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I am submitting herewith a thesis written by Nancy Elizabeth Fugate entitled "Effect of Oven and End-Point Temperatures on the Sensory Properties of Beef Rib Roast." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science.

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EFFECT OF OVEN AND END-POINT TEMPERATURES ON THE SENSORY PROPERTIES OF BEEF RIB ROAST

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Nancy Elizabeth Fugate

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TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
II.	REVIEW OF LITERATURE	3
	Effect of Heat on Muscle Components in Relation to Tenderness	3
	Effect of Cooking Methods on Tenderness of Beef	7
	Cooking temperature	7
	End-point temperature	8
	Effect of Cooking and Internal Temperature on Juiciness and Cooking Loss	10
III.	PROCEDURE	13
	Source of the Meat	13
	Plan of Study	13
	Cooking and Testing Procedures	15
IV.	RESULTS AND DISCUSSION	18
	Effect of Oven Temperature and Internal Temperature on Cooking Time, Heat Penetration, and Energy Consumption	18
	Cooking time	18
	Rate of heat penetration	20
	Energy consumption	20
	Effect of End-Point and Oven Temperature on Cooking Losses	22

CHAPTER PAGE

IV. (continued)

Volatile loss 25

Drip loss 25

Total cooking losses 26

Effect of Oven Temperature and End-Point Temperature on Tenderness 27

Panel scores 27

Shear values 30

Effect of Oven Temperature and End-Point Temperature on Juiciness, Flavor, and Degree of Doneness 32

Juiciness 32

Flavor 32

Degree of doneness 32

V. SUMMARY 37

Scope of the Study 37

Principal Findings 37

Conclusions 39

BIBLIOGRAPHY 40

APPENDIX 43

LIST OF TABLES

TABLE		PAGE
I.	Summary of Cooking Plan.	14
II.	Time Required for Roasting Beef Rib Cuts at Two Oven Temperatures.	19
III.	Percentage Cooking Losses of Beef Rib Roasts	23
IV.	Mean Squares From Analyses of Variance	24
V.	Panel Scores for Tenderness of Beef Rib Roasts	28
VI.	Warner-Bratzler Shear Values in Pounds for Beef Rib Roasts	29
VII.	Panel Scores for Juiciness of Beef Rib Roasts.	33
VIII.	Panel Scores for Flavor of Beef Rib Roasts	34
IX.	Panel Scores for Degree of Doneness of Beef Rib Roasts . .	35

CHAPTER I

INTRODUCTION

It is generally accepted that tenderness, juiciness, and good flavor are the characteristics of meat most desired by consumers. Perhaps of these three desired qualities, tenderness is the most important and also lends itself to closest and most reproducible measurement. Important contributions have been made to the current knowledge of tenderness in meat. As a result, evidence has been obtained that has been useful in guiding further study.

Cover (1937) was one of the first to point out that slow heat penetration produced more tender meat than was produced with a faster rate of heating. In 1959, Bramblett et al. reported that beef rounds cooked at 154°F. for eighteen hours were less tender than beef rounds cooked at 145°F. for thirty hours. In addition, at the lower temperature, cooking losses were reduced. In a more recent study, however, data collected by Bramblett and Vail (1964) indicated that roasts cooked at 155°F. were more tender and flavorful than those roasted at 200°F., but the meat was less juicy, and the cooking losses were greater. Neilson and Hall (1965) roasted rump and blade cuts of beef to 160°F. internal temperature at oven temperatures of 325 and 225°F. The blade roasts were significantly more tender when roasted at 225 than 325°F. as measured by sensory and shear determinations. In 1965, Simmers found that beef semimembranosus roasted to 154°F. at 200°F. was more tender than roasts cooked to 158°F. at 300°F., but there was an increase in

cooking losses, cooking time, fuel consumption, and decreased juiciness of the meat at the lower oven temperature.

Because published reports of studies relating end-point and cooking temperatures to tenderness, juiciness, and flavor of beef are limited, further research is needed to compare and formulate recommended practices of cooking beef.

The primary purpose of this study was to compare the effects of reduced oven temperature with currently recommended oven temperature and end-point temperatures on tenderness, juiciness, and flavor of beef rib roasts. A secondary purpose was to obtain information on cooking losses, energy consumption, and rate of heat penetration.

Seventy-two roasts, averaging approximately four pounds in weight, were tested in this study. They were procured from twelve Angus steers. The right and left rib sections of each animal were divided into three two-rib roasts containing the 7-8, 9-10, and 11-12 ribs respectively. Thirty-six roasts were cooked at an oven temperature of 225°F. which is 100°F. lower than the recommended 325°F. at which the thirty-six pair mates were cooked. Paired cuts were assigned to end-points of 140, 158, or 170°F. End-point and oven-temperature combinations were replicated twelve times, four times with each of the three cuts.

Sensory properties of tenderness, juiciness, and flavor were scored by a panel of six trained judges, and tenderness was evaluated objectively by a Warner-Bratzler shear. Data also were obtained on cooking losses, rate of heat penetration, and energy consumption. Analysis of variance was used to assess the data. Duncan's (1955) Multiple Range Test was used to locate significant differences.

CHAPTER II

REVIEW OF LITERATURE

Tenderness, juiciness, and flavor are considered to be the important attributes determining the acceptability of cooked beef. To many consumers, tenderness is the most important criterion of quality (Danner, 1959; Weir, 1960). In addition to such inherent characteristics as age, breed, sex condition, and location of cut, post-mortem treatment plays an important role in tenderness of beef. The consumer applies the final post-mortem treatment in the cooking process. Rate and method of heat application, as well as the end-point temperature to which the meat is heated, have an important effect on sensory properties. Some of the literature relative to tenderness, juiciness, and cooking losses of beef is discussed in this chapter.

Since all data in this study will be reported in the Fahrenheit scale, where reviewed literature has been reported in the Centigrade scale, the equivalent Fahrenheit temperature has been inserted for ease of comparison. If both scales were reported, only the Fahrenheit has been shown.

I. EFFECT OF HEAT ON MUSCLE COMPONENTS IN RELATION TO TENDERNESS

Muscle differences and the effect of different methods of cooking on the muscle components help to explain why some muscles become more tender during cooking while others become less tender. The primary muscle components altered by heat are the muscle fibers, which contain

the myofibrils, and connective tissue. Evidence is being accumulated that these two components respond differently to time and temperature of heating. According to Giffee et al. (1960) collagens are the most widely occurring group of proteins in the animal body, serving as connective tissue in almost every organ. In general, while cooking makes connective tissue more tender by the conversion of collagen to gelatin, the proteins of the myofibril are coagulated and tend to become less tender (Lawrie, 1966).

Rib or loin steaks, which should contain relatively small amounts of connective tissue, broiled to the well-done stage appeared to be less tender than those cooked rare (Weir, 1960). Although the toughening effect on the fibers and the softening effect on connective tissue during cooking were dependent on both time and temperature, the time factor was more important for collagen softening while the temperature factor appeared to be more important for myofibrillar toughening.

Satorius and Child (1938) were one of the first research teams to report that cooking causes a change in the muscle fibers. The diameter of muscle fibers was decreased with increased coagulation up to 67°C. (153°F.) but no difference was found between meat heated to 67°C. (153°F.) and that heated to 75°C. (167°F.). Evidently shrinkage of the muscle fibers owing to coagulation of muscle plasma was completed at 67°C. (153°F.).

Ramsbottom et al. (1945) heated sections of twenty-five beef muscles to 170°F. in approximately twenty minutes in deep fat. They found that seventeen of the muscles were less tender upon heating; some

did not change significantly, and others became more tender. They concluded that inasmuch as connective tissue is made more tender by cooking, the decrease in tenderness of the muscle may be associated with factors such as coagulation and denaturation of muscle proteins, together with varying degrees of shrinkage and hardening of muscle fibers.

In a study by Hamm and Deatherage (1960), heating of beef from 20-30°C. (68-86°F.) resulted in little change in muscle protein. Between 30-40°C. (86-104°F.) a mild denaturation occurred, resulting in an unfolding of protein chains and in the formation of new salt and/or hydrogen bonds. Strong denaturation started around 40°C. (104°F.) and continued to 50°C. (122°F.) resulting in the formation of new stable cross linkages which were not split off by addition of acid or alkali. The denaturation, which caused a tighter network of protein structure, continued with increasing temperature and was almost complete near 65°C. (149°F.).

The extent of solubilization of collagen appears to depend upon the duration of heating and the internal temperature reached. Winegarden et al. (1952) heated strips of the flexor tendon and the aponeurotic sheet from nine beef animals in distilled water for 1, 2, 4, 16, and 64 minutes at temperatures ranging from 60 to 95°C. (140-203°F.). Shear determinations were used to indicate the degree of softening of the connective tissues. In general there was little softening of the connective tissue at 60°C. (140°F.), even after sixty-four minutes of heating. Approximately the same degree of softening was obtained in sixteen minutes at 65°C. (149°F.), in four minutes at 70°C. (158°F.), and in one minute at 80°C. (176°F.). They also found that upon heating, connective tissues

lost weight, shortened in length, decreased in width, and increased in thickness. These changes occurred together. In general, the degree of changes increased as the time and temperature of heating increased and as the initial collagen content of the tissues increased.

Giffee et al. (1960) also reported that heating collagenous fibers in water at 60-70°C. (140-158°F.) caused the fibers to shorten to about one-third to one-fourth of their initial length. They reported that the temperature of shrinkage is sharp and is characteristic of the source.

In general, lower optimal temperatures for softening of connective tissue than reported by Winegarden et al. (1952) have been obtained by heating intact muscle tissues. Data of Bramblett et al. (1959) indicated that the length of time that beef round was in the region of 57-60°C. (135-140°F.) may have been the important factor for softening connective tissue without toughening myofibrillar proteins.

Machlik and Draudt (1963) heated cores of semitendinosus muscles of beef one-half inch in diameter. The cores were enclosed in test tubes and heated from thirty to sixty minutes in a temperature controlled water bath. Temperatures studied were in the range of 50-90°C. (122-194°F.). Minimum shear values were obtained in the range of 60-64°C. (140-147°F.). In this temperature range the collagen shrinkage reaction was completed quickly while hardening associated with higher heating temperatures was avoided. In the range of 66-70°C. (151-158°F.) hardening was substantial in one-half to one hour. They felt that the hardening was associated with changes in muscle fiber proteins.

Another study about the same time yielded similar results, but

the authors did not attempt to relate their findings to muscle components. Tuomy et al. (1963) heated cylinders of beef in stainless steel tubes in a water bath at 140, 160, 180, 190, or 210°F. for varying periods of time up to seven hours. An initial toughening effect was observed which increased as the temperature increased. When the meat was held below 180°F., the tenderness of the heated meat depended upon the temperature applied, with time having little or no effect. The meat, when held above 180°F., became tender at a rate and to a degree dependent upon both time and temperature.

II. EFFECT OF COOKING METHODS ON TENDERNESS OF BEEF

Cooking temperature. Cover (1937) was one of the first investigators to point out the effect of cooking time and temperature on tenderness of beef. Both chuck and rump of beef were roasted at oven temperatures of 257 and 435°F. She found that roasting meat at the lower temperature produced a more tender product than roasting at the higher temperature. Tenderness increased as the rate of heat penetration decreased. When the effect of extremely slow rates of heat penetration on tenderness of beef was studied, paired roasts cooked at 80°C. (176°F.) consistently had lower shear values than those cooked at 125°C. (257°F.) (Cover, 1943). In well-done bottom rounds cooked at 80°C. (176°F.), the large quantity of connective tissue seemed to be completely changed from a "hard, tough state" to a moist, viscous mass.

Griswold (1955) compared oven roasting at 250 and 300°F. with a standard braising method using beef round of U. S. Commercial and Prime

grades and top and bottom muscles. Beef round roasted at 250°F. had lower shear values than meat cooked by the other methods.

When paired beef round muscles were cooked at 145°F. for thirty hours and 154°F. for eighteen hours, the meat was significantly more tender as evaluated by the Warner-Bratzler shear and by a taste panel when cooked at 145°F. (Bramblett, et al., 1959). It also tended to be more tender as evaluated by tensile strength measurements of individual fibers. Data obtained in a 1964 study by Bramblett and Vail supported results of the previous study. Paired muscles of round were cooked to an internal temperature of 149°F. at two oven temperatures, 155 and 200°F. Results obtained from evaluating tenderness by taste panel scores, number of chews, and shear values indicated that meat cooked at 155°F. was more tender than paired cuts cooked at 200°F.

Nielsen and Hall (1965) roasted rump and blade cuts of beef at oven temperatures of 225 and 325°F. to 160°F. internal temperature. The blade roasts were significantly more tender when roasted at 225 than 325°F., as measured by both sensory and shear determinations. In 1965, Simmers found that beef semimembranosus roasted to 154°F. at 200°F. was more tender than that roasted to 158°F. at 300°F.

End-point temperature. Paul (1963) defined the end-point or internal temperature of cooked beef as the temperature at the center of the cut. For consumers, rare, medium, and well-done, based on color, are the end-points most commonly used. For research, however, it is necessary to pin-point the degrees of doneness to definite temperatures.

Although a range of temperatures is commonly recognized for each degree of doneness, Griswold (1962) suggested using 140, 160 and 170°F. for rare, medium, and well-done beef, respectively. Sanderson and Vail (1963) used 140, 158, and 176°F.

In 1957, Cover et al. cooked longissimus dorsi and biceps femoris muscles of beef to two degrees of doneness by broiling to internal temperatures of 61 and 80°C. (142 and 176°F.) and by braising to internal temperatures of 85°C. (185°F.) and to 100°C. (212°F.) plus a holding period of 25 minutes. Shear values indicated that longissimus dorsi was most tender when broiled to 61°C. (142°F.), but that biceps femoris was most tender when braised to 100°C. (212°F.) and held for 25 minutes. Thus, severe cooking conditions appeared to toughen the loin steaks, but the most severe of the four cooking conditions seemed to tenderize the bottom round steaks.

Less tender beef muscles were heated by Visser et al. (1959) to internal temperatures of 55, 70, and 85°C. (131, 158, and 185°F.) by oven roasting at 300°F., or cooking in deep fat at 110 or 100°C. (230 or 212°F.). For a given muscle, shear values and sensory scores were approximately the same regardless of internal temperature. Average tenderness scores for roast cooked in fat at 100°C. (212°F.) were slightly lower than scores for oven roasts or those cooked in deep fat at 110°C. (230°F.) Shear values usually were a little lower for oven roasts than those cooked in fat.

Sanderson and Vail (1963) compared longissimus dorsi from U. S. Choice and semimembranosus, semitendinosus, and longissimus dorsi muscles

from U. S. Good grade beef, oven roasted to three internal temperatures of 140, 158, and 176°F. The degree of cooking had little effect on the change in tenderness of the longissimus dorsi as indicated by shear values. As the internal temperature increased, the shear values for semimembranosus and semitendinosus muscles decreased. Panel scores for tenderness tended to substantiate these findings.

II. EFFECT OF COOKING AND INTERNAL TEMPERATURE ON JUICINESS AND COOKING LOSS

The water-holding capacity of meat affects the behavior of meat during cooking and juiciness on mastication. Lawrie (1966) stated that diminution of the in vivo water-holding capacity is manifested as "drip" in thawed uncooked meat and as "shrink" in cooked meats. No more than 5 per cent of the total water of muscle is directly bound to hydrophilic groups on the protein. The bound water is hardly altered by changes in the structure of protein. Most of the changes observed in water-holding capacity involve alterations in the "free-water," immobilized, but not bound by the physical configuration of the proteins. Hamm and Deatherage (1960) reported that muscles having a high content of intramuscular fat tend to have a high water-holding capacity. It is possible that the intramuscular fat may loosen the microstructure allowing more water to be entrained.

Hamm and Deatherage (1960) have related the water-holding capacity of meat to changes in meat protein with heat. They reported that dry heat up to 80°C. (176°F.) results in a loss of free acidic groups and

of water-holding capacity and a rise of pH as the temperature is increased. There is also an increase in the buffering power of the meat in the region of pH 5.5-7.0.

Several researchers have reported that increased internal temperatures result in increased cooking losses. Cover et al. (1957) found that juiciness scores decreased with increasing doneness in both braised and broiled steaks. In loin steaks, lower weight losses and higher juiciness scores also tended to be associated with lower shear values. Evidence obtained by Visser and coworkers (1959) substantiates the data of Cover. For both oven cooked roasts and those cooked in deep fat at 100°C. (212° F.), juiciness scores and press fluid yields usually decreased significantly as the internal temperature of the meat increased. At a given internal temperature, there was little variation among muscles in total cooking losses, juiciness scores, or press fluid yields. However, muscles with the lowest cooking losses did not always have the highest juiciness scores.

Sanderson and Vail (1963) cooked beef muscles to internal temperatures of 140, 158, and 176°F. The percentage of total moisture content and mean press fluid decreased as internal temperatures increased. Bound water, removed by vacuum drying, varied little when related to dry matter in the meat at each internal temperature. No sensory evaluation of juiciness was made.

Studies relating oven temperature to cooking losses and juiciness scores have not been in complete agreement. Bramblett et al. (1959) found that meat cooked at 145°F. had a lower percentage of cooking losses

and a higher per cent moisture content than that cooked at 154°F. The press fluid yields and scores for juiciness also were greater for the beef cooked at 145°F. than at 154°F. However, in a later study (Bramblett and Vail, 1964), roasts cooked at 155°F. exhibited greater cooking losses and were less juicy than the paired muscles cooked at 200°F. In support of the latter study, Nielsen and Hall (1965) reported that roasts cooked at 225°F. had greater cooking losses than those roasted at 325°F. There was no significant difference, however, between mean scores for juiciness of blades roasted at the two temperatures. In 1965, Simmers found that beef semimembranosis roasted to 158°F. at 300°F. was juicier and had lower cooking losses than that roasted to 154°F. at 200°F.

Data on the relation of time and temperature of cooking and end-point temperature to tenderness, juiciness, and other sensory characteristics of beef, have not always been in agreement. For this reason, further research is needed to clarify these differences.

CHAPTER III

PROCEDURE

I. SOURCE OF THE MEAT

The roasts used in this study were obtained from twelve pure-bred Angus steers from two sires. There were six animals in each sire group. The steers were finished on a full-feed ration for 245 days by the University of Tennessee Agricultural Experiment Station at Crossville, Tennessee. The animals weighed an average of 954 lbs. at slaughter. Seven steers graded U. S. Good and five U. S. Choice. The carcasses had a mean fat thickness over the rib eye of 8.3 mm.

The left and right 7-12 rib section of these steers was cut into seventy-two, two-rib roasts for use in this study. Six roasts were obtained from each animal, two containing 7-8, 9-10, and 11-12 ribs each.

II. PLAN OF STUDY

Half of the roasts were cooked at 225°F. oven temperature and the others at 325°F. Six paired roasts from the right and left side of one animal were cooked for each test. The paired roasts were assigned to end-points of 140, 158, or 170°F., one of each pair at each oven temperature. These end-points were selected to approximate rare, medium, and well-done. The cooking plan, shown in Table I, replicated location, end-point and cooking temperature combinations four times.

TABLE I

SUMMARY OF COOKING PLAN

Animal and Sire No.	U.S. Grade	225°F. Oven Temperature End-point 140°F.	225°F. Oven Temperature End-point 158°F.	225°F. Oven Temperature End-point 170°F.	325°F. Oven Temperature End-point 140°F.	325°F. Oven Temperature End-point 158°F.	325°F. Oven Temperature End-point 170°F.
1-1	Good	7-8 R	9-10 R	11-12 R	7-8 L	9-10 L	11-12 L
2-2	Good	7-8 L	9-10 L	11-12 L	7-8 R	9-10 R	11-12 R
3-1	Choice	7-8 R	11-12 R	9-10 R	7-8 L	11-12 L	9-10 L
4-2	Good	7-8 L	11-12 L	9-10 L	7-8 R	11-12 R	9-10 R
5-1	Good	9-10 R	7-8 R	11-12 R	9-10 L	7-8 L	11-12 L
6-2	Good	9-10 L	7-8 L	11-12 L	9-10 R	7-8 R	11-12 R
7-1	Choice	9-10 R	11-12 R	7-8 R	9-10 L	11-12 L	7-8 L
8-2	Good	9-10 L	11-12 L	7-8 L	9-10 R	11-12 R	7-8 R
9-1	Choice	11-12 R	7-8 R	9-10 R	11-12 L	7-8 L	9-10 L
10-2	Choice	11-12 L	7-8 L	9-10 L	11-12 R	7-8 R	9-10 R
11-1	Choice	11-12 R	9-10 R	7-8 R	11-12 L	9-10 L	7-8 L
12-2	Good	11-12 L	9-10 L	7-8 L	11-12 R	9-10 R	7-8 R

III. COOKING AND TESTING PROCEDURES

On the day prior to testing, the frozen roasts were thawed at room temperature to 32°F. in the approximate geometric center of the longissimus dorsi muscle. The geometric center was estimated by measuring the height, width, and depth of the muscle, and a thermocouple was inserted into the roast to this point. All internal temperatures were recorded by the use of a recording potentiometer. The thawed roasts were stored in a household refrigerator over night.

On the day of testing, the roasts were weighed to the nearest gram on a Torsion balance and placed fat-side up in shallow aluminum pans, using the rib bones as racks. A thermocouple was again inserted into the approximate geometric center of the longissimus dorsi muscle. Two household electric ranges were used for cooking the roasts, three at 225°F. and three at 325°F. Preliminary tests had indicated that the thermostat range was approximately $\pm$ 7°F. in each oven. Oven temperatures and internal temperatures of the roasts were recorded every three or six minutes.

To measure energy consumption, a watt-hour meter was connected to the power line of each range. Readings were taken at the beginning and the end of the cooking period for each roast.

Cooking of the roasts was begun at different times in order that the selected end-point temperatures would be reached at approximately the same time. When the desired internal temperature was reached in each roast, the roast was removed from the oven and cooled for thirty minutes. At the end of the cooling period, the roasts were weighed in

the pan. The difference in this weight and the sum of the weights of the pan and roast before cooking indicated evaporation loss. The pan containing the drip was weighed after the roast was removed from the pan. The difference in this weight and the weight of the pan represented the drip loss. Drip loss and evaporation loss were expressed as a percentage of the original weight of the roast. The sum of the evaporation and drip loss was considered as the total cooking loss. If necessary, roasts were held in a warming oven until carved for sensory testing.

For sensory testing, the entire longissimus dorsi muscle was removed from each roast. Four slices of the muscle were cut from the roast after an outer slice had been removed. The meat was cut with a hand-operated meat slicer to control the thickness of the slices. The four slices were cut in half to provide eight samples for sensory testing. The samples were placed on separate plates marked with the code letter. The six samples for each panelist were placed on enamel trays. Order of sample presentation was randomized.

Six experienced panel members evaluated the roasts for flavor, juiciness, and tenderness. Tenderness was evaluated on an 11-point scale, and flavor and juiciness were evaluated on a 9-point scale. Degree of doneness was estimated by the panelists checking appropriate adjectives ranging from rare to well-done. These were later converted to scores to obtain an average degree of doneness rating for each roast. Each panelist scored samples from the same location of each roast at each test. Sample score cards for subjective evaluations are found

in the Appendix.

An objective index to tenderness was obtained by use of a Warner-Bratzler shear apparatus. Two cores, 1-inch in diameter, cut parallel to the muscle fibers, were removed from the half of the longissimus dorsi muscle remaining after slices had been removed for sensory evaluation. The cores were cooled thirty minutes before shearing to assure uniform temperature. Each core was sheared two times to give an average of four shears per roast.

The data were assessed by analysis of variance with respect to end-point temperature, oven temperature, and the interaction between the end-point and oven temperatures. Duncan's Multiple Range Test was used to locate significant differences.

CHAPTER IV

RESULTS AND DISCUSSION

I. EFFECT OF OVEN TEMPERATURE AND INTERNAL TEMPERATURE ON COOKING TIME, HEAT PENETRATION, AND ENERGY CONSUMPTION

Cooking time. There was a marked difference in cooking time for the roasts cooked at the two oven temperatures as shown in Table II. The cooking time per pound at 225°F. increased approximately thirty-five minutes compared to a ten minute increase at 325°F. for each chosen increase in end-point temperature. For roasts cooked to 140°F. the cooking time per pound at 225°F. averaged about twice as long as for roasts cooked at 325°F. Roasts cooked to 170°F. required almost three times longer per pound at 225°F. than at 325°F. Location of the cut had little effect on the cooking time per pound of the roasts.

Bramblett and Vail (1964) reported that muscles from the round cooked at 155°F. required two to four times as long to cook as paired muscles roasted at 200°F. Longer cooking time for rump and blade roasts cooked at 225°F. than at 325°F. were reported by Nielsen and Hall (1965). In their study blade and rump roasts cooked to 160°F. required about two hours per pound at 225°F. while at 325°F. rump roasts required forty-seven minutes per pound and blade roasts twenty-five minutes per pound. Simmers (1965) found that at 200°F., top round roasts required an average of approximately three hours per pound to reach an end-point of 154°F., while those cooked at 300°F. required only fifty-four minutes

TABLE II

TIME REQUIRED FOR ROASTING BEEF RIB CUTS AT TWO OVEN TEMPERATURES

Cut	Mean Weight	225°F. Oven			325° Oven		
		140°F.	158°F.	170°F	140°F.	158°F.	170°F.
	pounds	minutes					
7-8 Rib	4.4[a]	58	96	126	29	39	46
9-10 Rib	3.8[a]	65	105	134	31	40	50
11-12 Rib	3.6[a]	59	92	142	33	39	50
Mean	3.9	61	98	134	31	39	49

[a]Mean of twenty-four roasts.

per pound to reach 158°F.

Rate of heat penetration. Heat penetration curves for the roasts cooked at each oven temperature are shown in Figure 1. Initially points on each curve represented the mean for thirty-six roasts. After 102 minutes at 325°F. and 186 minutes at 225°F., when the first roasts reached an end-point of 140°F., the number of roasts represented then progressively decreased as each roast reached its assigned end-point temperature. The curves were discontinued when only two roasts had not reached 170°F. at both temperatures. Since two roasts had not reached the internal temperature of 170°F., the heat penetration curves show the maximum temperature reached as being slightly below 170°F.

End-point temperatures of 140, 158, and 170°F. were reached in approximately 216, 396, and 540 minutes respectively when the roasts were cooked at 225°F. The rate of heat penetration decreased markedly in roasts cooked at 225°F. as the difference between the oven temperature and internal temperature of the meat decreased. More than one-half of the total cooking time was required for raising the internal temperature from 140°F. to 170°F. when the roasts were cooked at 225°F. End-point temperatures of 140, 158, and 170°F. were reached in 144, 180, and 216 minutes respectively when roasts were cooked at 325°F. Heat penetration was approximately linear up to about 126°F. in the 225°F. oven and up to 151°F. in the 325°F. oven.

Energy consumption. The data on energy consumption were limited by the facilities available. It was necessary to cook three roasts in

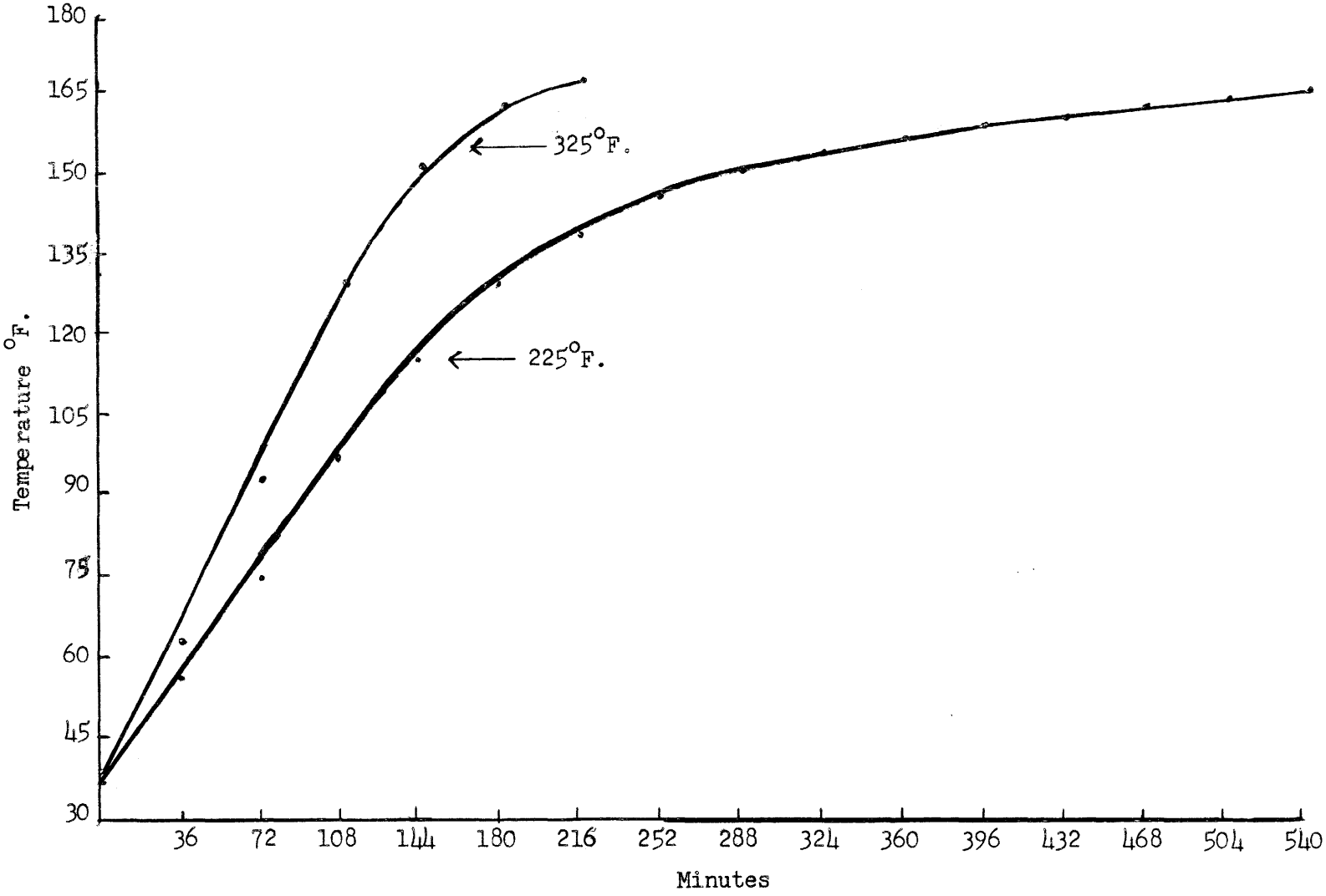


FIGURE 1

HEAT PENETRATION IN BEEF RIB ROASTS AT TWO OVEN TEMPERATURES

each oven so that the load varied from one to three roasts during each cooking period. For each test, the roast to be heated to 170°F. was started in a cold oven and the others added to the heated oven. Roasts were removed at different times as the specified end-points were reached. Therefore, there seemed to be no valid basis for expressing energy consumption on a per-pound basis. However, the average energy consumed for cooking the three roasts at each temperature was considered valuable information. An average of 2.9 kilowatts was required to cook three roasts at 225°F. and 2.1 kilowatts were consumed at 325°F. While the increased consumption at 225°F. was 38 per cent, the actual increase was not great enough to be of practical consideration to consumers.

Two other studies have shown that cooking at lower temperatures required more energy. Simmers (1965) reported that semimembranosus muscles roasted at 200°F. required approximately 50 per cent more watt-hours per pound than paired cuts roasted at 300°F. Nielsen and Hall (1965) reported a 100 per cent increase in energy consumption for roasts cooked at 225°F. as compared to 325°F.

II. EFFECT OF END-POINT AND OVEN TEMPERATURE ON COOKING LOSSES

The data obtained for cooking losses of the roasts at the three end-point temperatures and two oven temperatures are shown in Table III. Mean squares from the analysis of variance of the cooking losses are shown in Table IV.

TABLE III

PERCENTAGE COOKING LOSSES OF BEEF RIB ROASTS

Type of Loss	225°F. Oven			325°F. Oven		
	140°F.	158°F.	170°F.	140°F.	158°F.	170°F.
Volatile						
7-8 Rib	9.8	15.8	19.0	12.1	15.4	17.8
9-10 Rib	7.7	14.9	18.4	10.5	13.9	16.6
11-12 Rib	7.0	12.8	18.9	10.3	12.4	16.6
Mean[a]	8.1	14.5[b]	18.8[c]	11.0	13.9[b]	17.0[c]
Drip						
7-8 Rib	1.7	3.3	6.0	4.5	6.3	7.8
9-10 Rib	1.8	3.3	5.4	5.1	6.9	8.8
11-12 Rib	2.0	3.5	5.4	6.3	6.8	7.9
Mean[a]	1.8	3.4	5.6[de]	5.3[e]	6.7[d]	8.2
Total						
7-8 Rib	11.5	19.1	25.0	16.6	21.7	25.6
9-10 Rib	9.5	18.2	23.9	15.6	20.8	24.7
11-12 Rib	8.9	16.3	24.4	16.6	19.3	24.6
Mean[a]	10.0	17.9[f]	24.4[g]	16.2[f]	20.6	25.0[g]

[a]Mean of twelve values.

[bcdefg]Means in the same line with the same superscript are not significantly different. Other means differ, $P \leq 0.01$.

TABLE IV

MEAN SQUARES FROM ANALYSES OF VARIANCE

Source	df	Cooking Losses			Tenderness		Flavor scores	Juiciness scores
		Per cent drip	Per cent volatile	Per cent total	Warner-Bratzler shear	Sensory panel scores		
Oven temperature	1	175.13**	0.44	183.42**	79.28**	10.22**	0.23	2.05
End-point temperature	2	67.19**	420.89**	803.62**	20.01*	0.83	4.49**	22.29**
Oven X end-point	2	1.40*	33.85**	49.64**	14.56	1.07*	0.98**	1.40*
Error	66	1.02	3.77	4.05	5.38	0.27	0.09	0.31

*Significant $P \leq 0.05$.

**Significant $P \leq 0.01$.

Volatile loss. Volatile loss increased significantly as the degree of doneness increased at both oven temperatures. There was a tendency for the volatile loss to decrease from the 7-8 to the 11-12 rib cuts, which could have been due to differences in surface area, weight of roast, or both factors. Oven temperature did not affect volatile losses significantly except at the 140°F. end-point where a higher volatile loss was associated with the higher oven temperature.

Data obtained in this study are in partial agreement with the findings of Nielsen and Hall (1965) who reported that volatile losses of rump roasts cooked at 225°F. and 325°F. differed by less than 1 per cent. However, in the same study volatile losses for blade cuts roasted at 225°F. were 24.5 per cent, but were only 12.8 per cent when cooked at 325°F. Simmers (1965) reported that volatile losses were 9.3 per cent higher for semimembranosus cuts roasted at 200°F. than at 300°F.

Drip loss. Drip loss was affected by both oven and end-point temperature. The per cent drip loss increased significantly as the degree of doneness increased at each oven temperature, with the magnitude of the increase being slightly greater at the 225°F. oven temperature. Also at each end-point temperature, drip losses were significantly higher for roasts cooked at the higher than at the lower oven temperature. It was noted that the drip from the roasts cooked at 325°F. was lighter in color and more fluid than the rather dry and dark residue from the roasts cooked at 225°F.

Simmers (1965) obtained a mean of 7.4 per cent drip loss for semimembranosus roasts cooked at 300°F. as compared to 5.2 per cent at

200°F. Nielsen and Hall (1965) also reported a higher drip loss for blade and rump cuts roasted at 325°F. than at 225°F.

Total cooking losses. Both cooking temperature and end-point temperature significantly affected the total cooking losses except at end-point 170°F. For roasts cooked to 140 and 158°F. end-points, total cooking losses were greater at the higher than at the lower oven temperature ($P \leq 0.01$) (Table III, p. 23). For roasts cooked at the same oven temperature, cooking losses increased significantly with each increase in end-point temperature.

The results of this study are not in complete agreement with previous studies. Bramblett and Vail (1964) reported that total cooking losses of paired muscles from beef round were significantly lower for meat cooked at 200°F. than at 155°F. Blade cuts roasted at 225°F. by Nielsen and Hall (1965) had significantly greater total cooking losses than those roasted at 325°F. However, they found no difference in total cooking losses between rumps roasted at the two oven temperatures. Simmers (1965) reported that total cooking losses were 35.5 per cent and 29.9 per cent for the roasts cooked at 200 and 300°F. respectively.

The disagreement between results from this study and others may be due in part to the size and shape of the roasts, which is dependent to some extent on the muscles involved. There is some evidence that cooking losses vary with different muscles. Bramblett and Vail (1964) reported significant difference in total cooking losses with different

muscles from the round cooked at 155 and 200°F. Nielsen and Hall (1965) found no significant difference in the total cooking losses for rump roasts, but with the same heat treatment, cooking losses were significantly different for blade roasts.

III. EFFECT OF OVEN TEMPERATURE AND END-POINT TEMPERATURE ON TENDERNESS

Panel scores for tenderness of roasts cooked at two oven temperatures and to three internal temperatures are presented in Table V. Shear data on tenderness are shown in Table VI.

Panel scores. Roasts cooked at 225°F. to each end-point temperature and those cooked at 325°F. to 140°F. were scored significantly more tender than roasts cooked to 158 or 170°F. at 325°F. The location of the cut may have had some effect on tenderness scores, but data were not analyzed statistically with respect to cut. However, trends may be noted in panel scores for the different cuts (Table V). For the 7-8 rib cuts, tenderness scores tended to increase slightly as the internal temperature increased. Scores for the 11-12 rib cut tended to decrease as internal temperature increased, and the trend was more marked at the higher oven temperature. If the 11-12 cuts had less connective tissue than the 7-8 cuts, the toughening effect may have been due to a toughening of the myofibril proteins. The increased tenderness in the 7-8 cuts then could have been due to the conversion of the collagen in the connective tissue to gelatin.

TABLE V

PANEL SCORES FOR TENDERNESS OF BEEF RIB ROASTS

	225°F. Oven			325°F. Oven		
Cut	140°F.	158°F.	170°F.	140°F.	158°F.	170°F.
7-8 Rib	8.0	8.1	8.5	7.2	7.2	7.6
9-10 Rib	8.0	8.3	8.4	7.9	7.2	7.3
11-12 Rib	8.6	8.2	7.8	8.7	7.2	6.8
Mean[a]	8.2[b]	8.2[b]	8.2[b]	7.9[b]	7.2[c]	7.2[c]

[a]Mean of twelve values.

[bc]Means with the same superscript are not significantly different. Other means differ, $P \leq 0.01$.

TABLE VI

WARNER-BRATZLER SHEAR VALUES IN POUNDS FOR BEEF RIB ROASTS

	225°F. Oven			325°F. Oven		
Cut	140°F.	158°F.	170°F.	140°F.	158°F.	170°F.
7-8 Rib[a]	14.5	13.2	11.6	17.3	16.1	14.5
9-10 Rib[a]	17.6	11.8	10.1	16.0	14.5	15.0
11-12 Rib[a]	12.9	12.1	13.8	12.6	15.2	15.3
Mean	15.0[b]	12.4[c]	11.8[c]	15.3[b]	15.3[b]	14.9[b]

[a]Mean value for eight cores sheared twice each.

[bc]Means with the same superscript are not significantly different. Other means differ, $P \leq 0.01$.

Panel scores indicated that muscles from the round were more tender ($P \leq 0.01$) when cooked at 145°F. for thirty hours than at 154°F. for eighteen hours (Bramblett et al., 1959). Sanderson and Vail (1963) found little difference in panel scores for tenderness when the longissimus dorsi was cooked to 140, 158, or 176°F. For semimembranosus and semitendinosus muscles, however, panel scores increased as the end-point temperature increased. In a study by Bramblett and Vail (1964) results obtained from evaluating tenderness by panel scores indicated that muscles from the round cooked at 155°F. were more tender than paired cuts cooked at 200°F. Simmers' (1965) panel evaluated semimembranosus roasts cooked at 200°F. as being more tender ($P \leq 0.05$) than roasts cooked at 300°F.

Shear values. There is not complete agreement between shear values and panel scores for tenderness. Roasts cooked at 225°F. to end-points of 158 and 170°F. sheared significantly lower than roasts cooked by all other heat treatment combinations (Table VI, p. 29). The trend obtained by the panel in regard to the location of the cut was supported to some extent by shear value. Shear values for the 7-8 and 9-10 cuts tended to decrease as the internal temperature increased. However, the trend toward increased toughening in the 11-12 rib cut as the end-point temperature increased was not as clearly demonstrated with shear values as with panel scores. The lower oven temperature yielded more tender rib roasts as determined by both sensory and shear values, provided the roasts were cooked to 158 or 170°F.

Shear values were not affected by end-point temperature when roasts were cooked at 325°F. (Table VI, p. 29). For a given muscle, Visser et al. (1959) found that shear values and sensory scores were approximately the same regardless of internal temperature. When the longissimus dorsi was roasted to end-points of 140, 158, and 176°F., Sanderson and Vail (1963) found that the degree of cooking had little effect on the change in tenderness as indicated by shear values.

Weir (1960) has stated that the rib and loin muscles are low in connective tissue. Up to the present time, most reported studies have been conducted with muscles containing relatively large amounts of connective tissue: round, Griswold (1955), Bramblett et al. (1959), Bramblett and Vail (1964); blade and rump, Nielsen and Hall (1965); and semimembranosus, Simmers (1965). Low temperature and long cooking times are factors in the conversion of collagen to gelatin. It is generally assumed that tenderness resulting from low temperature cookery is due to the breakdown of collagen. It is therefore surprising that the longissimus dorsi, low in connective tissue, was significantly more tender when cooked at 225°F. to end-points of 158 and 170°F. than at the higher oven temperature. Histological and chemical analyses of collagenous connective tissue in rib cuts before and after cooking might facilitate interpretation of these data. In addition, further studies relating tenderness to low temperatures and varying end-points on the longissimus dorsi are needed.

IV. EFFECT OF OVEN TEMPERATURE AND END-POINT TEMPERATURE ON JUICINESS, FLAVOR, AND DEGREE OF DONENESS

Juiciness. Mean panel scores for juiciness are presented in Table VII. Juiciness scores decreased as internal temperature increased at each oven temperature ($P \leq 0.01$). Only when cooked to 170°F. was there a significant difference between juiciness scores of the roasts cooked at the two temperatures, those cooked at 325°F. being scored as more juicy.

Flavor. Mean panel scores for flavor are shown in Table VIII. For all the roasts mean scores ranged from "good" to "very good" (see Appendix). The panel tended to prefer the flavor of beef that had a greater degree of doneness. The roasts cooked to 170°F. at 225°F. scored highest ($P \leq 0.01$), and those cooked to an end-point of 140°F. at 225°F. scored lowest ($P \leq 0.01$).

Degree of doneness. Degree of doneness ratings by panel are shown in Table IX. The panel evaluated the degree of doneness on the basis of color. These evaluations were performed as preliminary tests for further studies on the relationship of color and end-point temperature. At both oven temperatures, the panel scored roasts cooked to end-point 158°F. as medium-well done and to end-point 170°F. as well-done. At 140°F., however, roasts cooked at 325°F. were scored medium-done while those cooked at 225°F. were scored medium-rare. The reason for this may have been that after the roasts cooked at 325°F. were removed from the oven,

TABLE VII

PANEL SCORES FOR JUICINESS OF BEEF RIB ROASTS

	225° Oven			325° Oven		
Cut	140°F.	158°F.	170°F.	140°F.	158°F.	170°F.
7-8 Rib	7.9	7.2	5.7	7.9	7.3	6.4
9-10 Rib	8.0	7.2	5.4	8.0	7.3	6.5
11-12 Rib	8.4	6.5	6.0	8.0	7.4	6.7
Mean[a]	8.1[b]	7.0[cd]	5.7	8.0[b]	7.3[c]	6.5[d]

[a]Mean of twelve values.

[bcd]Means with the same superscript are not significantly different. Other means differ, $P \leq 0.01$.

TABLE VIII

PANEL SCORES FOR FLAVOR OF BEEF RIB ROASTS

	225°F. Oven			325°F. Oven		
Cut	140°F.	158°F.	170°F.	140°F.	158°F.	170°F.
7-8 Rib	7.0	8.0	8.4	7.5	7.7	8.1
9-10 Rib	7.0	7.8	8.2	7.5	8.2	8.0
11-12 Rib	7.1	7.6	8.3	7.6	8.0	7.9
Mean[a]	7.0	7.8[b]	8.3	7.5	8.0[b]	8.0[b]

[a]Mean of twelve values.

[b]Means with the same superscript are not significantly different. Other means differ, $P \leq 0.01$.

TABLE IX

PANEL SCORES FOR DEGREE OF DONENESS[a] OF BEEF RIB ROASTS

	225°F. Oven			325° Oven		
Cut	140°F.	158°F.	170°F.	140°F.	158°F.	170°F.
7-8 Rib	4.3	2.1	1.3	3.5	2.2	1.2
9-10 Rib	4.1	2.3	1.2	3.3	1.9	1.1
11-12 Rib	4.3	2.4	1.1	3.4	2.2	1.1
Mean[b]	4.2	2.3	1.2	3.4	2.1	1.1

[a]Numerical ratings assigned to descriptive terms were: rare, 5; medium-rare, 4; medium, 3; medium-well, 2; well-done, 1.

[b]Mean of twelve observations.

the temperature continued to rise approximately 8 to 12°F. above the 140°F. end-point. This rise did not occur in roasts cooked at 225°F. It should be noted that the commonly recommended end-point temperatures of 140 and 158°F. for rare and medium doneness respectively yielded meat that was scored as being more well-done than was expected.

CHAPTER V

SUMMARY

I. SCOPE OF THE STUDY

The purpose of this study was to compare the effects of reduced oven temperature with currently recommended oven and end-point temperatures on tenderness and other sensory properties, cooking losses, cooking time, rate of heat penetration, and energy consumption of beef rib roasts.

Seventy-two roasts, weighing approximately four pounds each were obtained from twelve Angus steers. Three two-rib roasts containing the 7-8, 9-10, and 11-12 ribs respectively were taken from the left and right rib sections of each animal. Thirty-six roasts were cooked at each oven temperature of 225 and 325°F. End-points of 140, 158, or 170°F. were assigned to paired cuts, so that end-point-oven-temperature combinations were replicated four times with each cut.

Sensory evaluations of tenderness, juiciness, and flavor were made by a panel of six judges. Tenderness was also evaluated objectively by a Warner-Bratzler shear. Heat penetration, cooking losses, and energy consumption were measured.

II. PRINCIPAL FINDINGS

Cooking time was approximately two to three times longer for roasts cooked at 225°F. than at 325°F. Over one-half of the total cooking time was required for raising the end-point temperature from

140 to 170°F. when roasts were cooked at 225°F. An average of approximately 38 per cent more energy was consumed in cooking the roasts at 225 than at 325°F.

Volatile loss increased significantly as the degree of doneness increased at both oven temperatures. The oven temperature did not, however, significantly affect the volatile loss except at an end-point of 140°F. At this end-point temperature, volatile losses were greater ($P \leq 0.01$) at the 325°F. oven temperature. Drip loss was influenced by both oven and end-point temperature. The per cent drip loss increased as the degree of doneness increased ($P \leq 0.01$). Drip losses were greater at the higher oven temperature ($P \leq 0.01$). Total cooking losses increased as end-point temperature increased at each oven temperature ($P \leq 0.01$). For end-points of 140 and 158°F. total cooking losses were greater at the higher oven temperature ($P \leq 0.01$). There was no difference in cooking losses at the two oven temperatures when roasts were cooked to 170°F.

Panel scores indicated that roasts cooked at 225°F. to each end-point temperature and those cooked at 325°F. to 140°F. were more tender ($P \leq 0.01$) than roasts cooked to 158 or 170°F. at 325°F. Roasts cooked at 225°F. to end-points of 158 and 170°F. sheared significantly lower than roasts cooked by all other heat treatment combinations.

Juiciness decreased as the internal temperature increased. Only at end-point 170°F. did the oven temperature affect juiciness ratings, the roasts cooked at the higher temperature being more juicy. The panel preferred the flavor of beef that had a greater degree of doneness than

rare (140°F.) regardless of the temperature at which the cuts were roasted.

III. CONCLUSIONS

Reducing the cooking temperature 100°F. below the currently recommended temperature for roasting beef rib yielded meat that was more tender when cooked to 158 or 170°F. These roasts also resulted in lower cooking losses with only slightly higher energy consumption. Flavor of beef cooked to the well-done stage tended to be preferred by the panel. All of these factors need to be considered when deciding on the temperature combinations for roasting beef rib cuts.

Chemical and/or histological studies are recommended to help explain the tenderizing effect of the reduced rate of heating.

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APPENDIX

GRADING CHART FOR MEAT

Date_____ Name_____

Directions: Give full value for excellent quality.
Do not use fractional points.

Scale for scoring tenderness:

10 - Extremely Tender
9 - Very Tender
8 - Tender
7 - Moderately Tender
6 - Slightly Tender
5 - Slightly Tough
4 - Moderately Tough
3 - Tough
2 - Very Tough
1 - Extremely Tough
0 - Reject Sample

Scale for scoring flavor and juiciness:

9 - Excellent
8 - Very Good
7 - Good
6 - Fair plus
5 - Fair
4 - Fair minus
3 - Poor
2 - Very Poor
1 - Extremely Poor

Sample No.								
Flavor								
Juiciness								
Tenderness								

Comments:

CHART FOR DEGREE OF DONENESS

Date_____ Name_____

In which of the five categories of doneness would you place each sample:

Rare
Medium-rare
Medium
Medium-well
Well-done

Sample No.										
Degree of Doneness										

Comments: