EFFECT OF OVEN TEMPERATURE AND DRY AND MOIST HEAT ON FROZEN BEEF RIB ROASTS

by

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INTRODUCTION

Freezing, as a method of food preservation, has increased rapidly for the past 20 to 25 years. For example, in 1940, the combined retail and institutional sales of all commercial frozen food was estimated at $108 million, whereas by 1965 the figure increased to $6 billion (Enochian, 1968). An area for further expansion is increased retailing of red meats in the frozen state.

Frozen retail cuts of red meat will benefit meat processors, retailers, and consumers. Through central cutting, packaging, and freezing, processors will be able to utilize the entire carcass under optimum conditions. Shrinkage and spoilage problems will be reduced, and uniform products and supplies of red meat will be provided at lower cost. Retailers will be able to stock frozen cuts according to consumer demand in a particular area. Thus, consumers will gain, because the consolidation of meat processing will lower the cost of meat and provide products of consistent quality.

Methods recommended for cooking fresh meat also are suitable for cooking frozen meat (Vail, 1948). In the Kansas Agricultural Experimental Station study (1969) the percentage of respondents who cooked meat from the frozen state varied with income level. Less than one-fourth of the income group under $3000 followed this practice as compared with about a half of the respondents in other income groups ($3000 to over $10,000). In general, over 94% of all interviewees and 88% of low income respondents knew frozen meat could be cooked without thawing. USDA workers (1969) found that two-thirds of those who reported home freezing of meat said they usually thaw meat completely before cooking it. Only 5% generally cooked meat from the frozen state, whereas the remainder thawed meat partially before cooking it.

Research has indicated that thawing frozen meat before or during cooking has little effect on the end product (Kalen et al., 1948; Lowe, 1952; Lind, 1969). However, approximately one-third to one-half longer time is required to cook meat from the frozen state than if it is thawed before cooking (Lowe, 1952; Lind, 1969).

It may be possible to reduce the time of cooking from the frozen state by increasing the temperature of cooking over that generally recommended for a given cut of meat. The work presented here was designed to study the effect of three oven temperatures (300°, 325°, 350°F) on selected characteristics of frozen boned beef rib roasts cooked by dry and moist heat. Factors studied were: (a) differences among the three oven temperatures, and (b) differences between dry and moist heat cookery. This study was a part of an over-all frozen meat merchandising project being conducted at Kansas State University.

REVIEW OF LITERATURE

Potential for Merchandising Frozen Meat

Adding more frozen red meat to the market is feasible because homemakers and large eating establishments, the major users of frozen food, have the freezer space available. The American 0°F storage capacity was over 5 billion pounds at the end of 1965. This figure excludes the capacity in two-compartment home refrigerators (Enochian, 1968).

Enochian (1968) stated that in 1966, the net profit of the frozen food department in supermarkets was 4% of the total sales; twice the profit of the entire store. He predicted that many grocers will take an active part in promoting frozen foods, especially meat, because of its high dollar value. In addition, frozen meat is ideally suited for self-service retail stores and is adapted to branding and merchandising. Ziemba (1959) stated that prices of frozen meat would have less seasonal fluctuation than prices of fresh meat if the majority of meat was sold in the frozen state.

Some of the problems involved with increased merchandising of frozen meat are labor resistance and high cost of relocating meat processing plants. Also, retailers will have to revamp store lay-out to allow more space and holding conditions for frozen meat. An attempt in beginning a frozen meat line on the consumer market in the Chicago area showed some public resistance to frozen meat because of discoloration of the product, frost packets in some packages, and the desire of some consumers for fresh meat for quick meals (Ziemba, 1959).

Future growth of marketing frozen meat will be influenced by factors such as population increases, labor and consumer acceptance, growth in personal income, which will increase the ability to purchase home freezers and the frequency of eating away from home. Relative costs of frozen versus other forms of preservation, and additional study on freezing and cooking methods also will affect marketing practices for meat (Ziemba, 1959).

Factors Affecting the Thermal Conductivity of Meat

Heat flows, by conduction, through a mass such as meat from the area of highest heat concentration to the area of least heat by heating the molecules on the surface first and transferring the heat molecule by molecule towards the center of the mass. The rate at which heat flows through a solid is measured as the amount of heat (kcal.) transferred from the area of most heat to the cooler part of a substance (Boelter et al., 1965).

Composition of the meat. Lentz (1961) stated that the prediction of heat conductivity through a heterogeneous mass like meat cannot be determined by measuring the thermal conductivity of a single component such as protein, ice, or water. From his data he concluded that the thermal conductivity of beef did not appear to be related directly to moisture or fat content. However, Quashou et al. (1970) stated that moisture and fat content did affect thermal conductivity in beef. Also, Miller et al. (1963) and Hill et al. (1967) found that thermal conductivity values for beef increased with an increase in moisture content. Thille et al. (1932) stated that meat fibers conducted heat faster than any other constituent of beef muscle in the initial period of heating. They found that fat is a poor conductor of heat when solid, but is a good heat conductor when melted. At approximately 50°C the rate of conductivity in beef muscle slowed down and conduction in fat increased. Hill et al. (1967) reported that at temperatures below freezing, heat conductivity was inversely related to the internal temperature of the meat and above freezing, conductivity increased slightly as temperature increased.

Funk et al. (1968) studied the rate of heat conductivity in ground beef cylinders with and without bone containing 2.39, 10.12, 19.96, and 29.07% fat. Bone-in cylinders with 10.12% fat required more time ($P \leq 0.01$) to reach an end point of 80°C than "plain" (without bone) cylinders at the same fat level. There were no appreciable differences between cylinders with and without bone in the average time-temperature relationships for the cylinders at the other fat levels. Another factor studied was the effect of an external layer of fat on the rate of temperature rise in cylinders of ground beef containing the same four fat levels used to study the effect of bone on rate of heat conductivity. Significantly ($P \leq 0.01$) less time was required to cook fat-wrapped cylinders than was needed to cook "plain" cylinders at each of the four fat levels.

Direction of heat transfer. Lentz (1961) and Hill *et al.* (1967) found that thermal conductivity of muscle fibers depended upon the direction of the fibers or structure of the sample with respect to the direction of heat flow. Conduction was 15 to 30% greater along or parallel to the fibers than it was perpendicular to the fibers (Lentz, 1961). Hill *et al.* (1967) found that when comparing samples of meat with approximately the same moisture content, conductivity was between 8 to 16% higher for samples measured parallel to the grain than for those measured perpendicular to the grain. Dickerson (1968) stated that the rate thermal energy travels depends upon the molecular structure or the mean path between molecules, or through the lattice if it is a solid. Nelson *et al.* (1968) reported that the physical properties of meat pertinent to conduction heat transfer include specific heat, mass density and thermal conductivity.

Cooking medium. Lentz (1961) stated that temperature of the cooking medium influences the rate of heat transmission in meat. The higher the temperature of the medium, the faster heat will penetrate to the interior. Several workers (Cover, 1943; Hunt *et al.*, 1963; Weir *et al.*, 1963) showed that beef cooked at temperatures between 257° and 400°F takes less time to cook than that cooked at temperatures between 176° and 300°F.

Harrison (1943) cooked beef loin and rib roasts in water, steam, oil, and air and found that the cuts cooked in water required the least amount of time to reach 70°C. For the other cooking mediums, cooking time increased in the following order: fat, steam and air. Those roasts cooked in steam took longer than was expected. She explained that cooking time seemed to be related to the distance from the outer surface to the centers of the roast.

Schock et al. (1970) cooked pieces of semimembranosus muscle, relatively uniform in weight and shape, by deep fat frying, oven-roasting, oven-braising and pressure-braising (10 psig) to an internal temperature of 70°C. Cooking time for muscle cooked in those four mediums was: oven-roasting > oven-braising > deep fat frying > pressure-braising.

Visser et al. (1960) stated that at a given temperature liquid fat conducts heat six times faster than air. They presented heat penetration curves for three beef muscles cooked in deep fat at 100° and 110°C and roasted in an oven (air) at 150°C. Curves for muscles cooked in deep fat were steeper and shorter than those for oven roasts cooked to the same internal temperature. The fat transferred heat to the meat more rapidly than the air in the oven, although temperature of the fat was less than that of the air. Also, as a result of the endothermic reaction associated with protein coagulation, the heat conductivity in oven roasts was slower after an internal temperature of 55°C was reached than in the earlier part of the cooking period. The rate of heat penetration in roasts cooked in fat was about the same through the entire cooking period.

Cover (1941) found that water was a better conductor of heat than air. Heat penetration was much more rapid in meat cooked in water than in meat cooked in air.

Initial temperature of meat. The temperature at the center of the meat when cooking begins influences the rate of heat penetration (Committee on Preparation Factors, National Cooperative Meat Investigations, 1942; Lowe, 1955; Lentz, 1961). Lowe (1955, p. 240) stated that the lower the initial temperature at the center of the meat, the longer it takes to cook. She also stated that when cooking frozen meat, during the first part of the cooking period the ice melts, and during the last part of cooking the internal temperature increases until the desired degree of doneness is obtained.

Size and shape of cut. Lowe (1955, p. 238) said that the weight, surface area, and shortest distance to the center of the thickest portion of a cut of meat determines the cooking time. The Committee on Preparation Factors, National Cooperative Meat Investigations (1942) explained that the longer the distance heat must travel to reach the center of the thickest part of the cut, the longer the total cooking time. As pointed out previously, Harrison (1943) found that cooking time was associated with the distance from the surface to the center of beef roasts cooked in water, steam, air, and oil; the greater the distance to the center, the longer the cooking time.

Methods of Cooking Frozen Meat

In cooking meat, heat is transferred from the heat source to the cooking medium and from the cooking medium to the surface of the meat.

Roasting, a dry heat method of cooking, consists of transferring heat from the source to the air in an oven, and heat flows through the air by convection. The hot air surrounds the meat in an open pan and is transferred to the meat. In braising, a moist heat method, the meat receives heat from the steam that comes from the moisture vaporizing in a covered pan (Griswold, 1962).

Vail (1948) pointed out that methods recommended for cooking fresh cuts are suitable for cooking frozen meat. Vail _et al_. (1943) reported values for both objective and subjective measurements of "quality" that were nearly the same for fresh and frozen defrosted meat cooked by the same methods.

No studies were found in the literature that compared dry and moist heat cooking of red meat cooked from the frozen state. Travnicek _et al_. (1968) found that total cooking time, losses and total and expressable moisture were greater for roasted than for braised turkey quarters cooked from the frozen state.

Lowe (1955, pp. 246-7) pointed out that early studies on methods of cooking fresh beef indicated that, in general, cooking time is longer, but weight and nutritive losses are less and the meat is more palatable when roasted than when braised. Harrison _et al_. (1953) confirmed those findings for cooking time and weight losses. Lowe _et al_. (1952) reported that juiciness scores for frozen defrosted meat cooked by dry heat were higher than those for meat cooked by moist heat.

Methods of Thawing Frozen Meat

Frozen meat may be thawed before or during cooking. Studies on frozen meat have included the effects of various methods of thawing on cooking time, thawing and cooking losses, and palatability of the cooked meat. Effects of methods of thawing on cooking time and weight losses during thawing and cooking varied among studies. In general, methods of thawing had little effect on the palatability of cooked meat.

Effects on cooking time and cooking and thawing losses. Some of the first reports on cooking frozen meat indicated that meat cooked from the frozen state required approximately one-third to one-half longer to cook than fresh or thawed meat (Vail et al., 1943; Kalen et al., 1948; Lowe et al., 1952). Lind (1969) confirmed this finding.

Vail et al. (1943) thawed 33 pair of 2-in. boned beef steaks from the longissimus dorsi muscle and 48 pair of pork loin roasts by three methods: (1) at room temperature for 15 hr, (2) in the refrigerator at 3.3°C (38°F) for 23 hr and (3) during cooking in oven at 200°C (392°F). Steaks thawed before cooking required about 50% less time to reach the internal end point temperature of 65.6°C (150°F) than those cooked from the frozen state. The pork loin roasts thawed before cooking required 81 to 87 min/lb to reach 82.2°C (180°F) or approximately 8 to 17% less cooking time than the 95 min/lb required for roasts cooked from the frozen state. Cooking losses for the steaks thawed before cooking were approximately 20 to 21% whereas, those for steaks cooked from frozen state were about 22%. Roasts thawed before cooking resulted in 31 to 32% cooking losses and those cooked from the frozen state lost about 32% of their initial weight.

Kalen et al. (1948) thawed several cuts of frozen beef and pork under a variety of conditions: (1) at room temperature in still air, (2) during cooking, (3) in cold running water, (4) in a warming oven at 73°C (163°F), and (5) at refrigerator temperature of approximately 3°C (37.4°F). The cooking rate per lb was reported for pot roasts only in this study. The pot roasts not thawed before cooking required 11-15 min per lb longer than those thawed during cooking. Steaks thawed in running water required from 21 to 27 min/lb, those thawed in the warming oven required 50 to 80 min/lb, and steaks thawed at refrigerator temperature required 630 to 757 min/lb. Thaw loss for cuts thawed before cooking was between 1 and 3%. Cooking losses for those cuts averaged between 32.16 and 37.32% which was the same as those for the cuts thawed during cooking. Steaks thawed in water had 6 to 10% greater cooking losses than the steaks thawed by the other three methods.

In a general discussion of studies on frozen meat, Vail (1948) stated that steaks and roasts defrosted in the refrigerator thawed more slowly and at a more uniform rate than steaks defrosted in front of a fan, under running water, and in a warming oven. Meat defrosted in the refrigerator had less drip and surface discoloration than meat thawed by the other methods.

Causey _et al_. (1950) studied two methods of thawing ground beef patties: (1) at room temperature (18.3° to 23.8°C, 65° to 75°F) to an internal temperature of 28°C (37°F) and (2) during cooking. The patties were cooked by four methods: (1) pan-broiling to an internal temperature of 74°C (165°F), (2) oven-broiling to 74°C, (3) dielectrically, without prebrowning, for 4.4 min if frozen and 5.3 min if thawed, and (4) dielectrically with prebrowning to an internal temperature of 80°C (176°F). They found that cooking pork dielectrically without prebrowning resulted in less cooking time for pork patties thawed at room temperature than for those thawed during cooking. Causey et al. (1950) found that there was no drip when thawing beef patties during cooking, and thawing before cooking shortened the conventional cooking time from 3 to 8 min. However, prethawing did not result in shortening dielectrical cooking time. Dielectric cooking methods required about one-third to one-fourth the time required for pan-broiling and one-half the time for oven-broiling. Patties cooked from the frozen state had less weight and drip loss than patties thawed prior to cooking. Patties conventionally cooked had 24% weight loss as compared to 32% weight loss from dielectrically cooked patties.

Lowe et al. (1952) conducted an extensive study on defrosting and cooking frozen beef, pork, lamb, and veal. Methods of defrosting studied were: (1) room temperature (25°C, 77°F), (2) refrigerator temperature (4-4.5°C, 39.2°F), (3) in running water (49°C, 120°F), and (4) during cooking. They found that cooking time was affected by the oven temperature, how well-done the meat was cooked, whether the cuts were frozen or defrosted at the beginning of cooking, the size of the cut, and the shortest distance from the exterior to the center of the cuts. Average cooking time for roasts thawed before cooking was one-third less than cooking time for roasts that were frozen when cooking began; also cooking losses were less for the prethawed meat. Similar to the data for cooking time reported by Lowe et al. (1952) Lind (1969) found that cooking time for lamb chops thawed in a refrigerator at 45°F (7.5°C) was approximately one-third less than that for chops cooked from the frozen state. However, Lind (1969) found no significant effect of the two methods of thawing on cooking losses.

Fenton et al. (1956) used two methods of thawing frozen top and bottom round and chuck cuts of U.S. Utility and Choice Grade beef: (1) at refrigerator temperature (4.4° to 10°C, 39.9° to 50°F) to an internal temperature of 1.1°C (34°F) and (2) during cooking. The cuts were braised in the oven at 149°C (300.2°F) to 98.3°C (208.9°F) and in a pressure saucepan at 116°C (240.8°F) to 102°C (215.6°F). They reported that for roasts thawed before cooking total cooking time and cooking time in min/lb were significantly ($P \leq 0.01$) less than cooking times for roasts thawed during cooking. They also found that the method of thawing did not affect weight loss, evaporation and cooking drip.

Paul et al. (1937) froze beef rib roasts at -18°C (-0.4°F) and thawed them in an electric oven at 175°C (347°F) to 5°C (41°F) and at room temperature (24° to 25°C, 75.2° to 77°F) to the same end point. Roasts thawed at 175°C averaged 35.06 min/lb to reach 5°C, whereas roasts thawed at 24° to 25°C averaged 187.96 min/lb to reach the end point. Cooking times for those roasts were not reported in the study. The total losses, including freezing, thawing and cooking, were significantly ($P \leq 0.05$) less when the roasts were thawed at 24° to 25°C than when they were thawed at 175°C.

Effects on palatability of meat. In general, there is little difference in the palatability of meat thawed before or during cooking (Paul et al., 1937; Vail et al., 1943; Kalen et al., 1948; Causey et al., 1950; Lowe et al., 1952; Fenton et al., 1956; Lind, 1969).

Vail et al. (1943) found that roasts thawed during cooking were slightly less tender than those thawed before cooking. She and Lowe et al. (1952) reported that meat thawed before cooking had less press fluid than meat defrosted during cooking.

Kalen et al. (1948) found that steaks thawed at room, refrigerator or oven temperature did not differ significantly in palatability. However, steaks thawed in the refrigerator received the highest palatability scores. Steaks thawed in running cold water had the lowest scores for desirable aroma, flavor of fat and lean and juiciness.

Paul et al. (1937), Causey et al. (1950), Fenton et al. (1956) and Lind (1969) found no significant difference in palatability between thawing meat before or during cooking.

EXPERIMENTAL PROCEDURE

Experimental Design and Statistical Analysis

The experimental design was a 6 X 6 Latin square (animal X type of heat X oven temperature) with the following treatment combinations:

	Treatment combination	
Treatment no.	Type of heat	Oven temperature, °F
1	Dry	300
2	Moist	300
3	Dry	325
4	Moist	325
5	Dry	350
6	Moist	350

Data for each measurement used to evaluate the effects of type of heat and oven temperature were analyzed by the following analysis of variance:

Source of variation		D/F
Treatment		5
Type of heat (dry or moist)	1	
Linear temp	1	
Quadratic temp	1	
Linear temp X trmt	1	
Quad temp X trmt	1	
Animals		5
Position		5
Left vs right	1	
Linear left	1	
Quad left	1	
Linear right	1	
Quad right	1	
Error		20
Total		35

Eighteen pair, i.e. from the same position on the left and right sides of the carcass, of boned beef rib roasts (approximately 3 to 5 lb each, Table 7, Appendix p. 47) were cut from six U.S.D.A. Choice Grade carcasses by personnel in the Kansas State University Department of Animal Science and Industry. Each rib section was separated from the carcass halfway between the 7th and 8th ribs and between the 9th and 10th ribs. The skeletal breaking points were at the middle of the 8th and 10th thoracic vertebra. The separated rib section was boned and divided into three roasts numbered 1 to 3 from the anterior to posterior on the left side and 4 to 6 on the right side.

Half of the roasts were selected at random (Table 2) and placed in oxygen permeable pouches (Cryovac L-300), the air removed, and the pouches sealed. The remaining roasts were placed on aluminum foil trays and wrapped in a 3M Scotchpak Oven Service film furnished by the

Minnesota Mining and Manufacturing Company. All roasts were frozen by liquid nitrogen vapor according to the cycle presented in Table 1, and stored 1 to 13 weeks in a household freezer at -20°F (-28.9°C) until cooked and evaluated according to the plan presented in Table 2.

Table 1. Freezing cycle in liquid nitrogen vapor for beef rib roasts as programmed in a National Cylinder Gas Simulator Freezer.

Liquid Nitrogen vapor, °F	Minutes	Interior temperature, °F
0	3	---
- 50	4	---
-100	5	---
-150	5	---
-200	5	---
tempered[a]	5	0[b]

[a] Liquid nitrogen was shut off from the freezer and the products were left in the freezer for the specified tempering time. The temperature at the surface of the meat ranged from -200°F to approximately -100°F during tempering (temperature decreased as tempering time increased).

[b] After 5 min at -200°F the interior temperature of roasts was 0°F at a point one-half of the radius of the product. The interior temperature of the roasts was equilibrated so that approximately 0°F was established throughout the product.

Table 2. Roasts assigned to treatments by cooking period.

Evaluation period	Treatments		
	Oven temperature, °F	Dry heat	Moist heat
1	300	I 6	I 1
2	325	I 4	I 5
3	350	I 2	I 3
4	300	II 3	II 2
5	325	II 6	II 1
6	350	II 5	II 4
7	300	III 1	III 3
8	325	III 5	III 6
9	350	III 4	III 2
10	300	IV 2	IV 6
11	325	IV 1	IV 4
12	350	IV 3	IV 5
13	300	V 5	V 4
14	325	V 3	V 2
15	350	V 6	V 1
16	300	VI 4	VI 5
17	325	VI 2	VI 3
18	350	VI 1	VI 6

I, II, III, IV, V, VI = Animal numbers.

1, 2, 3 = Roast numbers, left side of carcass from anterior to posterior position in the ribs.

4, 5, 6 = Roast numbers, right side of carcass from anterior to posterior position in the ribs.

Cooking Procedure

At each evaluation period two roasts were cooked, from the frozen state, in a rotary hearth gas oven at 300°, 325°, or 350°F to an internal temperature of 60°C (140°F). A hole was bored in each roast so that a right angle centigrade thermometer could be inserted into the center of the longissimus dorsi (LD) muscle. Each roast was placed on a flat rack in a shallow roasting pan. The pouches were removed from the roasts cooked by dry heat, whereas the film was left on those roasts cooked by moist heat, with four holes punched in the top to allow the escape of some steam and prevent the film from breaking.

Measurements for Evaluating Effects of Treatments

Rate of heat penetration. Rate of heat penetration for each sample was observed by recording the time required to reach an internal temperature of 0° and to increase from 0° to 10°C, and thereafter for each 5°C increase until the end point, 60°C.

Cooking time. Total cooking time in minutes was recorded, and the cooking time in min/lb was calculated.

Cooking losses. Percentage total, volatile, and dripping cooking losses, based on the weight of the frozen roast, was computed for roasts cooked by dry heat. Only the percentages of the total and dripping losses, based on the weight of the frozen roast were calculated for roasts cooked by moist heat. To determine the weight of the frozen roast, the roast + tray + film were weighed before cooking. After cooking, the roast was removed from the package and film. The tray was washed, dried with a hand towel, left overnight in a desiccator, and weighed. The weight of the film + tray was subtracted from the initial weight of the roast + film + tray. The percentage of fat in dripping losses was based on volume. The drippings were collected in a 100 ml graduated cylinder and allowed to stand 1/2 to 3/4 hr. After the fat had stabilized at the top of the column of drippings, the total volume (ml) and volume (ml) of fat were recorded, and the percentage of fat was calculated.

Samples for the following measurements were taken from the LD muscle at the location indicated in Figure 1.

Warner-Bratzler shear value. Tenderness was measured by shearing three (lateral, central, medial positions) 0.5-in. cores of the LD on a Warner-Bratzler shearing apparatus with a 25-lb dynamometer. Triplicate readings were made on each core. The overall shear value was the average of the three shear scores.

Water-holding capacity. Triplicate measurements for water-holding capacity were made according to the method described by Miller and Harrison (1965).

Total moisture. Percentage total moisture was measured by drying two 10-g samples of ground LD muscle from each roast in a C. W. Brabender Semi-Automatic Rapid Moisture Tester for 60 min at 121°C.

Color-difference. Color difference was measured by the Gardner Color Difference meter. The instrument was standardized using a satin finish ceramic tile with calculated values of: Rd (reflectance), 38.01; a+ (redness), 6.6; and b+ (yellowness), 14.7. Approximately 25.0 g of ground meat were placed in plexiglass cells in a manner and depth so that light did not filter through the sample. Duplicate readings were taken for each color-difference factor. After the first reading,

Fig. 1. Sampling of the Longissimus Dorsi Muscle

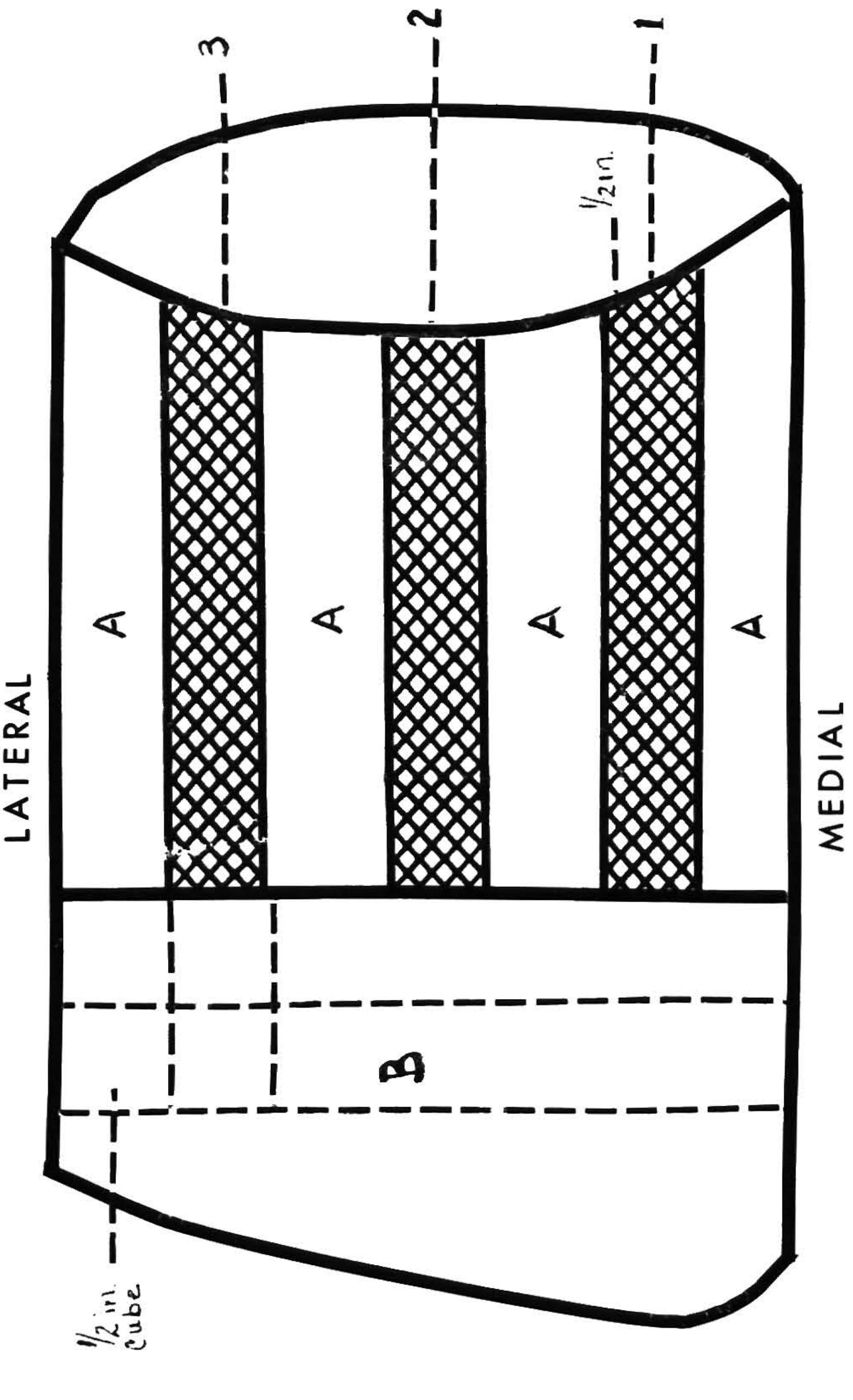
1. Median shear core and WHC

2. Central shear core and WHC

3. Lateral shear core and WHC

A. pH, total moisture, color, Macbeth skylight

B. Palatability samples


LATERAL
MEDIAL
1
2
3
1/2 in.
A
A
A
A
B
1/2 in. cube

the cell was rotated at 90° for the second reading.

Sensory evaluation. Six members, using a 7- to 1-point scale (Form I, Appendix, p. 44) evaluated each sample for flavor, tenderness, juiciness, and overall acceptability. During preliminary work instructions for sensory evaluation (Form II, Appendix, p. 45) were given the panelists. Panel members made a random selection of 0.5-in. cubes of LD muscle from each roast that were placed in the top of a one-pint enamel double boiler and set over hot water. The entire system was held at a constant low heat (35 ± 1°C) on a General Electric hot tray until all samples were judged (no longer than 30 min). Apparent degree of doneness was scored by observing a slice of the LD muscle under the MacBeth Skylight and rating it as rare, medium-, or well-done.

RESULTS AND DISCUSSION

Rate of Heat Penetration and Cooking Time

The rate of heat penetration to the center of the roasts depended on the type of heat and the oven temperature. However, differences among treatments were not significant (Table 3). Mean values for the minutes required for the internal temperature at the center of the roasts to rise to 0°C were similar for dry heat at 325° and 350° and approximately 7 min less than for dry heat at 300°F. For moist heat, roasts cooked at 325°F required the shortest time for the internal temperature to rise to 0°C; roasts cooked at 300°F took 13.9 min more than at 325°F, and those cooked at 350°F took 6.2 min longer.

The average time for the temperature at the center of roasts cooked by dry heat to increase from 0° to 10°C was least at 300°F; 8.1 and 4.8 min less than at 325° and 350°F, respectively (Table 3). With moist

Table 3. Means, F-values, and LSD[a] for objective and organoleptic measurements of frozen, boned beef rib roasts.

Measurement	Dry Heat, °F			Moist Heat, °F			F-value	LSD[a]
	300	325	350	300	325	350		
Initial weight, g	1903	1944	1884	1928	1779	1968	---	---
Initial weight, lb	4.2	4.3	4.2	4.2	3.9	4.3	---	---
Rate of heat penetration								
Min to 0°C	118.8	111.5	111.8	129.7	115.8	121.7	1.78 ns	---
Min 0° to 10°C	17.2	25.3	22.0	23.5	18.2	18.3	0.76 ns	---
Min/5°C, 10°-60°C	5.8	6.3	5.9	4.6	4.8	4.5	---	---
Cooking time								
Total, min	195.2	199.3	192.2	198.5	182.5	185.5	1.59 ns	---
Min/lb	49.0	47.4	47.3	47.8	47.3	43.4	1.16 ns	---
Cooking losses, % of original wt. of roast								
Total	26.4	27.1	23.1	26.2	27.8	23.3	0.55 ns	---
Volatile	12.8	17.6	12.3	---	---	---	---	---
Dripping	8.0	8.6	9.6	16.0	18.0	16.4	49.60**	4.1
Fat in drippings, % of volume	75.4	88.0	77.0	27.7	33.9	36.5	12.50**	20.1
Total moisture, %	65.0	64.0	64.4	63.0	62.9	62.9	14.42**	1.5

Table 3. (continued)

Measurement	Dry Heat, °F			Moist Heat, °F			F-value	LSD[a]
	300	325	350	300	325	350		
WHC[b]	0.68	0.67	0.69	0.66	0.66	0.66	2.06 ns	---
Shear value, lb/1/2 in. core								
Over-all	5.6	5.8	5.9	7.0	7.0	7.2	17.68*	0.9
Medial	5.5	5.8	5.7	7.4	6.8	7.2	15.80*	1.4
Central	5.9	5.8	5.0	6.5	6.8	6.3	9.02*	1.1
Lateral	5.4	5.7	7.1	7.0	7.4	6.3	4.65*	1.4
Gardner Color-difference								
Rd (reflectance)	19.6	19.9	19.2	20.0	20.0	20.0	0.23 ns	---
a+ (redness)	8.4	6.8	8.9	6.1	4.9	6.2	12.52*	2.3
b+ (yellowness)	11.6	11.1	11.2	11.3	11.2	11.2	0.26 ns	---
pH	5.7	5.7	5.7	5.7	5.7	5.7	0.14 ns	---
Sensory scores								
Flavor[c]	5.5	5.8	5.6	5.6	4.9	5.4	5.61*	0.6
Tenderness[c]	5.8	5.4	6.0	5.5	5.3	5.5	1.42 ns	---
Juiciness[c]	5.3	5.3	5.3	5.1	4.5	5.2	1.00 ns	---
Over-all acceptability[c]	5.3	5.6	5.6	5.2	4.9	5.2	5.43*	0.6

Table 3. (concluded)

Measurement	Dry Heat, °F			Moist Heat, °F			F-value	LSD[a]
	300	325	350	300	325	350		
Apparent degree of doneness[c]	1.3	1.6	1.6	1.9	2.0	2.1	10.12**	0.6

[a] LSD, least significant difference at 5% level.

[b] WHC, water-holding capacity (1.0--expressible moisture index).

[c] Range, 7 (extremely desirable, tender, juicy or acceptable) to 1 (extremely undesirable, tough, dry, or unacceptable).

* $P \leq 0.05$.

** $P \leq 0.01$.

heat, at 325° and 350°F the average time for the temperature to increase from 0° to 10°C was similar and about 5 min less than at 300°F.

With both dry and moist heat the average time for a 5°C increase in internal temperature was about the same at all three oven temperatures.

Details of mean data in Table 3 can be observed in the heat penetration curves (Figures 2 and 3) and in Table 8, Appendix. With both moist and dry heat and at all oven temperatures, heat penetrated the muscle at a fairly constant rate. Also, with both dry and moist heat and below an internal temperature of 0°C, heat penetrated the muscle a little more slowly at 300° than at 325° and 350°F.

After an internal temperature of 0°C (0° to 60°C), with dry heat the rate of heat penetration was faster at 300° than at 325° and 350°F, and at 350°F the rate of penetration was faster than at 325°F. With moist heat, the internal temperature rose a little more slowly from 0° to 60°C at 300°F than at the two higher temperatures. Moist heat curves for 325° and 350°F followed almost the same pattern; at 325°F, heat penetrated the muscle slightly faster than at 350°F until the 20° to 25°C interval was reached. After that, the internal temperature of roasts cooked at 350°F rose slightly faster than the temperature of roasts cooked at 325°F, and reached the end point first.

Between 0° and 60°C differences among oven temperatures in rate of heat penetration were greater with dry than with moist heat (Table 3). When data for all oven temperatures were combined, differences between dry and moist heat were significant ($P \leq 0.05$ or 0.01) at every 5°C interval from 20° to 60°C except between 25° and 30°C (Table 31, Appendix). Differences among all six treatments (type of heat and oven

Fig. 2. Rate of heat penetration from initial temperature to 0°C and from 0° to 60°C for longissimus dorsi muscle heated to 60°C by dry heat.

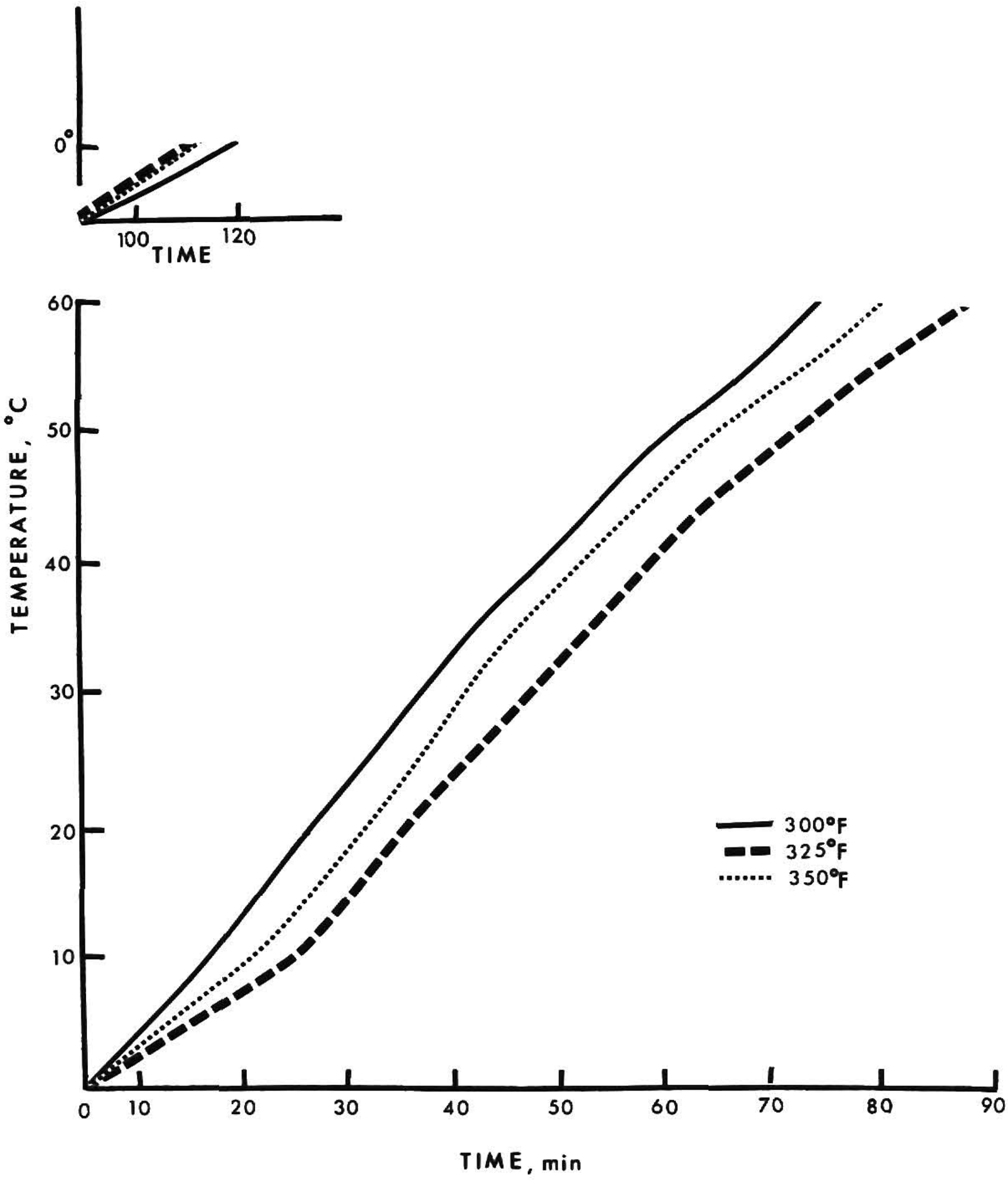
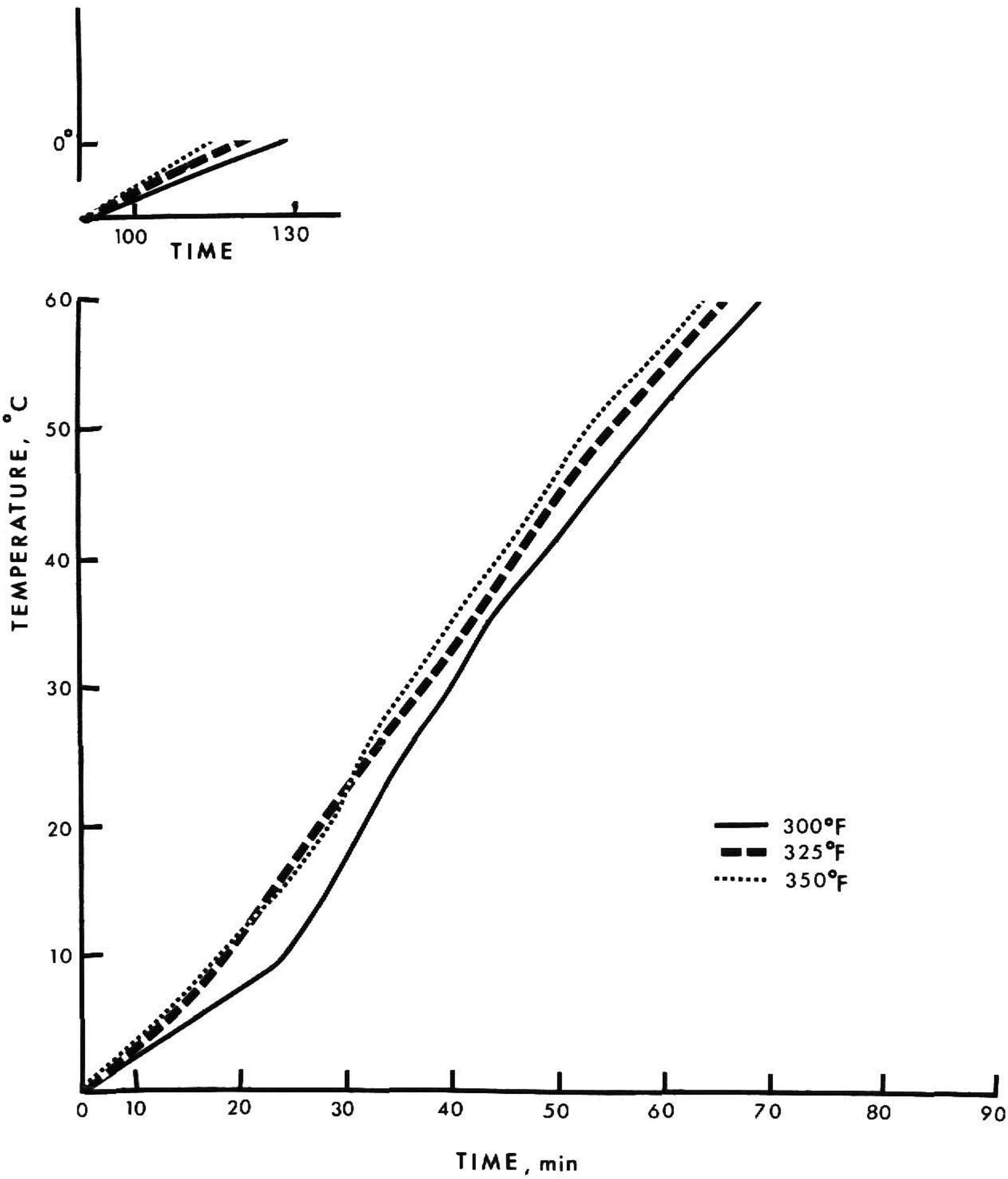

0°
100
TIME
120
60
50
40
30
20
10
TEMPERATURE, °C
0
10
20
30
40
50
60
70
80
90
TIME, min
300°F
325°F
350°F

Fig. 3. Rate of heat penetration from initial temperature to 0°C and from 0° to 60°C for longissimus dorsi muscle heated to 60°C by moist heat.


0°
100
130
TIME
60
50
40
30
20
10
TEMPERATURE, °C
0
10
20
30
40
50
60
70
80
90
TIME, min
300°F
325°F
350°F

temperature) were significant ($P \leq 0.05$ or 0.01) at every 5°C interval between 20° and 60°C except between 25° and 30°, 35° and 40° and 55° to 60°C (Table 31, Appendix).

The longest part of the cooking time was the time to rise to 0°C (Table 3, Figures 2 and 3). Generally, total cooking time for roasts cooked by moist heat was slightly less than for those cooked by dry heat (Table 3). Differences between the two types of heat or among oven temperatures were not significant. Also, on the basis of min/lb, cooking time was not affected significantly by type of heat or oven temperature (Table 3). Also, Schock _et al._ (1970) found that oven-braised beef cooked slightly faster than oven-roasted beef.

Cooking Losses, Total Moisture, Water-holding Capacity

Total cooking losses were not affected significantly by type of heat or oven temperature. At all oven temperatures dripping losses were significantly ($P \leq 0.05$) less for dry than for moist heat. Volatile losses were not measured for moist heat. However, if calculated as the difference between total and dripping losses, they ranged from approximately 30 to 40% of the total losses; whereas volatile losses for dry heat (Table 3) were approximately 50 to 65% of total losses. The percentage of fat in drippings, on the basis of volume, was less ($P \leq 0.05$) for moist than for dry heat (Table 3). This is attributed to the larger volume of drippings from roasts cooked by moist heat.

Within each type of heat, total moisture was not affected by oven temperature, but at 300° and 350°F it was affected ($P \leq 0.05$) by type of heat. At 300°F dry heat produced muscle with more ($P \leq 0.05$) moisture than muscle from roasts cooked by moist heat at all three oven temperatures; at 350°F dry heat produced muscle with more ($P \leq 0.05$) moisture than was produced by moist heat at 325° and 350°F. At 325°F differences in total moisture were not significant (Table 3).

Water-holding capacity was not affected by type of heat or oven temperature (Table 3).

Shear Values, Color-difference, and pH

Warner-Bratzler shear values for cores taken at each of three positions (medial, central, lateral) and the over-all (average of all three positions) shear value for the LD muscle were significantly ($P \leq 0.05$) lower (more tender muscle) for muscle from roasts cooked by dry heat than for muscle from roasts cooked by moist heat. Oven temperature had no significant effect on shear values (Table 3).

Gardner color-difference reflectance (Rd) and yellowness (b+) values for LD muscle were not affected significantly by type of heat or oven temperature. Within one type of heat color-difference values for redness (a+) were not affected significantly by oven temperature. With dry heat at 300°F a+ values were significantly ($P \leq 0.05$) greater (more red muscle) than with moist heat at 300° and 325°F. Dry heat at 350°F produced muscle that was significantly ($P \leq 0.05$) redder than muscles produced by moist heat at all three oven temperatures (Table 3).

Neither type of heat nor oven temperature affected pH significantly (Table 3).

Effect of Type of Heat and Oven Temperature on Sensory Characteristics

For flavor and over-all acceptability, significant ($P \leq 0.05$) differences between dry and moist heat occurred only at 325°F. With dry heat, flavor scores were not affected significantly by oven temperature. With moist heat, flavor scores were higher ($P \leq 0.05$) at 300° than at 325°F (Table 3).

The only difference in over-all acceptability attributable to type of heat occurred at 325°F; roasts cooked by dry heat were more acceptable ($P \leq 0.05$) than those cooked by moist heat. Within each type of heat over-all acceptability scores were not significantly affected by oven temperature (Table 3).

Tenderness and juiciness scores were not affected significantly by type of heat or oven temperature.

In general, apparent degree of doneness scores agreed with Gardner color-difference a+ values. With dry heat at 300°F, doneness scores were higher ($P \leq 0.05$, more rare) than at 325° and 350°F and higher ($P \leq 0.05$) than with moist heat at all three oven temperatures. Within both types of heat doneness scores were not affected significantly by oven temperature (Table 3).

Effect of Animal Variation and Position in the Carcass on Data Obtained

When the experiment was designed the analysis of variance (p. 14) was planned to study differences in each measurement attributable to: (1) variation among animals (carcasses), (2) the side (left or right) of the carcass, and (3) the position (anterior, middle, posterior) in the rib section. Twenty measurements were made on 36 roasts (18 pair) from three positions in the rib section of six carcasses. Data for 65% (13) of the measurements varied significantly among animals, whereas significant differences attributable to treatment occurred for 40% (7) of the measurements (Tables 4 and 32, Appendix). Harrison *et al.* (1953) found that for 13 different cuts from nine beef carcasses significant differences attributable to animals were more numerous than those attributable to treatment (cooking method). In their study measurements for which significant animal variation occurred frequently were percentage cooking losses; percentage fat in the muscle; and panel scores for flavor, tenderness, and juiciness. Measurements for which animal variation occurred less frequently were pH and press fluid yield. Data from this study and that of Harrison et al. (1953) support the generally accepted idea that in designing experiments with meat, animal variation must be considered, and a sufficient number of animals should be used to provide "sound" data.

Data for only one measurement, pH, differed significantly ($P \leq 0.05$) between left and right sides of the carcass (Table 5). These data support the hypothesis that paired cuts of beef ribs may be used to compare effects of treatments.

Significant differences attributable to position (anterior to posterior) in the rib section were numerous (Table 5), and indicated that samples from the anterior to the posterior of beef ribs should be assigned at random to treatments. A significant linear effect occurred in 85% (17) of the 20 measurements; 55% (11) were for measurements on the left side of the carcass and 30% (6) were for measurements on the right side. A quadratic effect occurred in 25% (5) of the measurements; 15% (3) on the left side and 10% (2) on the right side.

Satorius and Child (1938) studied differences among beef roasts from the 7-8th, 9-10th, and 11-12th ribs on the right side of 13 carcasses. Press fluid was higher and cooking losses lower in 11-12th rib

Table 4. Significant differences attributable to animals and treatment.

Measurement	Level of probability	
	Animals	Treatment
Cooking time		
Total min	*	ns
Min/lb	**	ns
Cooking losses, % of initial wt		
Total	ns	ns
Dripping	*	**
Fat in drippings, % of volume	ns	**
Waterholding capacity	ns	ns
Total moisture	**	*
Juiciness score	ns	ns
Flavor score	ns	*
Over-all acceptability score	ns	ns
Apparent doneness score	ns	ns
Tenderness score	**	ns
Shear		
Over-all	**	*
Medial	**	*
Central	**	ns
Lateral	**	*
Color-difference		
Reflectance, Rd	*	ns
Redness, a+	**	*
Yellowness, b+	*	ns
pH	**	ns

*, $P \leq 0.05$.

**, $P \leq 0.01$.

Table 5. Significant differences between left and right sides of the carcass and among positions in the rib section.

Measurement	Level of probability				
		Position in rib section			
	Left vs right	Linear Effect Left	Linear Effect Right	Quadratic effect Left	Quadratic effect Right
Cooking time					
Total, min	ns	decr.**	ns	ns	ns
Min/lb	ns	incr.**	incr.**	ns	ns
Cooking losses, % of initial weight					
Total	ns	ns	incr.*	ns	ns
Dripping	ns	ns	incr.**	ns	ns
Fat in drippings, % of volume	ns	ns	ns	ns	ns
Waterholding capacity	ns	ns	ns	ns	ns
Total moisture	ns	incr.*	ns	ns	ns
Juiciness score	ns	decr.**	ns	ns	ns
Flavor score	ns	decr.**	ns	ns	ns
Over-all acceptability	ns	decr.**	ns	ns	ns
Apparent doneness score	ns	incr.**	incr.*	ns	ns
Tenderness score	ns	ns	ns	*	ns
Shear value					
Over-all	ns	decr.**	ns	ns	*
Medial	ns	ns	ns	ns	*
Central	ns	decr.*	ns	ns	ns
Lateral	ns	ns	ns	*	ns
Color-difference					
Reflectance, Rd	ns	incr.*	incr.*	*	ns
Redness, a+	ns	decr.**	decr.**	ns	ns
Yellowness, b+	ns	ns	ns	ns	ns
pH	*	ns	ns	ns	ns

*, $P \leq 0.05$. decr., decrease from anterior to posterior.

**, $P \leq 0.01$. incr., increase from anterior to posterior.

roasts than in 9-10th or 7-8th ribs, between which there were no differences. Shear force did not differ among the three cuts. Ether extract was higher in 7-8th ribs than in 9-10th or 11-12th ribs. Total moisture was lowest in 7-8th ribs and highest in 11-12th ribs with the 9-10th ribs ranking between the roasts from the other two positions. They concluded that for work involving only physical properties, i.e. press fluid, tenderness, and cooking losses the 7-8th and 9-10th ribs can be used as comparable cuts, but if chemical analyses are involved none of the three cuts (7-8th, 9-10th, 11-12th ribs) are comparable. However, they stated that the order of the roasts should always be rotated in the experiment.

SUMMARY

A 6 X 6 Latin square was used to evaluate the effect of type of heat and oven temperature on 18 pair of beef rib roasts frozen by liquid nitrogen vapor. Roasts were cooked by dry and moist heat at 300°, 325°, and 350°F to an internal temperature of 60°C, and evaluated by selected objective and sensory measurements.

Both types of heat penetrated the roasts at a fairly constant rate, and rate of heat penetration was not affected significantly by type of heat or oven temperature, but the rate of penetration was slower below 0°C than it was from 0° to 60°C. Generally, total cooking time was slightly less for roasts cooked by moist heat than for those cooked by dry heat. Total cooking losses were not affected significantly by type of heat or oven temperature. At all oven temperatures dripping losses were significantly ($P \leq 0.05$) less for dry than for moist heat, and the percentage fat, by volume, in the drippings was less ($P \leq 0.05$) for moist than for dry heat. Within each type of heat, total moisture was not affected by oven temperature, but at 300° and 350°F it was affected by type of heat. Waterholding capacity of the LD muscle was not affected by type of heat or oven temperature.

Shear values were lower ($P \leq 0.05$) for roasts cooked by moist heat, but were not affected significantly by oven temperature. Both Gardner $\underline{a+}$ values and apparent degree of doneness scores rated the degree of redness of the LD muscle higher ($P \leq 0.05$) for dry than for moist heat. Neither type of heat or oven temperature significantly affected pH.

For flavor and over-all acceptability, significant ($P \leq 0.05$) differences between dry and moist heat occurred only at 325°F. Tenderness and juiciness of the LD muscle were not affected significantly by type of heat or oven temperature.

Data for 20 measurements on 36 roasts from three positions in the rib sections of six carcasses indicate that in designing experiments with meat: (1) animal variation must be considered, (2) paired cuts of beef ribs may be used to compare effects of treatments, and (3) samples from the anterior to the posterior of beef ribs should be assigned at random to treatments.

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APPENDIX

Form I

Project 5-944

Score Card for Evaluating the Palatability of Boned Rib Roasts

Judge ______________ Code ______________ Date ______________

Sample No.	Desirability of flavor	Juiciness	Tenderness		Over-all acceptability	Apparent degree of doneness	Comments
			No. chews	Score			
1							
2							

Descriptive terms for scoring:

Desirability of flavor	Juiciness	Tenderness	Over-all acceptability
7. Extremely desirable	7. Extremely juicy	7. Extremely tender	7. Extremely desirable
6. Desirable	6. Juicy	6. Tender	6. Desirable
5. Moderately desirable	5. Moderately juicy	5. Moderately tender	5. Moderately desirable
4. Acceptable	4. Acceptable	4. Acceptable	4. Acceptable
3. Slightly undesirable	3. Slightly dry	3. Slightly tough	3. Slightly undesirable
2. Undesirable	2. Dry	2. Tough	2. Undesirable
1. Extremely undesirable	1. Extremely dry	1. Extremely tough	1. Extremely undesirable

Apparent degree of doneness

1. Rare
2. Medium-done
3. Well-done

Form II

Instructions to Judges for Sensory Evaluation of Boned Beef Rib Roasts

You may select two cubes of meat from each double-boiler for scoring the palatability characteristics. Use one cube for counting the number of chews and the other for scoring flavor, juiciness and over-all acceptability.

Scoring for flavor and juiciness

Record a score for flavor and another for juiciness within a range of 7 to 1 that describes your impression of the sample. See the score card for descriptive terms for specific scores within the range of 7 to 1. Record the score describing your impression of flavor and juiciness at the beginning of the chewing process.

Scoring for tenderness

Count the number of times you chew the 0.5-in. cube of meat before swallowing. Chew until the cube is masticated completely, then swallow. Record the number of chews required to masticate the cube. Record a score from 7 to 1 that describes your impression of the tenderness of the cube. See the score card for descriptive terms for specific scores within the range of 7 to 1.

Use the number of chews to help you standardize your tenderness scores from day to day. Set up for yourself a range of the number of chews for each score from 7 to 1. For example, if you chew from 15 to 25 times, you might record a score of 7; if you chew 25 to 35 times, a score of 6; 35 to 45, a score of 5; continuing to reduce the score by a given number of increased chews. Each judge sets his own range of chews for a given score.

Over-all acceptability

Record a score that describes your impression of the general desirability of the sample. This is not a total score, i.e., it is not a score obtained by adding the scores for the other factors. Score over-all acceptability within the range of 7 to 1, the same as for each of the other factors listed on the score card.

Apparent degree of doneness

Observe the slices of meat placed under the MacBeth Skylight and record a score that describes your impression of degree of doneness; i.e., 1 = rare, 2 = medium-done, and 3 = well-done.

Comments

Comments about a sample and/or explaining your reason for giving a particular score are helpful.

Take your time to score each sample. Water is provided for rinsing your mouth between samples.

Table 6. Initial weight, g.

Temperature, °F	Dry Heat An. and roast number	Dry Heat wt., g	Moist Heat An. and roast number	Moist Heat wt., g
300	I,6	1454	I,1	2193
	II,3	1266	II,2	1641
	III,1	2439	III,3	1748
	IV,2	1781	IV,6	1654
	V,5	2216	V,4	2409
	VI,4	2264	VI,5	1921
	Av.	1903		1928
325	I,4	2071	I,5	1873
	II,6	1224	II,1	1941
	III,5	2038	III,6	1550
	IV,1	2250	IV,4	1693
	V,3	2162	V,2	2198
	VI,2	1921	VI,3	1417
	Av.	1944		1779
350	I,2	1786	I,3	1683
	II,3	1712	II,4	1880
	III,4	1718	III,2	2079
	IV,3	1421	IV,5	2023
	V,6	2218	V,1	2528
	VI,1	2450	VI,6	1615
	Av.	1884		1968

Table 7. Initial weight, lb.

Temperature, °F	Dry Heat		Moist Heat	
	An. and roast number	wt., lb	An. and roast number	wt., lb
300	I,6	3.2	I,1	4.8
	II,3	2.8	II,2	3.6
	III,1	5.4	III,3	3.8
	IV,2	3.9	IV,6	3.6
	V,5	4.9	V,4	5.3
	VI,4	5.0	VI,5	4.2
	Av.	4.2		4.2
325	I,4	4.6	I,5	4.1
	II,6	2.7	II,1	4.3
	III,5	4.5	III,6	3.4
	IV,1	5.0	IV,4	3.7
	V,3	4.8	V,2	4.8
	VI,2	4.2	VI,3	3.1
	Av.	4.3		3.9
350	I,2	3.9	I,3	3.7
	II,3	3.8	II,4	4.1
	III,4	3.8	III,2	4.6
	IV,3	3.1	IV,5	4.4
	V,6	4.9	V,1	5.6
	VI,1	5.4	VI,6	3.6
	Av.	4.2		4.3

Table 8. Rate of heat penetration in minutes to reach 0°C and to increase from 0° to 10°C and every 5°C from 10° to 60°C.

Oven (°F)	Temperature (°C)												
	0	10	15	20	25	30	35	40	45	50	55	60	Avg, 10° to 60°C
							Dry Heat						
300	169	11	7	4	3	4	4	5	4	2	4	6	
	93	22	6	5	4	5	4	6	5	5	8	8	
	95	23	6	4	4	5	4	5	6	10	14	5	
	103	16	4	6	5	5	5	6	5	5	7	6	
	138	10	5	5	4	7	6	6	8	8	6	5	
	115	21	4	5	5	7	7	7	6	8	10	10	
	118.8	17.2	5.3	4.8	4.2	5.5	5.0	5.8	5.7	6.3	8.2	6.7	5.8
							Moist Heat						
	164	27	4	4	3	5	3	4	3	5	4	7	
	131	28	6	3	4	3	5	4	4	6	4	6	
	123	12	4	4	5	4	4	5	6	6	6	6	
	127	20	2	2	3	3	3	4	4	3	6	5	
	115	24	6	7	5	5	2	9	5	7	4	7	
	118	30	5	2	2	5	4	5	5	4	6	5	
	129.7	23.5	4.5	3.7	3.7	4.2	3.5	5.2	4.5	5.2	5.0	6.0	4.6

Table 8. (continued)

Oven (°F)	Temperature (°C)												
	0	10	15	20	25	30	35	40	45	50	55	60	Avg, 10° to 60°C
	Dry Heat												
325	107	25	8	6	8	6	7	7	8	9	8	10	
	80	24	4	3	5	5	5	5	5	8	6	9	
	131	25	4	4	6	4	6	5	7	6	7	8	
	117	27	7	5	5	6	5	5	6	6	10	3	
	113	27	6	6	4	7	6	6	7	8	8	8	
	121	24	2	5	5	5	5	6	9	8	8	9	
	111.5	25.3	5.2	5.5	5.5	5.5	5.7	5.7	7.0	7.5	7.8	7.8	6.3
	Moist Heat												
	106	20	5	7	5	7	6	7	6	7	8	8	
	129	21	7	3	5	5	5	3	4	4	5	4	
	110	15	4	3	4	4	4	4	3	5	5	4	
	94	16	6	6	5	5	6	4	3	5	5	6	
	131	24	6	5	5	6	5	3	5	5	5	6	
	125	13	2	3	3	3	3	3	4	4	4	5	
	115.8	18.2	5.0	4.5	4.5	5.0	4.8	4.0	4.2	5.0	5.3	5.5	4.8

Table 8, (concluded)

Oven (°F)	Temperature (°C) 0	10	15	20	25	30	35	40	45	50	55	60	Avg, 10° to 60°C
							Dry Heat						
350	122	20	3	5	5	5	5	6	6	7	7	10	
	109	29	5	4	4	4	5	6	6	8	9	6	
	103	18	4	4	4	5	5	5	5	7	6	6	
	110	14	2	3	3	3	4	4	7	3	6	8	
	108	30	10	9	5	6	5	6	7	8	9	9	
	119	21	7	5	5	5	5	7	6	10	9	10	
	111.8	22.0	5.2	5.0	4.3	4.7	4.8	5.7	6.2	7.2	7.7	8.2	5.9
							Moist Heat						
	104	23	6	6	4	5	6	5	4	4	6	5	
	119	18	3	5	4	6	3	4	4	4	4	5	
	130	19	5	3	3	3	4	4	5	3	5	4	
	139	12	3	3	4	6	2	6	4	4	6	6	
	128	17	5	4	4	5	3	6	6	5	6	10	
	110	21	8	4	3	4	3	4	3	4	5	5	
	121.7	18.3	5.0	4.2	3.7	4.8	3.5	4.8	4.3	4.0	5.3	5.8	4.5

Table 9. Total cooking time in minutes.

Temperature, °F	Dry Heat: An. and roast number	Dry Heat: Time	Moist Heat: An. and roast number	Moist Heat: Time
300	I,6	223	I,1	233
	II,3	171	II,2	204
	III,1	191	III,3	185
	IV,2	173	IV,6	182
	V,5	208	V,4	196
	VI,4	205	VI,5	191
	Av.	195.2		198.5
325	I,4	209	I,5	192
	II,6	159	II,1	195
	III,5	213	III,6	165
	IV,1	202	IV,4	161
	V,3	206	V,2	206
	VI,2	207	VI,3	176
	Av.	199.3		182.5
350	I,2	201	I,3	178
	II,3	195	II,4	179
	III,4	172	III,2	188
	IV,3	167	IV,5	195
	V,6	212	V,1	199
	VI,1	206	VI,6	174
	Av.	192.2		185.5

Table 10. Cooking time in min/lb.

Temperature, °F	Dry Heat		Moist Heat	
	An. and roast number	Time	An. and roast number	Time
300	I,6	69.7	I,1	48.5
	II,3	61.1	II,2	56.6
	III,1	35.4	III,3	48.7
	IV,2	44.4	IV,6	50.6
	V,5	42.4	V,4	37.0
	VI,4	41.0	VI,5	45.5
	Av.	49.0		47.8
325	I,4	45.4	I,5	46.8
	II,6	58.9	II,1	45.3
	III,5	47.3	III,6	48.5
	IV,1	40.4	IV,4	43.5
	V,3	42.9	V,2	42.9
	VI,2	49.3	VI,3	56.8
	Av.	47.4		47.3
350	I,2	51.5	I,3	48.4
	II,6	51.3	II,4	43.6
	III,4	45.3	III,6	40.9
	IV,3	53.9	IV,5	44.3
	V,6	43.3	V,1	35.5
	VI,1	38.7	VI,6	48.3
	Av.	47.3		43.4

Table 11. Variation in cooking time as related to oven temperature, method of cooking and weight of roast.

300°F			325°F			350°F		
An. and roast no.	Wt,lb	Min	An. and roast no.	Wt,lb	Min	An. and roast no.	Wt,lb	Min
			Dry Heat					
I,6	3.2	223	I,4	4.6	209	I,2	3.9	201
II,3	2.8	171	II,6	2.7	159	II,5	3.8	195
III,1	5.4	191	III,5	4.5	213	III,4	3.8	172
IV,2	3.9	173	IV,1	5.0	202	IV,3	3.1	167
V,5	4.9	208	V,3	4.8	206	V,6	4.9	212
VI,4	5.0	205	VI,2	4.2	207	VI,1	5.4	206
Av.	4.2	195.2		4.3	199.3		4.2	192.2
			Moist Heat					
I,1	4.8	233	I,5	4.1	192	I,3	3.7	178
II,2	3.6	204	II,1	4.3	195	II,4	4.1	179
III,3	3.8	185	III,6	3.4	165	III,2	4.6	188
IV,6	3.6	182	IV,4	3.7	161	IV,5	4.4	195
V,4	5.3	196	V,2	4.8	206	V,1	5.6	199
VI,5	4.2	191	VI,3	3.1	176	VI,6	3.6	174
Av.	4.2	198.5		3.9	182.5		4.3	185.5

Table 12. Total cooking losses, % of original weight of roast.

Temperature, °F	Dry Heat An. and roast number	Dry Heat Loss	Moist Heat An. and roast number	Moist Heat Loss
300	I,6	22.6	I,1	15.5
	II,3	44.1	II,2	21.4
	III,1	20.0	III,3	21.1
	IV,2	24.4	IV,6	42.9
	V,5	22.7	V,4	23.2
	VI,4	24.0	VI,5	33.0
	Av.	26.4		26.2
325	I,4	25.0	I,5	21.2
	II,6	27.3	II,1	23.8
	III,5	29.0	III,6	45.9
	IV,1	26.4	IV,4	21.8
	V,3	28.3	V,2	26.4
	VI,2	26.4	VI,3	27.9
	Av.	27.1		27.8
350	I,2	21.8	I,3	21.9
	II,3	26.9	II,4	20.6
	III,4	20.0	III,6	23.7
	IV,3	18.4	IV,5	22.5
	V,6	31.5	V,1	24.8
	VI,1	20.0	VI,6	26.2
	Av.	23.1		23.3

Table 13. Volatile cooking loss, % of original weight of roast.

Temperature, °F	Dry Heat An. and roast number	Dry Heat Loss	Moist Heat An. and roast number	Moist Heat Loss
300	I,6	7.4		---
	II,3	13.3		---
	III,1	10.7		---
	IV,2	12.0		---
	V,5	14.7		---
	VI,4	18.4		---
	Av.	12.8		
325	I,4	20.7		---
	II,6	21.0		---
	III,5	10.1		---
	IV,1	19.0		---
	V,3	17.0		---
	VI,2	17.6		---
	Av.	17.6		
350	I,2	13.9		---
	II,3	14.7		---
	III,4	7.6		---
	IV,3	7.7		---
	V,6	15.2		---
	VI,1	14.6		---
	Av.	12.3		

Table 14. Dripping cooking losses, % of original weight of roast.

Temperature, °F	Dry Heat: An. and roast number	Dry Heat: Loss	Moist Heat: An. and roast number	Moist Heat: Loss
300	I,6	8.5	I,1	17.5
	II,3	6.7	II,2	9.4
	III,1	5.0	III,3	22.2
	IV,2	11.3	IV,6	18.9
	V,5	11.8	V,4	8.5
	VI,4	4.6	VI,5	19.2
	Av.	8.0		16.0
325	I,4	4.2	I,5	11.0
	II,6	6.0	II,1	16.1
	III,5	15.0	III,6	22.4
	IV,1	7.2	IV,4	18.5
	V,3	11.0	V,2	17.3
	VI,2	8.4	VI,3	22.7
	Av.	8.6		18.0
350	I,2	7.7	I,3	11.2
	II,3	6.5	II,4	12.7
	III,4	5.6	III,6	15.7
	IV,3	16.9	IV,5	21.4
	V,6	16.0	V,1	15.7
	VI,1	5.2	VI,6	21.5
	Av.	9.6		16.4

Table 15. Fat in drippings, % of volume of drippings.

Temperature, °F	Dry Heat An. and roast number	Dry Heat Fat	Moist Heat An. and roast number	Moist Heat Fat
300	I,6	---	I,1	---
	II,3	71.4	II,2	32.2
	III,1	88.2	III,3	41.7
	IV,2	96.5	IV,6	42.6
	V,5	36.5	V,4	23.5
	VI,4	84.2	VI,5	26.4
	Av.	75.4		27.7
325	I,4	87.2	I,5	20.0
	II,6	66.7	II,1	30.5
	III,5	91.7	III,6	72.4
	IV,1	90.6	IV,4	27.4
	V,3	96.7	V,2	19.8
	VI,2	95.0	VI,3	33.4
	Av.	88.0		33.9
350	I,2	23.3	I,3	37.2
	II,3	83.3	II,4	21.5
	III,4	91.0	III,2	46.0
	IV,3	83.0	IV,5	52.7
	V,6	89.7	V,1	34.0
	VI,1	92.0	VI,6	27.4
	Av.	77.0		36.5

Table 16. Total Moisture (T.M.), %.

Temperature, °F	Dry Heat An. and roast number	Dry Heat T.M.	Moist Heat An. and roast number	Moist Heat T.M.
300	I,6	66.5	I,1	62.4
	II,3	66.8	II,2	62.6
	III,1	65.6	III,3	65.4
	IV,2	64.5	IV,6	61.4
	V,5	64.3	V,4	63.6
	VI,4	62.1	VI,5	62.7
	Av.	65.0		63.0
325	I,4	64.8	I,5	67.2
	II,6	64.4	II,1	62.9
	III,5	64.9	III,6	64.5
	IV,1	63.3	IV,4	61.9
	V,3	64.2	V,2	60.1
	VI,2	62.6	VI,3	60.8
	Av.	64.0		62.9
350	I,2	67.2	I,3	66.4
	II,3	65.3	II,4	64.0
	III,4	66.3	III,2	62.5
	IV,3	64.2	IV,5	61.0
	V,6	62.2	V,1	61.5
	VI,1	61.4	VI,6	62.1
	Av.	64.4		62.9

Table 17. Water-holding capacity, WHC.

Temperature, °F	Dry Heat An. and roast number	Dry Heat WHC	Moist Heat An. and roast number	Moist Heat WHC
300	I,6	0.686	I,1	0.699
	II,3	0.743	II,2	0.684
	III,1	0.631	III,3	0.647
	IV,2	0.724	IV,6	0.611
	V,5	0.687	V,4	0.693
	VI,4	0.601	VI,5	0.663
	Av.	0.679		0.666
325	I,4	0.675	I,5	0.690
	II,6	0.698	II,1	0.693
	III,5	0.699	III,6	0.737
	IV,1	0.648	IV,4	0.564
	V,3	0.658	V,2	0.653
	VI,2	0.649	VI,3	0.626
	Av.	0.671		0.660
350	I,2	0.673	I,3	0.605
	II,3	0.707	II,4	0.690
	III,4	0.714	III,2	0.614
	IV,3	0.693	IV,5	0.689
	V,6	0.696	V,1	0.705
	VI,1	0.679	VI,6	0.641
	Av.	0.694		0.657

Table 18. Over-all shear value; lb/0.5-in. core.

Temperature, °F	Dry Heat: An. and roast number	Dry Heat: Shear	Moist Heat: An. and roast number	Moist Heat: Shear
300	I,6	4.9	I,1	7.5
	II,3	7.3	II,2	8.8
	III,1	5.1	III,3	6.1
	IV,2	5.4	IV,6	5.6
	V,5	5.7	V,4	6.7
	VI,4	5.0	VI,5	7.0
	Av.	5.6		7.0
325	I,4	5.8	I,5	5.2
	II,6	7.0	II,1	11.9
	III,5	4.8	III,6	5.2
	IV,1	6.2	IV,4	7.4
	V,3	5.6	V,2	6.2
	VI,2	5.2	VI,3	6.0
	Av.	5.8		7.0
350	I,2	6.0	I,3	5.9
	II,3	8.2	II,4	8.9
	III,4	5.1	III,2	4.1
	IV,3	5.3	IV,5	7.2
	V,6	5.8	V,1	7.0
	VI,1	5.2	VI,6	6.3
	Av.	5.9		6.6

Table 19. Shear values (Medial).

Temperature, °F	Dry Heat: An. and roast number	Dry Heat: Shear	Moist Heat: An. and roast number	Moist Heat: Shear
300	I,6	4.1	I,1	8.6
	II,3	7.6	II,2	9.8
	III,1	4.8	III,3	5.3
	IV,2	5.2	IV,6	7.2
	V,5	6.0	V,4	6.1
	VI,4	5.1	VI,5	7.2
	Av.	5.5		7.4
325	I,4	5.6	I,5	5.3
	II,6	7.0	II,1	10.9
	III,5	4.8	III,6	5.8
	IV,1	6.1	IV,4	7.4
	V,3	6.7	V,2	6.4
	VI,2	4.4	VI,3	5.1
	Av.	5.8		6.8
350	I,2	6.2	I,3	6.8
	II,3	7.6	II,4	9.4
	III,4	5.3	III,2	3.7
	IV,3	3.5	IV,5	9.4
	V,6	6.5	V,1	7.4
	VI,1	4.9	VI,6	6.3
	Av.	5.7		7.2

Table 20. Shear values (Central).

Temperature, °F	Dry Heat: An. and roast number	Dry Heat: Shear	Moist Heat: An. and roast number	Moist Heat: Shear
300	I,6	5.3	I,1	7.2
	II,3	7.1	II,2	8.5
	III,1	5.7	III,3	6.2
	IV,2	6.6	IV,6	4.0
	V,5	5.7	V,4	6.4
	VI,4	5.0	VI,5	6.6
	Av.	5.9		6.5
325	I,4	5.4	I,5	5.8
	II,6	6.3	II,1	11.3
	III,5	6.0	III,6	4.5
	IV,1	6.3	IV,4	7.2
	V,3	5.4	V,2	6.4
	VI,2	5.4	VI,3	5.8
	Av.	5.8		6.8
350	I,2	5.5	I,3	5.9
	II,3	6.6	II,4	8.0
	III,4	4.7	III,2	4.5
	IV,3	3.8	IV,5	6.1
	V,6	5.5	V,1	6.8
	VI,1	4.2	VI,6	6.4
	Av.	5.0		6.3

Table 21. Shear values (Lateral).

Temperature, °F	Dry Heat		Moist Heat	
	An. and roast number	Shear	An. and roast number	Shear
300	I,6	5.3	I,1	6.8
	II,3	7.3	II,2	8.0
	III,1	4.8	III,3	6.9
	IV,2	4.5	IV,6	5.7
	V,5	5.5	V,4	7.7
	VI,4	5.0	VI,5	7.0
	Av.	5.4		7.0
325	I,4	6.3	I,5	4.4
	II,6	7.6	II,1	13.5
	III,5	3.6	III,6	5.8
	IV,1	6.1	IV,4	7.7
	V,3	4.8	V,2	5.8
	VI,2	5.8	VI,3	7.0
	Av.	5.7		7.4
350	I,2	6.2	I,3	5.1
	II,3	10.5	II,4	9.2
	III,4	5.3	III,2	4.2
	IV,3	8.5	IV,5	6.2
	V,6	5.5	V,1	6.8
	VI,1	6.6	VI,6	6.3
	Av.	7.1		6.3

Table 22. Gardner color-difference Rd (reflectance) values.

Temperature, °F	Dry Heat An. and roast number	Dry Heat Rd	Moist Heat An. and roast number	Moist Heat Rd
300	I,6	22.8	I,1	19.7
	II,3	18.2	II,2	17.8
	III,1	17.8	III,3	22.7
	IV,2	19.8	IV,6	18.6
	V,5	20.7	V,4	17.5
	VI,4	18.0	VI,5	23.5
	Av.	19.6		20.0
325	I,4	19.3	I,5	18.9
	II,6	20.8	II,1	15.8
	III,5	19.8	III,6	23.1
	IV,1	18.7	IV,4	20.1
	V,3	18.2	V,2	22.2
	VI,2	22.8	VI,3	20.3
	Av.	19.9		20.0
350	I,2	21.0	I,3	22.4
	II,3	16.7	II,4	16.4
	III,4	19.8	III,2	22.4
	IV,3	20.4	IV,5	21.2
	V,6	21.0	V,1	18.0
	VI,1	16.6	VI,6	19.6
	Av.	19.2		20.0

Table 23. Gardner color-difference a+ (redness) values.

Temperature, °F	Dry Heat An. and roast number	Dry Heat a+	Moist Heat An. and roast number	Moist Heat a+
300	I,6	6.2	I,1	8.1
	II,3	1.5	II,2	4.0
	III,1	12.6	III,3	5.4
	IV,2	6.9	IV,6	4.3
	V,5	7.8	V,4	8.7
	VI,4	15.2	VI,5	6.0
	Av.	8.4		6.1
325	I,4	7.8	I,5	9.0
	II,6	2.8	II,1	1.1
	III,5	6.8	III,6	6.3
	IV,1	8.9	IV,4	6.0
	V,3	7.2	V,2	4.1
	VI,2	7.4	VI,3	3.1
	Av.	6.8		4.9
350	I,2	8.2	I,3	6.8
	II,3	7.4	II,4	7.8
	III,4	13.0	III,2	5.0
	IV,3	5.3	IV,5	4.0
	V,6	6.1	V,1	8.0
	VI,1	13.4	VI,6	5.5
	Av.	8.9		6.2

Table 24. Gardner color-difference b+ (yellowness) values.

Temperature, °F	Dry Heat An. and roast number	Dry Heat b+	Moist Heat An. and roast number	Moist Heat b+
300	I,6	12.0	I,1	11.6
	II,3	11.4	II,2	11.2
	III,1	11.6	III,3	11.6
	IV,2	11.0	IV,6	10.8
	V,5	11.7	V,4	11.0
	VI,4	11.7	VI,5	11.5
	Av.	11.6		11.3
325	I,4	10.6	I,5	10.9
	II,6	11.2	II,1	10.7
	III,5	11.1	III,6	11.8
	IV,1	11.0	IV,4	11.2
	V,3	11.1	V,2	11.8
	VI,2	11.4	VI,3	11.0
	Av.	11.1		11.2
350	I,2	11.1	I,3	11.7
	II,3	11.0	II,4	10.7
	III,4	11.8	III,2	11.3
	IV,3	10.8	IV,5	10.8
	V,6	11.2	V,1	11.0
	VI,1	11.4	VI,6	11.5
	Av.	11.2		11.2

Table 25. pH.

Temperature, °F	Dry Heat An. and roast number	pH	Moist Heat An. and roast number	pH
300	I,6	5.6	I,1	5.6
	II,3	5.6	II,2	5.5
	III,1	5.8	III,3	5.8
	IV,2	5.8	IV,6	5.9
	V,5	5.7	V,4	5.8
	VI,4	5.8	VI,5	5.8
	Av.	5.7		5.7
325	I,4	5.6	I,5	5.6
	II,6	5.7	II,1	5.7
	III,5	5.8	III,6	5.8
	IV,1	5.7	IV,4	5.7
	V,3	5.8	V,2	5.8
	VI,2	5.7	VI,3	5.7
	Av.	5.7		5.7
350	I,2	5.4	I,3	5.4
	II,3	5.8	II,4	5.9
	III,4	5.7	III,2	5.7
	IV,3	5.7	IV,5	5.7
	V,6	5.8	V,1	5.8
	VI,1	5.7	VI,6	5.7
	Av.	5.7		5.7

Table 26. Flavor scores; range, 7.0--extremely desirable to 1.0--extremely undesirable.

Temperature, °F	Dry Heat An. and roast number	Dry Heat Scores	Moist Heat An. and roast number	Moist Heat Scores
300	I,6	5.6	I,1	6.0
	II,3	4.8	II,2	5.0
	III,1	5.7	III,3	5.8
	IV,2	5.6	IV,6	4.8
	V,5	6.0	V,4	5.3
	VI,4	5.5	VI,5	6.8
	Av.	5.5		5.6
325	I,4	6.0	I,5	5.4
	II,6	5.7	II,1	5.7
	III,5	5.3	III,6	4.8
	IV,1	6.1	IV,4	4.3
	V,3	5.8	V,2	5.2
	VI,2	5.8	VI,3	3.8
	Av.	5.8		4.9
350	I,2	6.1	I,3	5.0
	II,3	5.4	II,4	5.6
	III,4	5.7	III,2	5.8
	IV,3	5.1	IV,5	5.3
	V,6	5.6	V,1	5.4
	VI,1	6.0	VI,6	5.2
	Av.	5.6		5.4

Table 27. Tenderness scores; range, 7.0--extremely tender to 1.0--extremely tough.

Temperature, °F	Dry Heat An. and roast number	Dry Heat Scores	Moist Heat An. and roast number	Moist Heat Scores
300	I,6	6.0	I,1	5.8
	II,3	4.2	II,2	3.7
	III,1	6.2	III,3	5.7
	IV,2	6.4	IV,6	5.6
	V,5	6.0	V,4	5.4
	VI,4	6.0	VI,5	7.0
	Av.	5.8		5.5
325	I,4	4.7	I,5	5.6
	II,6	4.8	II,1	4.0
	III,5	6.3	III,6	6.3
	IV,1	5.8	IV,4	5.4
	V,3	5.5	V,2	5.5
	VI,2	5.5	VI,3	4.8
	Av.	5.4		5.3
350	I,2	6.6	I,3	5.3
	II,3	6.0	II,4	5.4
	III,4	6.0	III,2	6.3
	IV,3	5.4	IV,5	5.8
	V,6	5.8	V,1	5.2
	VI,1	6.0	VI,6	5.2
	Av.	6.0		5.5

Table 28. Juiciness scores; range, 7.0--extremely juicy to 1.0--extremely dry.

Temperature, °F	Dry Heat An. and roast number	Dry Heat Scores	Moist Heat An. and roast number	Moist Heat Scores
300	I,6	5.1	I,1	6.6
	II,3	5.2	II,2	3.3
	III,1	6.0	III,3	5.2
	IV,2	5.2	IV,6	3.6
	V,5	5.7	V,4	5.3
	VI,4	4.8	VI,5	6.8
	Av.	5.3		5.1
325	I,4	5.7	I,5	5.4
	II,6	5.5	II,1	4.5
	III,5	4.0	III,6	4.6
	IV,1	6.7	IV,4	4.6
	V,3	4.8	V,2	4.3
	VI,2	5.3	VI,3	3.5
	Av.	5.3		4.5
350	I,2	5.0	I,3	4.8
	II,3	6.2	II,4	5.0
	III,4	5.8	III,2	5.8
	IV,3	4.3	IV,5	5.0
	V,6	4.4	V,1	5.8
	VI,1	6.3	VI,6	4.2
	Av.	5.3		5.1

Table 29. Over-all acceptability scores; range, 7.0--extremely acceptable to 1.0--extremely unacceptable.

Temperature, °F	Dry Heat An. and roast number	Dry Heat Scores	Moist Heat An. and roast number	Moist Heat Scores
300	I,6	5.6	I,1	6.0
	II,3	4.2	II,2	4.0
	III,1	5.0	III,3	4.7
	IV,2	5.6	IV,6	4.4
	V,5	5.8	V,4	5.1
	VI,4	5.5	VI,5	6.8
	Av.	5.3		5.2
325	I,4	5.8	I,5	5.7
	II,6	5.7	II,1	5.0
	III,5	4.8	III,6	5.0
	IV,1	6.3	IV,4	4.8
	V,3	5.5	V,2	5.0
	VI,2	5.7	VI,3	4.0
	Av.	5.6		4.9
350	I,2	6.0	I,3	4.8
	II,3	5.6	II,4	5.2
	III,4	5.8	III,2	5.2
	IV,3	4.7	IV,5	5.3
	V,6	5.2	V,1	5.8
	VI,1	6.2	VI,6	5.0
	Av.	5.6		5.2

Table 30. Apparent degree of doneness (1 = rare, 2 = medium done, 3 = well-done).

Temperature, °F	Dry Heat An. and roast number	Dry Heat Scores	Moist Heat An. and roast number	Moist Heat Scores
300	I,6	2.0	I,1	1.0
	II,3	1.1	II,2	3.0
	III,1	1.0	III,3	2.0
	IV,2	1.2	IV,6	3.0
	V,5	1.4	V,4	1.1
	VI,4	1.0	VI,5	1.5
	Av.	1.3		1.9
325	I,4	2.0	I,5	1.3
	II,6	2.0	II,1	1.5
	III,5	1.7	III,6	2.4
	IV,1	1.0	IV,4	2.0
	V,3	1.0	V,2	2.0
	VI,2	2.0	VI,3	3.0
	Av.	1.6		2.0
350	I,2	1.6	I,3	2.0
	II,3	1.0	II,4	2.0
	III,4	1.2	III,2	2.0
	IV,3	2.7	IV,5	2.7
	V,6	2.0	V,1	1.0
	VI,1	1.0	VI,6	2.7
	Av.	1.6		2.1

Table 31. Mean squares and levels of probability of sources of variation for rate of heat penetration.

Source of variation	df	Initial to 0°C	0° to 10°C	10° to 15°C	15° to 20°C	20° to 25°C	25° to 30°C
Animal	5	249.97778	31.05000	4.09444	5.33333*	0.49444	2.44444*
Position	5	285.17778	12.58333	4.62778	1.60000	1.49444	1.9778
Left vs right	1	100.00000	2.25000	1.36111	0.44444	0.25000	1.77778
Linear left	1	588.00000	52.08333	10.08333	0.33333	0.75000	1.33333
Quad left	1	87.11111	6.25000	4.69444	0.11111	0.69444	0.44444
Linear right	1	216.75000	0.08333	3.00000	5.33333	5.33333*	5.33333*
Quad right	1	434.02778	2.25000	4.00000	1.77778	0.44444	1.00000
Treatment	5	281.91111	66.58333	0.49444	1.53333	2.76111*	1.57778
Dry vs moist	1	625.00000	20.25000	1.36111	5.44444	4.69444*	2.77778
Linear temp	1	337.50000	0.16667	0.16667	0.66667	0.04167	0.04167
Quad temp	1	373.55556	18.00000	0.0556	0.50000	8.68056**	1.68056
Linear temp X trmt	1	1.50000	150.00000*	0.66667	0.16667	0.04167	3.37500
Quad temp X trmt	1	72.00000	144.50000*	0.22222	0.88889	0.34722	0.01389
Error	20	351.34444	26.48333	3.84444	1.83333	0.89444	0.89444
Total	35						

Table 31. (concluded)

Source of variation	df	30° to 35°C	35° to 40°C	40° to 45°C	45° to 50°C	50° to 55°C	55° to 60°C
Animal	5	0.64444	1.89444	2.09444	4.36111	1.31111	5.53333
Position	5	0.97778	1.96111	1.96111	3.49444	3.97778	0.86667
Left vs right	1	0.11111	3.36111	0.69444	0.25000	1.77778	0.00000
Linear left	1	0.33333	0.08333	0.33333	8.33333	8.33333	0.08333
Quad left	1	1.00000	0.02778	0.44444	0.11111	5.44444	0.25000
Linear right	1	3.00000	5.33333	2.08333	8.33333	0.33333	3.00000
Quad right	1	0.44444	1.00000	6.25000*	0.44444	4.00000	1.00000
Treatment	5	4.57778*	2.89444	7.96111**	14.36111**	13.04444*	7.33333
Dry vs moist	1	13.44444**	10.02778*	34.02778**	66.69444**	64.00000**	28.44444*
Linear temp	1	0.04167	0.37500	0.16667	1.50000	0.04167	2.66667
Quad temp	1	8.68056*	2.34722	1.38889	0.05556	0.01389	0.00000
Linear temp X trmt	1	0.04167	0.04167	0.66667	2.66667	1.04167	4.16667
Quad temp X trmt	1	0.68056	1.68056	3.55556	0.88889	0.12500	1.38889
Error	20	1.29444	1.39444	0.97778	1.96111	3.66111	3.66667
Total	35						

* $P \leq 0.05$. ** $P \leq 0.01$.

Table 32. Mean squares and levels of probability of sources of variation for objective and sensory measurements.

Sources of variation	df	Total cooking time, min	Cooking time, min/lb	Total cooking losses	Dripping losses
Animal	5	725.02778*	124.03978**	27.37361	35.86094*
Position	5	499.69444*	147.97044**	97.02294	39.90294*
Left vs right	1	90.25000	3.86778	70.28028	0.72250
Linear left	1	1704.08333**	381.94083**	81.12000	48.00000
Quad left	1	66.69444	7.02250	0.44444	8.80111
Linear right	1	4.08333	336.02083**	321.36750*	128.05333**
Quad right	1	633.3611	11.00028	11.90250	13.93778
Treatment	5	286.02778	21.11178	23.58094	120.19161**
Dry vs moist	1	406.69444	26.35111	0.61361	578.40250**
Linear temp	1	384.00000	54.60167	56.73375	6.51042
Quad temp	1	29.38889	1.50222	59.22347	5.50014
Linear temp X trmt	1	150.00000	10.93500	0.18375	2.34375
Quad temp X trmt	1	459.65	12.13	1.14	8.22
Error	20	179.49444	18.13194	42.49678	11.66528
Total	35				

Table 32. (continued)

Sources of variation	WHC	Total moisture	Juiciness scores	Tenderness scores	Over-all shear	Flavor scores
Animal	0.00259	13.31511**	0.23294	1.40378**	9.20778**	0.16778
Position	0.00087	2.54444	1.85294*	0.59644	1.44244	0.48244
Left vs right	0.00038	0.64000	0.02250	0.81000	0.25000	0.00444
Linear left	0.00057	9.54083*	5.46750**	0.36750	3.74083*	1.76333**
Quad left	0.00003	0.96694	0.96694	0.46694	1.64694	0.09000
Linear right	0.00145	0.21333	1.20333	0.05333	1.40083	0.04083
Quad right	0.00194	1.36111	1.60444	1.28444*	0.17361	0.51361
Treatment	0.00107	4.76778*	1.00051	0.38578	2.30044*	0.63311*
Dry vs moist	0.00354	21.16000**	1.64694	0.75111	10.45444**	1.21000*
Linear temp	0.00006	0.60167	0.00167	0.04167	0.00042	0.02042
Quad temp	0.00053	1.07556	0.80222	1.02722	0.11681	0.39014
Linear temp X trmt	0.00085	0.28167	0.00167	0.04167	0.84375	0.18375
Quad temp X trmt	0.0003	0.72	0.81	0.078	0.08	1.34*
Error	0.00172	1.46694	0.65061	0.27228	0.59128	0.21578

Table 32. (continued)

Sources of variation	Over-all acceptability	Apparent doneness	Color Rd	Color a+	Color b+
Animal	0.44400	0.31028	8.37911*	16.14761**	0.31444*
Position	0.91200*	1.15294**	10.86444	23.03561**	0.05444
Left vs right	0.32111	0.23361	0.25000	5.21361	0.00111
Linear left	3.41333**	2.34083**	20.28000*	43.32000**	0.00750
Quad left	0.01778	0.78028	14.95111*	2.89000	0.01361
Linear right	0.14083	1.92000*	18.25333*	62.10750**	0.18750
Quad right	0.66694	0.49000	0.58778	1.64694	0.06250
Treatment	0.43600	0.57294	0.62578	13.44494*	0.17178
Dry vs moist	1.44000*	2.40250**	1.69000	47.38028**	0.02778
Linear temp	0.18375	0.28167	0.10667	0.60167	0.32667
Quad temp	0.01125	0.09389	0.76056	18.20056*	0.20056
Linear temp X trmt	0.09375	0.04167	0.16667	0.28167	0.08167
Quad temp X trmt	0.45	0.05	0.05	0.75	0.22
Error	0.2650	0.23744	2.71661	3.78378	0.10728

Table 32. (concluded)

Sources of variation	pH	Fat in dripping, %	Medial shear	Central shear	Lateral shear
Animal	0.05044**	604.01778	10.06050**	5.64917**	13.23628**
Position	0.01111	135.57244	1.44383	1.68983	2.26028
Left vs right	0.04000*	17.64000	0.20250	1.40028	0.46694
Linear left	0.00750	2.25333	4.94083	4.44083*	2.08333
Quad left	0.00694	314.47111	1.10250	0.10028	6.41778*
Linear right	0.00000	129.36333	0.33333	1.84083	2.08333
Quad right	0.00111	214.13444	0.64000	0.66694	0.25000
Treatment	0.00178	3858.63644**	4.20250*	2.32850	3.91894*
Dry vs moist	0.00111	18696.00444**	19.80250**	8.12250**	6.16694*
Linear temp	0.00667	35.52667	0.00000	1.65375	1.45042
Quad temp	0.00056	234.00056	0.12500	1.20125	0.05014
Linear temp X trmt	0.00000	3.37500	0.24000	0.63375	8.76042*
Quad temp X trmt	0.0005	324.27	0.84	0.04	3.06
Error	0.00794	308.68	1.25367	0.900050	1.32694

* $P \leq 0.05$. ** $P \leq 0.01$.

EFFECT OF OVEN TEMPERATURE AND DRY AND MOIST HEAT ON FROZEN BEEF RIB ROASTS

by

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Retailing of red meat in the frozen state has potential for further expansion. Through central cutting, packaging, and freezing shrinkage and spoilage will be at a minimum, and uniform products will be provided at lower cost than for fresh meat. Little research on cooking meat from the frozen state has been reported. Therefore, a study was designed to investigate the effects of the type of heat and oven temperature on beef rib roasts frozen by liquid nitrogen vapor. A 6 X 6 Latin square was used to cook 18 pair of roasts by dry and moist heat at 300°, 325° and 350°F to an internal temperature of 60°C.

Generally, total cooking time was slightly less for roasts cooked by moist heat than for those cooked by dry heat. Total cooking losses were not affected significantly by type of heat or oven temperature. At all oven temperatures dripping losses were significantly ($P \leq 0.05$) less for dry than for moist heat, and the percentage fat, by volume, in the drippings was less ($P \leq 0.05$) for moist than for dry heat. Within each type of heat, total moisture was not affected by oven temperature, but at 300° and 350°F it was affected by type of heat. Waterholding capacity of the LD muscle was not affected by type of heat or oven temperature.

Shear values were lower ($P \leq 0.05$) for roasts cooked by moist heat, but were not affected significantly by oven temperature. Both Gardner $\underline{a+}$ values and apparent degree of doneness scores rated the degree of redness of the LD muscle higher ($P \leq 0.05$) for dry than for moist heat. Neither type of heat or oven temperature significantly affected pH.

For flavor and over-all acceptability, significant ($P \leq 0.05$) differences between dry and moist heat occurred only at 325°F. Tenderness and juiciness of the LD muscle were not affected significantly by type of heat or oven temperature.

Data for 20 measurements on 36 roasts from three positions in the rib sections of six carcasses indicate that in designing experiments with meat: (1) animal variation must be considered, (2) paired cuts of beef ribs may be used to compare effects of treatments, and (3) samples from the anterior to the posterior of beef ribs should be assigned at random to treatments.