Since the analysis of variance for some of the measures indicated an affect due to the time interval between trials, the corrected sums of squares for each trial were pooled to compute the simple correlations for each measurement. An average of the measurements from the eleventh and twelfth rib steak was used to compute the corrected sums of squares for the penetrometer readings and the panel firmness scores. The average reading was used in these analyses because the results of the correlations in Experiment II indicated that there could be differences in firmness between the two rib steaks. It was assumed also that the average reading or score would give a more accurate estimate of firmness for the longissimus dorsi muscle in the wholesale rib region.

The simple correlation coefficients between the various measures used to study some of the effects and the factors relating to the firmness of beef ribeyes are presented in Table XIV. When the objective measures of firmness (the single ball and the multiple spike) were compared with the subjective estimate of firmness, simple correlations of approximately 0.90 (d.f. 34) were obtained. A similar correlation was found between the single ball and multiple spike pressure head measurements. However, it should be pointed out that the average measurement for the single ball is the average of four separate readings, while the multiple spike measurement is the average of two readings.

Firmness, as measured by the multiple spike and single ball was not highly correlated with the palatability characteristics of the broiled rib steaks (Table XIV). However, the panel firmness scores were significantly correlated (r = 0.33 to 0.45, d.f. 34) with the tenderness, flavor and juiciness of the broiled rib steaks.

TABLE XIV

SIMPLE CORRELATIONS BETWEEN THE OBSERVATIONS EXPERIMENT III
ASSOCIATED WITH FIRMNESS

	% Ether Extract	Single Ball	Panel Firmness Score	Marbling Score	Multiple Spike	Tenderness	Flavor	Juiciness	Percent Moisture
Shear	-0.57**	0.16	0.28	-0.52**	0.15	-0.74**	-0.58**	-0.41*	0.54**
% Ether Extract		-0.64**	-0.78**	0.88**	-0.68**	0.57**	0.44**	0.59**	-0.88**
Single Ball			0.94**	-0.69**	0.92**	-0.28	-0.25	-0.40*	0.73**
Panel Firmness Score				-0.78**	0.93**	-0.40*	-0.33*	-0.45**	0.81**
Marbling Score					-0.72**	0.57**	0.49**	0.64**	0.82**
Multiple Spike						-0.27	-0.28	-0.28	0.74**
Tenderness							0.68**	0.68**	-0.63**
Flavor								0.52**	-0.50**
Juiciness									-0.60**

**$P < .01$ (d.f. 34)
*$P < .05$ (d.f. 34)

Fat and moisture content of the _longissimus dorsi_ muscle were found to be highly associated with the firmness of the muscle (Table XIV). Although the correlation between percent ether extract and panel firmness scores of 0.88 suggested that percent ether extract had the most influence on the firmness of the lean, the penetrometer readings were more closely correlated with the percent moisture of the lean ($r = 0.73$ and 0.74). Similar simple correlation coefficients were found between the three firmness measurements and the panel marbling scores.

Fat content was also found to influence the tenderness, flavor and juiciness of the broiled steaks (Table XIV). These results indicated that tenderness and juiciness were more closely related to the fat content of the meat than was flavor.

The correlations between the percent moisture of the lean and the tenderness and juiciness scores were approximately 0.60 (Table XIV). A slightly lower correlation (0.50) was found between percent moisture and the taste panel flavor scores.

Discussion

The analyses of variance for the palatability characteristics (tenderness, flavor and juiciness) indicated that they were associated with the firmness of the _longissimus dorsi_ muscle in the wholesale rib. Higher correlations were found between taste panel tenderness scores and firmness ($r \sim 0.30$) than between Warner-Bratzler shear values and firmness ($r \sim 0.20$). However, these were considerably lower correlations than were found between tenderness and firmness ($r = 0.68$ and 0.85) by Kropf and Graf (1959). The simple correlation coefficients between firmness and the taste panel flavor and juiciness scores were similar to the results obtained by Kropf and Graf (1959). Furthermore, the correlation of 0.74 between taste panel tenderness and Warner-Bratzler shear values was similar to correlations reported by Palmer et al. (1957), Hall et al. (1944) and Kropf and Graf (1959).

A high correlation was found between the fat content (percent ether extract and marbling scores) and the tenderness, flavor and juiciness of the broiled rib steaks. Although the correlation coefficients between the fat content and the tenderness and juiciness were higher than those reported by Cover et al. (1956), Wellington and Stouffer (1957) and Palmer et al. (1958), they did agree with the results reported by Mackintosh et al. (1936), Husaini et al. (1950) and Wilson et al. (1955). These data also indicated a relationship between fat content and flavor which agrees with the conclusions drawn from a study reported by Gaddis et al. (1950).

Fat content of the longissimus dorsi was also found to be highly correlated with the firmness of the muscle ($r = 0.88$, d.f. 34). These results agree with those reported by Branaman (1936), Hiner and Hankins (1941) and Gannaway (1955) where firmness of the lean was shown to increase with an increase in fat content. The correlation of -0.88 obtained between the percent moisture and the percent ether extract is similar to the conclusions drawn by Wilson et al. (1955) and Gannaway (1955) who found that as fat content of the lean increased, the percent moisture decreased. Furthermore, the correlation between marbling scores and percent ether extract (0.88) was higher than has been reported by Cover, Butler and Cartwright (1956), but similar to the correlations between these two fat measurements as reported by Palmer et al. (1958), Kropf and Graf (1959) and Wellington and Stouffer (1959).

Since statistically significant simple correlations were found between fat content and penetrometer readings, partial correlation coefficients were computed between firmness and tenderness holding fat content constant in order to determine if fat content was the major factor influencing tenderness (Table XV). The partial correlation coefficients resulted in a reversal of the sign and a total change of 0.40 to 0.50 units when compared to the simple correlation coefficients between the same observations. These results indicated that (1) factors in addition to and other than fat content also affect tenderness, and (2) rib steaks with higher penetrometer readings (softer steaks) are more tender than firmer rib steaks when the fat content of the lean is held constant. Factors, other than fat content, which have been shown to affect tenderness are the amount of connective tissue, Mackintosh (1936), Hall, et al. (1944), Husaini et al. (1950), Wilson et al. (1954) and Hiner et al. (1955); age of the animal, Hiner (1953), Ramsbottom et al. (1945) and Simone et al. (1959); heredity, Cover et al. (1957) and Alsmeyer (1959); and texture of the lean, Brady (1937) and Ramsbottom et al. (1945).

The results of the analyses of variance for the penetrometer firmness measurements and the panel firmness score indicated that they were able to measure differences in firmness between visually selected extremes in firmness. However, the eleventh rib steak was indicated to be firmer when firmness was measured by the single ball and panel firmness scores. When firmness of the ribeye was measured by the multiple spike the twelfth rib steak was the firmer of the two steaks.

Differences in firmness, as measured by the single ball, were also observed between the lateral and dorsal ends of the rib steaks. These data indicated that the dorsal end of the ribeye was firmer than the

TABLE XV

COMPARISON OF THE SIMPLE CORRELATIONS AND THE PARTIAL CORRELATIONS (FAT CONSTANT) BETWEEN FIRMNESS AND TENDERNESS OF RIB STEAKS

	Partial Correlation Coefficients					
	Percent Ether Extract Constant			Marbling Score Constant[1]		
Firmness	Single Ball[2]	Multiple Spike[2]	Firmness Score[3]	Single Ball	Multiple Spike	Firmness Score
Tenderness						
1. Warner-Bratzler Shear[4]	-0.33	-0.40*	-0.32	-0.32	-0.38*	-0.24
2. Taste Panel[5]	0.14	0.20	0.13	0.19	0.24	0.10

Simple Correlation Coefficients

Firmness	Single Ball	Multiple Spike	Firmness Score
Tenderness			
1. Warner-Bratzler Shear	0.16	0.15	0.28
2. Taste Panel	-0.28	-0.27	-0.40*

*$P < .05$ (d.f. 34)

[1]Scored from 1 to 12 with 12 = extremely abundant

[2]Measured in 1/10 mm.

[3]Scored from 1 to 7 with 1 = very firm

[4]Pounds required to shear a 1 inch core of meat

[5]Scored from 1 to 8 with 8 = extremely tender

lateral end (Table XVI). However, the magnitude of the differences in firmness between the two ends is greater in the soft ribeyes than in the firm ribeyes. A possible explanation for the difference in the degree of firmness between the lateral and dorsal ends of the longissimus dorsi muscle from firm and soft wholesale ribs is that the distribution of marbling is different in the different areas of the muscle. The soft wholesale ribs were from carcasses having less marbling, with a greater part of the marbling generally in the dorsal end of the ribeye. However, the firm wholesale ribs were generally from higher finished cattle which had a more uniform distribution of marbling throughout the ribeye.

TABLE XVI

POSITION AND SOFTNESS TWO-WAY TABLE

Softness Group	Position[1,2]		Difference
	Dorsal	Lateral	
Firm	1176.0	1258.0	82.0
Soft	1710.0	1996.0	286.0
Total	2886.0	3254.0	

[1]Depth of penetration in mm. (sum of 20 measurements)

[2]Deeper the penetration the softer the ribeye

The results of the analysis of variance for the single ball pressure head also indicated that there was an interaction between the firmness of the dorsal and lateral measurements by the single ball on the adjacent surfaces of the eleventh and twelfth rib steaks. A similar interaction was found between the seventh and eighth rib steaks in Experiment II. No interaction was found between position and steaks in Experiment I where the posterior surface of the right and left eighth rib steaks was used for the single ball firmness measurements. Thus, the interaction occurred in this study when duplicate single ball measurements were taken on the adjacent surfaces of two rib steaks. This interaction could perhaps be due to an anatomical difference between the lateral and dorsal end of the longissimus dorsi muscle in a rib steak. It was noted when teasing apart the fibers of this muscle that a dense lumbo-dorsal fascia slip separated the muscle into two portions. Fibers dorsal to the slip appeared more parallel to the long axis of the muscle than those in the lateral end of the muscle. Also, the fibers did not appear as tightly packed in the lateral end of the ribeye as in the dorsal end. In addition, the longissimus dorsi muscle tapered in diameter, being somewhat larger at the posterior end and smaller at the anterior end of the wholesale rib. Therefore, pressure applied to the two ends of a steak would result in the fibers being pressed into the epimysium on one of the adjacent surfaces and away from the epimysium on the other surface. This could result in the differences in firmness readings by the single ball pressure head on similar areas of the ribeye of the adjacent surfaces of the two steaks.

Simple correlation coefficients were computed between the individual single ball measurements on the same rib steak. Also, simple correlations were computed between the lateral measurements on the eleventh and twelfth rib steaks and between the dorsal measurements on the eleventh and twelfth rib steaks. These correlations were computed in an effort to help explain inconsistencies in the single ball measurements. The difference between these simple correlation coefficients and those previously discussed is that the pooled sums of squares were not used to compute these correlations. Table XVII presents the correlations and coefficients of determination for these single ball measurements. These results indicated that the variation in firmness in the location on one of the steaks accounted for approximately 60.0 percent of the firmness variation in the same position on the adjacent steak. A similar relationship was found between the lateral and dorsal single ball measurements on the same steak.

TABLE XVII

SIMPLE CORRELATION COEFFICIENTS BETWEEN THE INDIVIDUAL SINGLE BALL MEASUREMENTS

Observations	Correlations	Coefficient of Determination (r^2)	Variation Not Accounted For ($1-r^2$)
Lateral and Dorsal			
1. 11th Rib Steak	0.82**	0.67	0.33
2. 12th Rib Steak	0.79**	0.62	0.38
11th and 12th Rib Steaks			
1. Lateral	0.78**	0.61	0.39
2. Dorsal	0.76**	0.58	0.42

**$P < .01$ (d.f. 38)

Simple correlation coefficients were also compared between the individual single ball measurements and the multiple spike measurements (Table XVIII). The purpose of these correlations was to determine if the one multiple spike measurement was as precise a measure of firmness as one of the single ball measurements. Regardless of the position of the steak, one penetrometer measurement accounted for approximately 43.0 percent of the variation in firmness measured by the other penetrometer measurement. Thus, these results indicate that either penetrometer pressure head could be used with equal precision if only one objective measure of firmness was made.

TABLE XVIII

SIMPLE CORRELATIONS BETWEEN THE INDIVIDUAL SINGLE BALL MEASUREMENTS AND THE MULTIPLE SPIKE MEASUREMENT ON THE ELEVENTH AND TWELFTH RIB STEAKS

Observations	Correlations	Coefficient of Determination (r^2)	Variation Not Accounted For ($1-r^2$)
11th Rib Steak			
1. Lateral with Multiple S.	0.79**	0.62	0.38
2. Dorsal with Multiple S.	0.73**	0.53	0.47
12th Rib Steak			
1. Lateral with Multiple S.	0.73**	0.53	0.47
2. Dorsal with Multiple S.	0.78**	0.61	0.39

**$P < .01$ (d.f. 38)

The repeatability of the firmness measures was studied by correlating the measurement on rib steak with the corresponding measure on the adjacent steak. Assumptions made in studying the repeatability of the firmness measures were the same as in Experiment II, namely that (1) there was no difference in firmness between the adjacent surfaces of the two steaks, and (2) the standard measure of firmness was the average panel firmness score. Table XIX presents the results of the correlations and the corresponding coefficients of determination. A $\underline{Z}$ transformation was used to test the differences between these correlations (Snedecor, 1956). The results of the $\underline{Z}$ transformation indicated that the single ball measurement was significantly more repeatable than the multiple spike measurement ($P < .05$). A significant difference was also found between the repeatability of the penetrometer measurements of firmness and the panel firmness scores ($P \sim .05$ and $P < .001$). Thus, these results do not agree with the data in Experiment II where the repeatability of all the measurements was similar and low.

TABLE XIX

REPEATABILITY OF THE FIRMNESS MEASUREMENTS

Observations	Single Ball	Multiple Spike	Panel Firmness Score
Correlation Between 11th and 12th rib steak measurements	0.86**	0.66**	0.94**
Coefficient of Determination (r^2)	0.74	0.44	0.88
Variation Not Accounted for ($1-r^2$)	0.26	0.56	0.12

**$P < .01$ (d.f. 38)

Hotelling's Test (1940) was used to study the difference between the penetrometer measurements of firmness at the eleventh or twelfth rib. For this test, the average single ball reading for each steak was used as the measure of firmness for this penetrometer head. Also, the average panel firmness score for each steak was used as the standard measure of firmness. Although the statistical probability for "t" is low (Table XX), the single ball pressure head measurements had a higher correlation coefficient with visual firmness at the eleventh or twelfth rib steaks than the multiple spike pressure head measurements. Thus, the results of this test and the repeatability of the penetrometer measurements indicate that the single ball pressure head is the more precise objective measure of firmness.

TABLE XX

HOTELLING'S TEST OF DIFFERENCE BETWEEN THE PENETROMETER MEASUREMENTS WITH THE PANEL FIRMNESS SCORES AS THE STANDARD MEASURE OF FIRMNESS

Observations	Simple Correlation Coefficient	Coefficient of Determination (r^2)	Variation Not Accounted For ($1-r^2$)
12th Rib Steak			
1. Panel Firmness Scores and			
a. Single Ball	0.90**	0.81	0.19
b. Multiple Spike	0.84**	0.71	0.29
2. Single Ball and Multiple Spike	0.81**	0.66	0.34
t = 1.53 (d.f. 33)			
11th Rib Steak			
1. Panel Firmness Scores and			
a. Single Ball	0.93**	0.86	0.14
b. Multiple Spike	0.91**	0.83	0.17
2. Single Ball and Multiple Spike	0.85**	0.72	0.28
t = 0.83 (d.f. 33)			

**$P < .01$

The results of the other phase of this experiment, namely the shelf-life phase, suggested that the trial influenced the pH during the five day storage period. A lower initial pH was found in the Trial 2 ribeye samples than was found in Trials 1, 3 and 4. The difference between the initial and final pH of the shelf-life samples indicated that the pH of the samples in Trial 2 became somewhat higher. However, the pH of the samples in the other three trials decreased. Similar changes in the pH during the storage of meat have been reported by Bate-Smith (1948), Paul (1952) and Wierbicki (1956).

Summary

This experiment was conducted to study the relationship between the firmness of the *longissimus dorsi* muscle and some palatability and chemical characteristics of this muscle in beef. Experimental material for this phase of the study consisted of forty wholesale ribs selected from the right side of carcasses from two-year old cattle. These wholesale ribs were selected for extremes in firmness and softness, regardless of the amount of marbling, color or texture of the ribeye.

Firmness of the ribeye was found to be associated with the tenderness, flavor and juiciness of the broiled rib steaks. The correlations between the firmness measurements (panel firmness scores, single ball and multiple spike) and palatability characteristics were approximately 0.30. Fat content as measured by marbling scores and percent ether extract was also found to be related to the palatability characteristics studied. The results, shown by the simple correlation coefficients, indicated that fat content had more influence on tenderness and juiciness of broiled rib steaks than on the flavor. Furthermore, the amount of marbling and percent ether extract of the *longissimus dorsi* muscle were found to exert a great influence upon the firmness of this muscle ($r \sim 0.70$). A correlation coefficient of 0.88 was obtained between the marbling scores and percent ether extract of the *longissimus dorsi* muscle.

Partial correlation coefficients were computed between the firmness measurements and tenderness measurements (Warner-Bratzler Shear and taste panel tenderness scores) holding fat content of the ribeye constant. The partial correlation coefficients differed from the corresponding simple correlation coefficients by (1) having the opposite sign, i.e. a positive simple correlation coefficient gives a negative partial correlation

coefficient, and (2) having a total change in the magnitude of the correlation coefficients of 0.40 to 0.50 units. These results indicated that (1) factors other than fat content of the lean were affecting the variation in tenderness accounted for by the firmness measurements, and (2) softer rib steaks are more tender than firmer rib steaks when the fat content of the lean is constant.

The influence of ribeye firmness or softness on the weight loss and change in pH during a five day storage period was also studied. Samples from the ribeye for this phase of the experiment were handled under simulated self-service meat market conditions. The results indicated that firmness of the lean had only a small influence on the weight loss and change in pH during the storage period. However, these results suggested that the initial pH of the steak influenced the final pH. Samples with a high initial pH decreased in pH during the storage period. The samples with a low initial pH had a higher pH at the end of the storage period.

Differences in firmness between the soft and firm wholesale rib groups were measured by the panel firmness scores, single ball and multiple spike. Significant differences in firmness between the adjacent surfaces of the eleventh and twelfth rib steaks were measured by the multiple spike and panel firmness scores. Although the multiple spike readings indicated that the twelfth rib steaks were the firmest, the average single ball readings and the panel firmness scores indicated that the eleventh rib steaks were the firmer of the two steaks. The single ball readings also indicated that the lateral end of the ribeye was significantly softer than the dorsal end. However, an interaction was found between the position (dorsal and lateral) and the steak (eleventh and twelfth).

Simple correlation coefficients were computed between the individual single ball measurements to help explain the inconsistency of the readings. The results indicated that the variation in firmness in one position accounted for approximately 60.0 percent of the firmness variation in the other position.

Comparisons were made between the multiple spike reading and the individual single ball readings for measuring firmness on the same steak. The results indicated that either penetrometer pressure head could be used with equal precision if only one objective measure of firmness was used.

Significant differences were found in the repeatability of the firmness measurements. The average panel firmness scores were more repeatable ($r = 0.94$) than the average of the single ball readings for each steak ($r = 0.86$). The multiple spike was found to have the lowest repeatability ($r = 0.66$).

Hotelling's Test indicated that there was no significant difference between the precision of the average single ball readings and the multiple spike readings on the same steak. However, the correlation between the average panel firmness score and the average single ball reading was higher than the correlation between the average panel firmness scores and the multiple spike reading.

These results suggest that the single ball is the most repeatable and precise of the two objective measures studied for measuring beef ribeye firmness.

SUMMARY

The objectives of this study were (1) to develop an objective measure of firmness in beef, and (2) to determine the relationship of firmness to certain palatability characteristics of cooked beef.

A total of seventy-four wholesale ribs was used in the three experiments reported in this study. Right and left seventh and eighth rib steaks from the carcasses of ten two-year old cattle were used in Experiment I. The adjacent surfaces of the seventh and eighth rib steaks used in Experiment II were from the right sides of carcasses from yearling steers. Wholesale ribs used in Experiment III were selected from the right sides of forty beef carcasses that were extremes in firmness and softness.

Single ball, multiple ball, single spike and multiple spike pressure heads were used as modifications of the Precision Penetrometer. The results of Experiment I indicated that the single ball, single spike and multiple spike pressure heads could measure differences in firmness among the ten wholesale ribs. Using the panel firmness scores as the standard measure of firmness, it was found that the single ball was able to measure differences in firmness with more precision than the single spike or the multiple spike. The results of the over-all study indicated a correlation of approximately 0.90 between the average single ball readings and the average panel firmness scores. Lower correlations were found between the average panel firmness scores and the multiple spike readings. Furthermore, the average single ball readings were significantly

more repeatable (r = 0.86) than the multiple spike readings (0.66) in Experiment III. Thus, these results indicate that the single ball was the most repeatable and precise penetrometer measure of beef ribeye firmness. Differences in firmness between the lateral and dorsal ends of the ribeye were also measured by the single ball.

Firmness of the ribeye was found to be positively correlated with the tenderness, flavor and juiciness of broiled rib steaks. However, the degree of relationship between the firmness or softness of the ribeye and the palatability characteristic was low ($r \sim 0.30$).

In this study, fat and moisture content of the ribeye were found to be more closely related to certain palatability characteristics ($r \sim 0.50$) than was the firmness of the ribeye. Fat and moisture content were also found to be highly related to the firmness of the ribeye.

Partial correlation coefficients were computed between the tenderness measurements (Warner-Bratzler Shear and taste panel tenderness scores) and the firmness measurements holding the fat content of the ribeye constant. The results indicated that (1) factors other than fat content were affecting the variation in tenderness accounted for by the firmness measurements, and (2) there was a tendency for the softer rib steaks to be more tender than the firmer rib steaks when the fat content of the ribeye was held constant.

Weight loss and change in pH of ribeye samples stored five days under simulated self-service meat market conditions were not found to be closely associated with the firmness of the ribeyes.

Before definite conclusions can be made as to (1) the use of the single ball as an objective measure of beef ribeye firmness, and (2) the degree of relationship between the firmness of the beef ribeye and certain of the palatability characteristics of the cooked rib steaks, further studies need to be conducted.

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