

COMPARATIVE STUDY OF DELAYED
SERVICE COOKERY, FORCED CONVECTION,
AND CONVENTIONAL ROASTING OF THE
LONGISSIMUS DORSI MUSCLE OF BEEF

Thesis for the Degree of Ph. D.
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Kaye Funk

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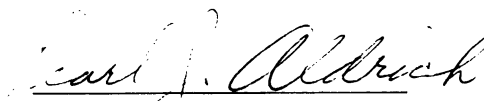
Comparative Study of Delayed Service Cookery,
Forced Convection, and Conventional Roasting
of the Longissimus Dorsi Muscle of Beef.

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ABSTRACT

COMPARATIVE STUDY OF DELAYED SERVICE COOKERY, FORCED CONVECTION, AND CONVENTIONAL ROASTING OF THE LONGISSIMUS DORSI MUSCLE OF BEEF

by Kaye Funk

This investigation compared the effects of delayed service cookery with 6- and 18-hour holding periods, forced convection, and conventional roasting of U.S. Choice loin cuts of beef on the rate of heat penetration, cooking losses, chemical and physical attributes, and palatability. Microbiological analyses were conducted on the delayed service cooked roasts. In a follow-up study, two roasts were injected with cultures of the organism Salmonella senftenberg and then cooked and held for 18 hours according to the delayed service method.

Potentiometer leads were positioned horizontally and in a vertical plane at five points within each roast. Another lead was embedded 0.13-inch into the surface fat of each of the 24 roasts. All roasts were cooked to an end internal temperature of 52°C , as recorded from the lead at the center of the roast.

For oven roasting by the delayed service method, a 204°C oven was used. After removal from the oven the roasts were

transferred to a 60°C forced circulation incubator which served as a holding cabinet for the 6- and 18-hour periods. Both the forced convection and the conventionally cooked samples were roasted in 149°C ovens.

The rate of heat penetration of the roasts was faster in the conventional oven at 204°C than at 149°C. Heat penetration rates were faster in a forced convection oven than in a natural convection oven at the same temperature. Delayed service cooked roasts required 22 per cent less oven time than was required for conventionally cooked roasts. Forced convection cooked roasts cooked in 18 per cent less time than was needed for conventional roasting of similar cuts.

Total cooking losses of delayed service cooked roasts with a 6-hour holding period were almost twice as high as conventionally cooked roasts. When an 18-hour holding period was used with the delayed service method, total cooking losses were two and one-fourth times higher than losses from similar cuts cooked conventionally. Total cooking losses of the forced convection cooked roasts were about 20 per cent higher than the losses from conventionally cooked samples.

Conventionally cooked roasts scored higher in all palatability factors except aroma than did delayed service cooked roasts. Forced convection cooked roasts scored slightly lower than conventionally cooked roasts in all palatability factors except flavor of fat with both

cooking methods scoring the same for juiciness. All differences in palatability factors were not significant, however.

Microbiologically, no food poisoning hazard existed when roasts were cooked by the delayed service method under the conditions of this study. Inoculated roasts contained no viable organisms after cooking and holding for 18 hours by the delayed service method as outlined in this study.

On the basis of findings in this study, the use of the delayed service method is not recommended because of high cooking losses and reduced palatability. Further investigation at different oven temperatures of the forced convection method of roasting is suggested.

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OF THE LONGISSIMUS DORSI MUSCLE OF BEEF

By

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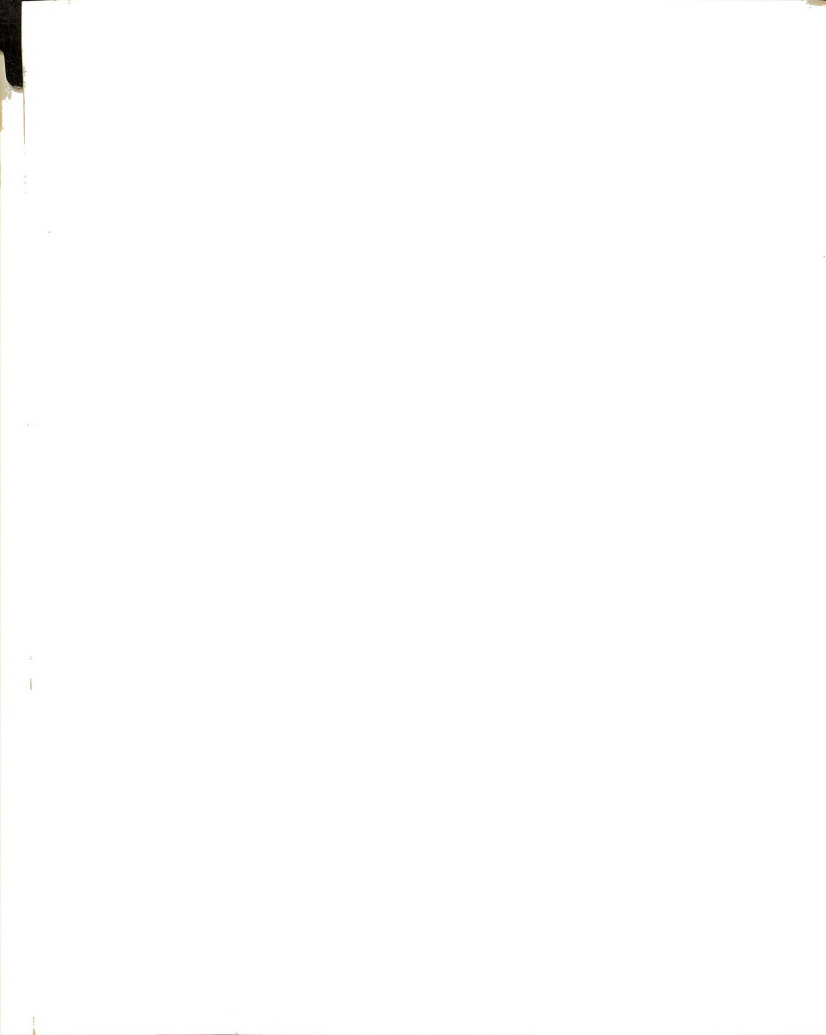
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INTRODUCTION

Primary objectives of the food service operator are the production and service of food of the highest quality attainable from the standpoint of health and enjoyment. In fulfilling these objectives, the food service operator must solve many problems such as providing adequate oven space for slow cooking items, such as meat, and the numerous menu items requiring cooking just before meal service. The length of the serving period, normally extending from one to several hours, presents still another problem. During this period, predicting the number of people desiring food as well as the time at which they will wish service poses additional problems in maintaining the quality and quantity of food required. Providing foods for immediate service to the consumer is usually accomplished by holding them in heated storage containers.

Delayed service meat cookery has recently been rather widely recommended as a means of having roasted meat available whenever needed for service. This method prescribes that the oven-ready cut of meat first be browned at a high temperature for a period of time dependent on the size of the roast and then be transferred to a temperature-controlled cabinet at 60°C until needed. Holding periods, ranging from 3 to 48 hours, reportedly resulted in safe, high quality roast meats.

At low temperature of the holding cabinet, low shrinkage of the uniformly cooked products was predicted by the originators of the method. These factors would seem to indicate increased yields from the roast and greater consumer satisfaction. Presumably, the food service operator would also enjoy the advantage of the lower capital investment in equipment since the cost of the holding cabinet would be much less than that of the oven.

A second relatively new approach to meat cookery was brought to the attention of food service operators with the development of the forced convection oven. This modification of the conventional natural convection oven reportedly offered the possibility of appreciable reductions in cooking time required and in cooking loss, with the subsequent advantages of improved yield and palatability. To understand more clearly how cooking by forced convection might aid in solving some of the quantity preparation and service problems previously described, one needs to understand how the principles involved apply to roasting meats.

Heat energy is transferred by three mechanisms: conduction, convection, and radiation. Conduction is defined as the transfer of heat from a high-temperature region to an adjacent lower-temperature region. Transfer of heat by movement of heated fluid (gaseous or liquid) material is convection. The transfer may result from natural convection, caused by a difference in density, or forced convection,

accomplished mechanically with a blower or fan. Radiation is the emission of energy, without need of a conducting or convecting medium.

The concept has developed that when a fluid flows over a surface, a stagnant film adheres to the surface and acts as a heat insulator. By increasing the velocity of the fluid, the film is partially wiped off and accordingly reduced in effectiveness as an insulator.

The surface of meat in an oven is heated by convection currents of heated air. Although some heat is conducted by the grid upon which the meat rests and to a very slight extent by radiation, the principle mode of transmission is by convection. If the oven contains no blower or fan, the heating is by natural convection. If the heated air is forced into circulation by a blower or fan, the heating is by forced convection.

Commercial ovens featuring forced air circulation and high humidity have recently appeared on the market. According to one manufacturer's brochure, these ovens represent a two-fold saving to the food service operation. Forced convection ovens can produce a greater total output of cooked food because less cooking time is required than in conventional ovens. Reports also indicate that more servings of roast meat would result from decreased cooking time because less shrinkage would occur. Reportedly, moisture is drawn from a pan of water rather than from the food to saturate the air in the unvented oven chamber.

Evaluating possible advantages of new methods of roasting meat requires careful comparisons in which the source of materials and all conditions of preparation and testing are as precisely controlled as possible. Sufficient replication of variables to verify findings is also essential if one is to draw conclusions from which he can make valid predictions. Since most reports available on delayed service cookery and forced convection roasting included only very limited supporting data, this investigation was planned to explore further some of the claims made for these methods.

The primary objective of this study was to compare the heat penetration rates in cuts from the longissimus dorsi muscle of beef when cooked by delayed service, forced convection and natural convection. Since factors related to sample composition and physical structure are presumed to be important determinants of heat penetration rates, the chemical and physical composition of the meat was studied in relation to the rate of heat transfer.

Changes occurring during the cooking of meat vary with the cooking method used as well as with composition. Associated with flavor, aroma, color, tenderness, and juiciness of the cooked product, are time and temperature relationships. A second objective of the study was to compare the quality of the meats roasted by the above methods as measured by sensory, chemical, and physical tests.

The delayed service cookery and the forced convection oven methods presumably both decrease actual oven cooking time. One might conclude they would increase over-all oven capacity. Hence, the third objective of this study was to examine the methods of cookery in terms of the efficiency of equipment use for the institutional setting.

REVIEW OF LITERATURE

Methods of Meat Cookery

As early as 1898, investigators at the University of Illinois were publishing results of meat cooking experiments. In their research bulletin of 1907, Sprague and Grindley (180) reported they obtained an accurate measure of meat doneness by inserting a thermometer in the center of a roast. They also were among the first to suggest end cooking temperatures for different degrees of doneness: 53 to 64°C for rare, 65 to 70°C for medium and 70 to 80°C for well done meat.

Early investigations

In their early work, Alexander and Clark (4) used an oven temperature of 265°C for 20 minutes and then reduced the oven temperature to 125°C and continued cooking until the thermometer at the center of a beef rib roast registered 58°C. They theorized that quickly searing the outside of the roast would form a crust which would minimize cooking losses by holding in the juices. However, high cooking losses resulted.

Conducting experiments on the effect of constant cooking temperature on roasts, Cline, et al. (40) roasted beef ribs to the rare stage by using oven temperatures of 110, 125, 163, 191, 218, and

260°C. They selected 125 and 163°C as the temperatures which yielded the most acceptable meat. In general, they found the lower oven temperatures produced more tender, juicier, and better flavored roasts than did the higher oven temperatures.

From the research of Alexander and Clark (4), Cline, et al. (40) and other workers at Agricultural Experiment Stations and colleges, the Cooking Committee of the Cooperative Meat Investigations (43) recommended directions for experimental meat cookery. By using standardized cooking methods, research workers could determine whether production or processing factors cause the differences shown by data analysis and could compare results with other investigators.

Other developments

In recent years a number of other cookery methods have been investigated. They include long slow cooking, forced convection roasting, electronic cooking, roasting in aluminum foil wrap, pressure cooking, and various combinations of these methods.

Long slow cooking. In her early study, Cover (47) cooked paired beef roasts at oven temperatures of 80 and 125°C. Roasts cooked at the lower temperatures were always tender, but less juicy and flavorful than roasts cooked at the higher temperature.

Using oven temperatures of 63 and 68°C, Bramblett, et al. (23) roasted aluminum foil-wrapped beef round muscles and found them to be juicy. Marshall, et al. (133) concluded the length of time and the variability in total cooking time of choice grade, top round beef roasts made oven temperatures of 93, 107, and 121°C impractical for roasting large cuts.

Forced convection. Forced convection roasting has been suggested as a means of obtaining the advantages of constant oven temperature roasting in a shorter period. The forced convection system appeared to improve the over-all heat transfer coefficient by moving heated air rapidly over the surface of the meat. The stagnant air film normally present on the surface of the meat dissipated, permitting rapid heat penetration. Ovens featuring forced convection have been described by Spinell (179) and others (143, 42).

According to the brochure of one manufacturer of forced convection ovens, moisture to saturate the air in the unvented oven chamber is provided by a pan of water rather than by the food, as in the conventional oven. Because of the low evaporation losses, more servings of meat were available, according to this source (97).

In early studies made with a conventional oven modified by installation of a blower, Borsenik and Newcomer (20) obtained about the same yields of ground beef loaves as with a conventional oven

without the blower when the same temperature was used in both. They reported reduced fuel consumption and decreased cooking time as advantages of the forced convection oven.

Schoman and Ball (172) investigated forced convection and the effects of pressure in combination with forced convection. Temperatures ranging from 100 to 115°C, moderate air circulation of 7.5 to 10 cubic feet per minute, and comparatively low pressure equivalents of saturated steam at the particular oven operating temperature resulted in the best meat yields in the shortest roasting periods.

Delayed service cookery. Delayed service cookery instructions for institution food service were suggested recently as a means of reducing cooking losses and freeing valuable oven space for other cooking. According to the outlined procedure, the oven-ready cut of meat was browned at a high temperature, ranging from 204 to 232°C, for a period of time dependent on the roast size. The meat was then transferred to a temperature controlled holding cabinet at 60°C and held for periods of 3 to 48 hours until needed for service. Dymit (65) reported the quality of the meat appeared to improve up to a holding time of 24 hours. During holding periods between 24 and 48 hours, the quality deteriorated slowly but remained acceptable to the end of 48 hours.

In her study comparing delayed service cookery with the searing method of meat cookery, Gaines (70) concluded delayed service

cooked beef round roasts scored too low in palatability for quantity service. Answering a reader's question on procedures for handling cooked meat, Logan (122) suggested the use of a warming cabinet sized to hold the cooked meat in its roasting pan to keep roasted meats until needed for service. He did not specify the warming oven temperature, however.

Davis (58) used a "slow roasting" method for the home situation. After browning the meat at 121°C for an hour, she reduced the oven temperature to that of the desired internal end temperature. Under these conditions the meat required a cooking period approximately three times longer to reach the desired doneness than did similar cuts conventionally roasted.

Other methods of meat cookery. Research has shown microwaves, generated by a magnetron oscillating at a frequency of 2450 megacycles, are immediately absorbed within the food mass. The resulting increase in thermal energy in the food depends on an interaction between the microwave energy and the food components. Small and medium-sized food masses are cooked too rapidly to permit surface browning. Large masses of food generally show considerable surface browning. Electronic meat cookery has been studied by Bollman, et al. (19), Apgar, et al. (8), Headley and Jacobsen (85), and Marshall (131). These investigators reported

the cooking time required for electronic meat cookery was shorter than conventional roasting times. However, cooking losses were high and electronically cooked meats scored lower in palatability than did conventionally roasted meats.

Infrared devices offer another relatively new method of meat cooking. Infrared heating components are used by broilers, barbecue-type, and rotisserie-type equipment. The adjustments involved in these devices point up some impractical characteristics of infrared. When the meat is too close to the heat source, cooking is very rapid, and the product is apt to be rare inside and charred outside. If the meat is too far from the heat source, operating efficiency is very low, fuel consumption high, cooking time prolonged and the meat surface dried and hard (157).

In their early studies, Morgan and Nelson (141), Thille, et al. (186), and Cover (46) investigated metal skewers as a means of reducing cooking time of beef roasts. Shaw (174) investigated a combination of internal radial heating and conventional oven roasting on the heat penetration rates of semitendinosus muscle of beef round. Radial heat was applied internally by means of a specially constructed thermal rod installed in a closed electrical circuit. From the rod positioned horizontally in the center of the meat, heat was transmitted directly from the rod to the sample. Total cooking time, compared with conventional oven roasting, was reduced nearly 50 per cent by

the use of heat applied simultaneously to the interior and exterior of the roast.

Thermo pins have been suggested as another means for reducing cooking time and cooking losses (185). According to the manufacturer, aluminum fins at the head of the pin conduct heat to the liquid contained within the pin. The vapor formed from the heated liquid flows through the pin to transmit heat to the roast. The manufacturer claimed a cooking loss reduction of 40 to 50 per cent and cooking time and fuel reductions of 50 to 75 per cent. However, no supporting data were given.

According to Korschgen, et al. (114), the "Roastek" procedure provided a means of increasing the percentage of the beef carcass available for broiling. After the large cut of meat from the beef round was preroasted at 149°C to an internal temperature of 43°C , the meat was cooled. As portions were needed for service, the investigators sliced and broiled the meat. Analysis of taste panel data showed significant correlation coefficients between general acceptability and flavor, tenderness, and juiciness of the meat. No comparison was made with conventionally cooked meat.

Blaker, et al. (15) conducted studies on the palatability, cooking losses, and fuel consumption of whole hams and boneless top round beef roasts wrapped in aluminum foil during cooking. Their data showed increased cooking losses, increased fuel consumption, and steamed flavor in the foil-wrapped roasts, particularly in the beef.



The search for new cooking methods continues. A device for heating frankfurters and other sausages by placing them on hot rollers recently received a patent (144) .

Factors Affecting Rate of Heat Penetration

Cooking directions for meat usually suggest the required cooking time in terms of minutes per pound. This offers only an estimate or a guide since many factors affect the length of time necessary to cook meat. Factors affecting heat penetration rates will be reviewed under the headings of cooking medium, cooking temperature, and physical and chemical characteristics of meat.

Cooking medium

Meat may be cooked in air, fat, steam, or water. If these media are all the same temperature, cooking time depends largely on the rate of heat conduction in the particular cooking medium used. After a study comparing the dry heat media of air and fat, Visser, et al. (194) reported slower rates of heat penetration in oven cooked roasts than in beef roasts cooked in fat. At a given temperature, they calculated that the heat conductivity of liquid fat was about six times that of air.

According to Schoman and Ball (172) and Borsenik and Newcomer (20), a forced convection oven decreased the roasting time of

top rounds of beef and ground beef loaves, respectively. Spinell (179) found forced convection roasting resulted in cooking time reductions ranging from 24.8 to 33.9 per cent when compared with conventional roasting at the same temperature.

Bollman, et al. (19), Apgar, et al. (8), Headley and Jacobsen (85), and Marshall (131) concluded electronic meat cookery was four to five times faster than conventional cookery for similar cuts. Metal skewers decreased cooking times of beef roasts in studies by Morgan and Nelson (141), Thille, et al. (186), and Cover (46). According to Blaker, et al. (15), aluminum foil acts as a thermal insulator equivalent to lowering the oven temperature approximately 42°C, thereby increasing the cooking period.

Using paired roasts, Cover (44) compared the heat penetration rates of dry and moist heat. She cooked one in water at 90°C and the other in an oven at the same temperature to an internal temperature of 80°C. The moist heat cookery required less than 3 hours while the oven cooked meat needed over 23 hours.

In an earlier study, Cover (45) reported faster heat penetration rates occurred in a poorly ventilated oven, where the humidity was high and the air flow very low, than in a well ventilated oven. In a study combining moist heat with pressure, Clark and Van Dyne (38) reported the roasts cooked at 15 pounds pressure required one-third of the time needed for cooking similar cuts in a 149°C oven.

Cooking temperature

High oven temperatures generally shorten cooking times because the high temperatures at the surface of the meat produced rapid heat penetration to the interior of the meat. As cooking temperatures vary, a wide difference in the cooking time results.

Oven temperature. In an early study, Latzke (118) compared the effect of oven temperatures on heat penetration rates. To cook to medium doneness the beef rib roasts required 20.75 minutes per pound at an oven temperature of 110°C , 19.08 minutes per pound at 115°C , 16.44 minutes per pound at 125°C , and 12.83 minutes per pound at 175°C . Morgan and Nelson (141), Alexander and Clark (4), Cover (45), and Hunt, et al. (98) reported similar results.

Bramblett, et al. (23) studied heat penetration rates at extremely low temperatures. Beef rounds cooked at 63°C for 30 hours required an average of 12 hours to reach an internal temperature of 57°C . The internal temperature remained in the range of 57 to 60°C for an average of 18 hours. Meat cooked at 68°C took an average of 8 hours to reach 57°C and during the next 10 hours, the meat reached a final internal temperature of approximately 65°C .

Rise after removal from heat source. In their early studies, Sprague and Grindley (180) found the internal temperature of a roast continued to rise after removal from the oven. Heat was carried to

the interior of the meat by conduction. Latzke (118) reported the rise in temperature after removal from the oven varied inversely with the internal temperature of the roast at the time of removal from the oven. In her study, 5- to 10-pound beef rib roasts removed at 51°C rose an average of 10°C over a 40 to 45 minute period. Roasts taken from the oven at 61°C rose an average of 7.1°C and roasts removed at 71°C showed a 4°C rise.

The data of Visser, et al. (194) demonstrated no internal temperature rise in 1- to 2-pound beef roasts from the round, tenderloin, and loin, cooked to 55 , 75 , or 85°C at an oven temperature of 149°C . However, when similar cuts were cooked in deep fat at 110°C , the internal temperature of the roasts cooked to 55°C rose 10 to 13°C after removal from the fat and the temperature of roasts cooked to 70°C rose 5 to 6°C . The rise in temperature of roasts cooked in deep fat to 85°C was negligible.

Gaines (70) found no increase in temperature during a 30-minute period following removal of 14.5-pound top round beef roasts from a 60 and 70°C oven used for holding meat in the delayed service cookery method. Lamb legs, ranging in weight from 3.3 to 5.6 pounds, showed an average temperature rise of 31°C after removal from an electronic oven, according to a study by Headley and Jacobsen (85).

Physical characteristics of the meat

The physical characteristics of the meat may influence the rate of heat penetration. These characteristics will be reviewed under the headings of surface area/weight ratio, initial temperature, location of fat, protein coagulation, bone, and connective tissue.

Surface area/weight ratio. As the size of a piece of meat increases, its weight increases in greater ratio than its dimensions. Because heat applied to the surface of a roast travels inward, cuts with large surface areas require shorter total cooking periods than those with less surface in proportion to their weight. Hence, large cuts of meat will require longer total cooking periods than smaller cuts but fewer minutes per pound of weight (123). Studies by Marshall, et al. (132) and Cline, et al. (40) pointed out this relationship.

Initial temperature. Wanderstock and Miller (197) compared cooking times of fresh roasts with frozen and thawed roasts. The longer cooking times required for the frozen and thawed roasts were attributed to the lower initial temperature of the roast at the beginning of the cooking period.

Location of fat. Thille, et al. (186) concluded that exterior fat, because of the increase in heat conductivity of fat as it passed

from the solid to the liquid condition, speeded up the rate of heat penetration in the muscle portion of the meat. Interior fat, however, retarded the rate of heat penetration. The investigators conducted their study on 3-rib beef roasts, cooking them to an internal temperature of 65°C in a 225°C oven.

Weir (201) reported the rate of internal temperature increase was independent of the thickness of fat cover on pork roasts, except for those with very little fat cover. Thinly covered roasts with surface fat measuring 0.10 inches or less in thickness, rose in temperature an average of 1.08°C per minute while those with 0.35 inches or more of surface fat rose an average of $.92^{\circ}\text{C}$ per minute.

To obtain data on the rate of heat penetration in muscular and fatty tissue, Lowe (123) filled pint jars with lean beef, lean pork, fat pork and suet. After positioning a thermometer in the center of each jar, she heated the jars in boiling water and steam for 3 hours. According to her data, heat penetrated the lean beef most rapidly, followed by lean pork, fat pork, and suet.

Protein coagulation. Visser, et al. (194) reported that as a result of the endothermic process of protein coagulation, the internal temperature of oven cooked beef roasts rose more slowly after they reached 55°C . Marshall, et al. (133) observed the same phenomenon.

Bone. Thille, et al. (186) inserted thermometers into beef rib roasts at the center, above the bone, and just under the fat layer. During cooking, temperatures rose at a much slower rate near the bone than near the fat and the investigators concluded bone was a poor conductor of heat. Paul, et al. (155) found no significant differences in cooking times between boned and unboned club, porterhouse, and sirloin steaks and rib roasts when the cooking times were calculated on the basis of the weight of the bone-in cuts and on the basis of the weight of the boneless meat plus the bone. Bollman, et al. (19) concluded boned rib roasts cooked in a shorter time in an electronic oven than did unboned rib roasts.

Connective tissue. Siemers, et al. (175) studied the heat penetration rates of rendered suet, finely minced suet, intact suet, and connective tissue. Approximately the same rectangular volumes of each were heated in a 163°C oven for 65 minutes. The rendered suet sample heated more rapidly than the samples of finely minced suet, intact suet, and connective tissue. Heat penetrated the finely minced suet more rapidly than either the intact suet or the connective tissue. The intact suet and connective tissue heated at approximately the same rate. From these data, the investigators theorized that the presence of connective tissue in the finely minced suet and the intact suet was inhibitory to the rate of heat penetration.

Chemical characteristics of meat

The literature contains little information on the relationship of chemical characteristics of meat to heat penetration rates. Sayre, et al. (170) studied the pH of the longissimus dorsi muscle of pork in relation to rigor development. When the onset of rigor occurred while pH values remained about pH 6.0, the muscle cooked at faster rates than when rigor onset occurred at pH values below 5.9. The authors attributed the differences in cooking rates to the moisture content as affected by pH. Muscles with pH values below 5.9 lost more moisture during cooking than did muscles with pH values above 6.0.

Paul and Bratzler (152) studied the effect of aging by cooking steaks from semimembranosus and adductor muscles in deep fat. Increased aging shortened cooking time for both muscles. Hanson, et al. (81) observed heat penetrated muscles of New York dressed broilers more rapidly as the post-mortem changes associated with aging progressed.

Weir (201) grouped data on pork roasts according to the percentage of fat in the lean and examined these data in relation to heat penetration rates. The results showed no differences in heating rates between the two groups containing 2 to 4 per cent fat and 6 to 8 per cent fat.

Factors Affecting Cooking Losses in Meat

The total loss occurring during meat cooking can be divided into volatile and dripping losses. Evaporation of water is mainly responsible for volatile losses. The drippings include fat, water, salts and nitrogenous and non-nitrogenous extractives. Depending on the fat content of the meat, the surface area/weight ratio, the temperature of the cooking medium, and the stage to which the meat is cooked, total losses reported for meat during cooking may vary from approximately 8 to more than 50 per cent (123).

Grade of meat

Thille, et al. (186), Hood (93), and Porter (158) concluded that grade influenced cooking losses: the higher grades were positively correlated with greater cooking losses. Day (59) reported no significant differences in total cooking losses among Good, Commercial, and Utility grades of the longissimus dorsi muscle of beef. The cuts were roasted at 149°C to an internal temperature of 80°C .

Studying the effect of Choice, Good, and Commercial grades on cooking losses, Masuda (134) found no significant differences due to grade of the longissimus dorsi muscle of beef. An oven temperature of 150°C was used for cooking. Roasts were removed from the oven and weighed at internal temperatures of 50, 60, 70, 80, and 90°C .

Comparing the cooking losses of Utility and Choice grade beef,

Cover and Shrode (55) reported similar losses for both grades when bottom round, top round, and chuck roasts were cooked by like methods. The investigators reported greater losses for the Choice grade beef ribs than for Utility grade, however.

Orme (146) found the evaporation and drip losses incurred during cooking inversely related to each other. With increased finish of surface fat the drip losses increased, and with a decrease in finish the evaporation losses increased. Reports of studies by Black, et al. (17) and Alexander and Clark (4) support these conclusions.

Surface area/weight ratio

The surface area of a meat cut of a given weight depends on its shape. Cooking compact pieces with correspondingly small surface area results in smaller losses than irregular shaped pieces with greater surface area, according to Helser, et al. (88) and Lowe, et al. (124). Using cuts from Choice grade top rounds of beef, Marshall, et al. (132) reported significantly lower cooking losses in 10- and 15-pound roasts than in 5-pound roasts.

Method and extend of cooking

According to a study by Cline, et al. (40), searing beef rib roasts at the beginning or at the end of the roasting period resulted in greater losses than constant low temperature roasting. Child and

Satorius (36) also reported greater losses in seared beef rib roasts than in similar cuts cooked at constant oven temperatures.

Spinel (179) reported 5.6 per cent higher weight losses with forced convection roasting of beef rib roasts than with conventional roasting. The weight losses were 24.8 per cent and 33.9 per cent, respectively. However, Borsenik and Newcomer (20) found similar losses for forced convection and conventional roasting of ground beef loaves of comparable size and composition.

Gaines (70) compared cooking losses of cuts cooked by the searing method of roasting with those prepared by delayed service cookery using holding periods of 24 hours at 60°C and 16 hours at 70°C. The data showed consistently greater losses, attributable to increased evaporation, for the 24-hour holding period than for seared roasts. Data from the 16-hour holding period and corresponding seared roasts showed no significant differences in total cooking losses.

Headley and Jacobsen (85) concluded greater evaporation accounted for the increased losses resulting from electronic roasting of boned, rolled lamb legs. However, Marshall (131) pointed out that high drip losses occurred when Choice grade, top round roasts of beef were cooked to well done in an electronic oven.

In her study of the effect of metal skewers on cooking time and cooking losses, Cover (46) reported the use of skewers reduced total weight loss by about 35 per cent when compared with

conventionally cooked roasts. She cooked the skewered and un-skewered paired roasts of round, armbone chuck, and standing rib to the well-done stage in a 125°C oven.

In a comparative study by Grindley and Mojonnier (76), a beef rib roast cooked in a covered pan lost more weight during cooking than rib roasts cooked in uncovered pans. This conclusion was based on the results of experiments with one covered and 16 uncovered roasts.

Hood (93) found greater cooking losses in aluminum foil-wrapped shoulder roasts of beef than in similar cuts roasted at the same temperature without the aluminum foil wrapping. According to a study reported by Clark and Van Dyne (38), cooking losses for top round beef roasts cooked at 15 pounds pressure in a pressure saucepan were greater than for similar cuts roasted in a 149°C oven to the same internal temperature of 82°C.

Alexander (3), Cline, et al. (40), Latzke (118), Alexander and Clark (4) and Vail and O'Neill (193) reported greater cooking losses for beef roasts cooked at high oven temperatures than for similar roasts cooked at moderate to low oven temperatures. Bramblett, et al. (23) noted the same relationship in a study of cooking losses occurring in beef roasts taken from the round and cooked at 63 and 68°C. Marshall, et al. (133) found evaporation losses increased as the oven temperature decreased, whereas drip

losses increased as the oven temperature increased. However, Hunt, et al. (98) found no significant effect of five oven temperatures of 130, 149, 163, 177, and 191°C, on cooking losses of Choice grade top rounds of beef.

Cooking losses have been generally reported to increase as the internal endpoint temperature of cooking increases. Studies by Grindley and Mojonnier (76), Clark, et al. (37), Marshall, et al. (132, 133), Porter (158), Kight (112), Hunt, et al. (98), and Sanderson and Vail (167) have reported data substantiating this general relationship.

Factors Affecting Aroma, Flavor, and Color of Meat

Meat palatability is comprised of such qualities as aroma, flavor, color, juiciness, and tenderness. The aroma and flavor of meat are affected by the composition, method and extent of cooking and the treatment prior to cooking. The color of cooked meat depends upon the composition and the changes which take place during cooking.

Composition of the meat

According to Crocker (57), the weak, blood-like flavor of raw meat is primarily in the juice. He believes the flavor of meat develops during cooking and arises from the muscle fiber protein. Kramlick and Pearson (116) found flavor constituents of the longissimus dorsi muscle of beef were largely water soluble in both raw and cooked

fractions. Their study indicated full flavor development resulted when the juice and fibers were heated together.

Fat. Mackintosh and Hall (127), Day (59), Jacobsen and Fenton (107), Simone, et al. (176), Cole, et al. (41), and Branaman, et al. (26) reported the presence of fat around and within the muscle increased the desirability of the flavor of beef. Conversely, Tuma, et al. (190) found no relationship between flavor and the marbling level in steaks from the longissimus dorsi muscle of beef.

The characteristic aroma of heated lamb is obtained from the fat, according to a study on lean lamb and lamb kidney fat, by Hornstein and Crowe (94). The lean meat portions of lamb contribute a basic meaty flavor similar to that obtained from lean beef and lean pork.

Hofstrand and Jacobsen (91) studied the role of fat in the flavor of lamb and mutton as tested with depot fats. The investigators concluded the water soluble and highly volatile compounds suspended in the fat contributed the characteristic aroma and flavor.

Tuma, et al. (190) studied the effect of marbling on color. The investigators reported no relationship between degree of marbling and color of the meat as measured by the Photovolt Reflectance Meter.

Bone. After studying the relation of bone to palatability of beef, Paul, et al. (155) concluded no significant flavor differences existed

between boned and unboned club, Porterhouse, and sirloin steaks, and rib, chuck, and rump roasts.

Aging

Investigating the effect of aging on palatability, Harrison, et al. (83) found flavor and aroma scores of the psoas major, longissimus dorsi, semitendinosus, and semimembranosus muscles of beef increased with aging up to 10 days and decreased after 30 days aging. Meyer, et al. (138) reported the flavor of lean and fat of grain-finished beef loin and round roasts decreased significantly after 21 days of aging. After storage for 37 days at 1.1°C , cooked beef tasted and smelled stronger than when the beef had been stored for only 9 days at the same temperature prior to cooking, according to a study reported by Griswold and Wharton (78).

Tuma, et al. (190) investigated the effect of aging on the longissimus dorsi muscle of beef and found no significant difference in flavor as evaluated before and after aging for a 14-day period. The same conclusion was reached by Tuma, et al. (189), in a later study.

Sleeth, et al. (177) compared the effect of various storage temperatures on the aging process. Beef rounds aged 2 to 3 days at 20°C scored the same for flavor and aroma as those aged 12 to 14 days at 1.1°C .

Method and extent of cooking

Cline and Foster (39) concluded searing beef roasts at 260°C and then completing cooking at 125°C produced better flavor of lean than did constant temperature roasting at 100 and 225°C . Cover (47) reported beef roasts cooked at very low temperatures, such as 80°C , less flavorful than conventionally cooked roasts. Griswold (77) found beef round roasted at 121°C scored higher in flavor of lean and acceptability than similar roasts cooked at 149°C .

According to Schoman and Ball (172), forced convection cooking resulted in a "weathered" appearance of top round beef roasts. In a study by Gaines (70), sensory panel members rated top round beef roasts cooked to 50 and 55°C by delayed service cookery methods slightly rare for quantity food service. She reported the outer surface of delayed service cooked roasts appeared very dark, hard, and dry.

Electronically cooked beef, pork, and lamb roasts scored lower in flavor and appearance than conventionally cooked roasts in studies reported by Bollman, et al. (19), Apgar, et al. (8), Headley and Jacobsen (85), and Marshall (131). Beef roasts from the round, tenderloin, and loin, cooked in deep fat did not have the rich brown surface appearance characteristic of oven roasts, according to data reported by Visser, et al. (194). Blaker, et al. (15) found foil-wrapped beef roasts scored lower in flavor and appearance than conventionally cooked roasts. The foil-wrapped roasts had a distinct steamed flavor and appearance.

In a comparative study on the effect of moist and dry heat on aroma, flavor, and color of beef rounds, Hood (93) found dry heat cooked roasts scored higher in the three factors. Clark and Van Dyne (38) reported oven roasting of top beef rounds yielded more palatable roasts than did pressure saucepan cooking.

According to descriptions by Sprague and Grindley (180), the interior of a rare beef roast may be bright red or have grey extending to varying depths so that only a small spot in the center is red. They described medium done beef as more pink or rose, less red. The grey color of well done beef, according to these early workers, is uniform throughout.

In a study comparing the effect of internal temperature on palatability, Lowe and Kastelic (125) reported lower flavor and aroma scores for roasts from the rib, loin, tenderloin and round of beef cooked to 90°C than for similar roasts cooked to 70°C . Aldrich and Lowe (2) found prolonged braising of cuts from the semitendinosus, rectus femoris, vastus lateralis, and adductor beef muscles decreased flavor scores. Clark, et al. (37) reported steaks from the top and bottom round of beef cooked to 80°C scored higher in flavor and aroma than similar steaks cooked under pressure to 112°C .

Temperature at which the meat is served

Few reports appear in the literature concerning the effect of serving temperature on meat flavor. Hotaling and Fenton (96) found



the temperature at which samples were served made little difference on the palatability scores of oat-, soy-, or wheat-extended pork meat loaves. The meat loaves were scored immediately after baking and after refrigerating overnight.

Blaker and Ramsey (16) observed the effect of holding temperatures on food quality. Slices of rare roast beef became well done within a 15-minute holding period on a steam table and showed evidence of surface drying.

Factors Affecting Tenderness of Meat

Tenderness is a universally desired quality of meat (123). Many factors, such as meat composition, treatment prior to cooking, and method and extent of cooking influence meat tenderness.

Composition of meat

Moisture. Arnold, et al. (9) reported the degree of hydration of muscle proteins influenced tenderness. They theorized that aging increased the ions present in the protein. Since the ions are firmly held by the protein, greater hydration of the protein results with a subsequent increase in tenderness. Urbin, et al. (192) and Goll, et al. (71) reported higher moisture content results in increased tenderness. However, Husaini, et al. (100) observed no relationship between moisture and tenderness in a study of 20 short loins of beef.

Fat. Husaini, et al. (100), Palmer, et al. (148), and Kropf and Graf (117) concluded good marbling contributed to the tenderness of meat. In a later study, Husaini, et al. (101) found no correlation between tenderness and carcass grade or intramuscular fat in beef short loins. Branaman, et al. (25), Ramsbottom and Strandine (162), Bowman, et al. (21), Cover and Hostetler (50), Mathews and Bennett (135), and Walter, et al. (196) also reported no correlation between tenderness and carcass grade.

Protein. In a study of the comparative tenderness of 25 beef muscles, Ramsbottom, et al. (163) noted most muscles decreased in tenderness on cooking. The authors suggested the decrease in tenderness was associated with factors such as coagulation and denaturation of muscle proteins together with varying degrees of shrinkage and hardening of muscle fiber. Winegarden, et al. (209) studied the physical changes of connective tissues of beef during cooking. In applying their findings to cooking of meat, the investigators theorized that cooking less tender cuts of meat a long time in moist heat to internal temperatures of 80 to 95°C softened the coagulated protein as well as the connective tissues. Tuomy and Lechner (191) indicated protein denaturation was responsible for the toughening effect produced by increasing internal temperatures of the longissimus dorsi muscle of pork.

In contradiction, Satorius and Child (168) found coagulation did not affect tenderness of triceps brachii and adductor muscles of beef, but the longissimus dorsi muscle became more tender with coagulation. The investigators measured tenderness by shear force.

Husaini, et al. (100) found no correlation between tenderness scores and total nitrogen, trichloroacetic acid soluble nitrogen, non-protein nitrogen, or heat coagulable nitrogen. Hegarty, et al. (87) fractionated intracellular muscle proteins from the longissimus dorsi muscle of beef and found a high correlation between fibrillar protein solubility and tenderness.

Ash. The minerals present in meat may affect tenderness. Arnold, et al. (9) found that although the total amounts of sodium, potassium, calcium, and magnesium showed no relation to tenderness, their distribution did because of their water-binding capacity.

Collagen nitrogen. Collagenous and elastic fibers are factors influencing meat tenderness, according to a histological study of nine beef muscles by Hiner, et al. (89). However, the way in which they affect tenderness was not clearly defined.

In an early study, Mitchell, et al. (139) determined the collagen nitrogen and elastin content of various muscles in the beef animal. In general, the workers found larger percentages of connective tissue in the less tender cuts of meat. The collagen nitrogen content of the longissimus dorsi muscle of beef was lower than the biceps femoris

muscle according to Cover, et al. (49). Irwin and Cover (106), and Ritchey and Cover (164). Felder, et al. (68) observed that cooked steaks from the semitendinosus muscles contained significantly more collagen and elastin than steaks from the longissimus dorsi muscle.

According to a study by Bell, et al. (13) cooked shoulder fillet, rump, and sirloin butts of beef contained less collagen than similar raw cuts. Cover (47) theorized that the chemical factor involved appeared to be the change from collagen to gelatin. Bell et al. (13), Cover, et al. (53) and Ritchey and Cover (164) reported long cooking decreased collagen content more than short cooking.

Felder, et al. (68) found the method of cooking steaks from the semitendinosus muscle of beef influenced collagen content. Results of their study indicated deep fat and electronic cooking decreased the collagen content significantly more than oven roasting and broiling.

Husaini, et al. (100) found the correlation between collagen content, defined as alkali insoluble protein, and tenderness scores of short loins of beef was not significant. Parrish, et al. (149), comparing hydroxyproline values of loin and round beef steaks with sensory tenderness evaluations, found a very highly significant correlation coefficient.

pH. Winkler (210), using pork muscle for his study on the relationship of pH to tenderness, adjusted the pH by injections of lactic acid or ammonia solutions. Maximum toughness occurred between pH 5.0 and 6.0. At higher or lower pH levels, the meat became progressively

more tender. Studies with beef gave similar results, but maximum toughness occurred at a somewhat lower pH than in pork muscle.

Callow (31) suggested a low pH is desirable with tough meat. The lactic acid producing a low pH of meat facilitates the conversion of collagen to gelatin and thus has a tenderizing effect on the cooked meat. In their study of the relationship between biochemical properties of pork and quality characteristics, Kauffman, et al. (111) reported muscle tissue with a relatively high pH scored higher in tenderness than muscle tissue with a low pH.

Animal characteristics

Many inherent characteristics of the animal influence meat tenderness. Variation in tenderness exists between animals and muscles within the animal.

Age, grade, and sex. As the age of the animal increased, tenderness decreased, according to studies reported by Hiner and Hankins (89), Webb, et al. (200), Simone, et al. (176), Tuma, et al. (189, 190), Goll, et al. (71), and Walter, et al. (196). However, Lowe and Kastelic (125) obtained data showing increased age does not in itself always indicate toughness of meat. Weller, et al. (202) reported tenderness appeared unrelated to animal age in lambs.

Data collected by Brady (22) while studying factors influencing tenderness and texture of beef, demonstrated that as the age of the

animal increased, the diameter of muscle fibers also increased. Since he associated tender meat with fine texture, Brady (22) concluded toughness increased with age.

Mackintosh and Hall (127), Harrison, et al. (83), Day (59), Paul and Bratzler (153), Kropf and Graf (117), McBee and Naumann (136), and Simone, et al. (176) reported better grades of meat scored higher in tenderness than poorer grades.

Adams and Arthaud (1) found steers significantly more tender than bulls. Their study showed no significant differences between tenderness of bulls and heifers or between heifers and steers, however. Kropf and Graf (117) reported steaks from steer carcasses showed lower tenderness scores and higher shear values than those from cows or heifers.

Animal and muscle variation. From their studies, Bray, et al. (28), Harrison, et al. (83), and Gaines (70) concluded tenderness varied from animal to animal within the same grade. Bray, et al. (28) reported the right side of the beef animal was significantly more tender than the left side. However, Hankins and Hiner (80) found no important differences in tenderness between steaks from the two sides of the beef carcass.

The longissimus dorsi muscle of beef became progressively less tender as the distance from the backbone increased, according to

Mathews and Bennett (135). Hankins and Hiner (80) and Bray, et al. (28) found posterior sections of the short loin more tender than anterior sections. Conversely, Paul and Bratzler (152) and Simone, et al. (176) reported steaks from the anterior of the longissimus dorsi muscle were more tender than steaks from the posterior. In their study on the comparability of cuts from one muscle, Satorius and Child (169) concluded physical properties of the longissimus dorsi muscle of beef were homogeneous.

Taylor (184) compared the composition of consecutive and matched steaks from the semitendinosus and semimembranosus muscles of Choice grade beef. Adjacent steaks in both the anterior and posterior portions of the semitendinosus muscle and in the anterior portion of the semimembranosus muscle differed significantly. Steaks from the posterior end of the semimembranosus muscle were homogeneous in cooking losses, shear force, press fluid, moisture, crude fat, nitrogen, pH, collagen and elastin. Matched steaks were relatively homogeneous.

After studying the intramuscular fat and nitrogen content, pH, and buffering power of the uncooked longissimus dorsi muscle of beef, Lawrie (119) concluded significant differences existed between the posterior and anterior portions of the muscle. Intramuscular fat was significantly higher, the nitrogen, pH, and buffering power were significantly lower, in the region of the 4th, 5th, and 6th

lumbar vertebrae than in the region of the 8th, 9th, and 10th thoracic vertebrae, according to the study.

Preliminary treatment of meat

Special treatments, both ante-mortem and post-mortem, have also been found to influence beef tenderness. Enzymatic treatment prior to slaughter and special aging procedures have been used for their tenderizing effect.

Aging. According to studies reported by Ramsbottom and Strandine (162), Harrison, et al. (83), Husaini, et al. (101), Paul, et al. (154), Webb, et al. (199), and Meyer, et al. (138), tenderness in beef improved with aging. Tuma, et al. (189) observed that the effect of aging beef for a 14-day period varied with animal age. In their study, tenderness of steaks from 42- and 90-month old animals improved with aging while tenderness of steaks from 18-month old animals showed no increased tenderness with aging.

The Tenderay process, based on the principle that the natural enzymes present in the meat are more active at higher temperatures, ages meat rapidly at an elevated temperature in the presence of mold-inhibiting light (142). "Tenderayed" meat from one-half of a beef carcass scored higher in tenderness than the untreated half in a study conducted by Deatherage and Reiman (62).

In a study of the organoleptic characteristics of beef aged in

a controlled environment, Sleeth, et al. (177) found aging beef at 20°C for 2 to 3 days resulted in meat tenderness equal to that obtained from 12 to 14 days at 1.1°C. Wilson, et al. (208) treated beef with microbial inhibiting oxytetracycline or gamma radiation prior to aging at 43°C. The investigators concluded aging for 24 hours at 43°C produced the same tenderness in meat as aging for 14 days at 2°C.

Enzyme treatment. Proteolytic enzymes have been found to increase the tenderness of meat (123). In an early study on enzymatic tenderizing of meat, Gottschall, et al. (74) found ground beef was digested rapidly by papain at 55 to 75°C but very slowly at room temperature. The investigators also found the enzyme did not penetrate the surface of a solid piece of meat. The study pointed out that the meat must be cooked before it becomes a pasty mass or some means must be found to inactivate the enzyme at the desirable stage of tenderizing. Tappel, et al. (183) confirmed these findings.

From their study of the effect of enzyme tenderizers on meat, Hay, et al. (84) concluded enzyme tenderizers increased the tenderness of steaks from less tender cuts of meat as measured by judges' scores. These investigators applied the enzyme to the surface of the meat and then pierced the meat several times with a fork to provide additional contact.

McIntosh and Carlin (137) studied the effect of papain preparations on beef skeletal muscle proteins. The results of their study

suggested that the tenderizing action of papain was due to breakdown of connective tissue.

The development of the ProTen process for tenderizing beef was reported by Goeser (72). In this method an enzymatic solution was injected into the vascular system of the live animal minutes before slaughter. The amount of enzyme solution used was dependent on weight, grade, and class of the animal.

According to a recently issued patent (206), when a tetracycline was injected along with the tenderizing enzyme before rigor was complete, a very small amount of enzyme was needed and the activity of the enzyme was self-limiting.

Other methods. Another approach to controlled tenderization of beef involves the use of various salt solutions. Deatherage (60) theorized the ionic atmosphere of the muscle proteins affected the water holding capacity of proteins and this was directly related to tenderness. He found that infusing the beef with saline solution by artery pumping increased tenderness. In a follow-up study, Wierbicki, et al. (204) found sodium chloride plus magnesium chloride provided an effective combination of the various salts tried. Beef round from an old cow was treated with this salt solution by stitch pumping and held for 24 hours. Twenty-nine people unanimously agreed that the treated meat was more tender than the untreated control from the other side of the animal.

A recently issued patent (207) described the use of molds Thamnidium and Aspergillus to improve meat tenderness and flavor. An isotonic solution of the molds was injected into the live animal 4 to 5 hours prior to slaughter and dressing the animal in the conventional manner. The animal carcass was then held at 1.1°C for 1 to 10 days.

Another recent patent outlined the use of an inert gas such as air, and water for meat tenderization. The gas and water were stitch pumped into the animal carcasses on the killing floor before rigor was complete (205).

Freezing. According to a study by Hankins and Hiner (80) freezing beef steaks significantly increased their tenderness when they were compared to similar steaks which had not been frozen. Conversely, Bray, et al. (28) and Guenther, et al. (79) reported freezing affected tenderness of beef very little. McBee and Naumann (136) evaluated steaks from the short loin of Utility and Choice grade beef fresh, immediately after freezing, and at the end of 2 and 4 months storage. The workers found freezing at temperatures of 6.7 , -17.8 , and -28.9°C and frozen storage did not increase tenderness over that of fresh steaks.

Method and extent of cooking

After studying the effect of oven temperature on the tenderness of meat, Cover (45) concluded an oven temperature of 80°C produced more tender meat than did an oven temperature of 125°C . She indicated the tenderizing effect noted in the meat roasted at the lower temperature resulted from slower rates of heat penetration.

In an early study, Cline, et al. (40) investigated the effect of cooking method on beef palatability. After cooking by the searing method, beef ribs were less tender than similar cuts cooked at constant oven temperatures of 110 and 163°C . A later study by Cline and Foster (39) confirmed these findings.

In the report of their study on factors affecting shrinkage and speed in the roasting of meat, Morgan and Nelson (141) stated skewered beef rib roasts were more tender than those cooked without skewers. Conversely, Cover (46) found the use of skewers in paired round-bone chuck roasts decreased the tenderness of the cooked product as compared to the tenderness of conventionally cooked roasts.

Visser, et al. (194) reported deep fat cooked beef roasts from the round and loin scored lower in tenderness than conventionally cooked roasts. Walter, et al. (196) reported beef steaks taken from the longissimus dorsi muscle were significantly more tender when broiled than when deep fat fried.

In her comparative study of searing and delayed service cooking, Gaines (70) found seared top round beef roasts more tender than corresponding roasts cooked by delayed service. Dymit (65) reported tenderness of delayed service cooked rib roasts seemed to improve as holding time increased from 3 to 24 hours. After the first 24 hours, an additional holding period of 24 hours had no effect on tenderness.

Electronically cooked beef rounds scored lower in tenderness than roasts cooked at 149°C in a conventional oven in a study by Marshall (131). The study by Apgar, et al. (8) on pork roasts from the longissimus dorsi muscle showed the same results. In their study of electronic and conventional cookery of boned and rolled legs of lamb, Headley and Jacobsen (85) showed tenderness, as measured by shear tests and "chew counts," was unrelated to cooking method.

Hood, et al. (92) studied the effect of cooking method on tenderness of low grade beef rounds. Dry heat cooked roasts were more tender than similar cuts cooked by braising.

Clark and Van Dyne (38) investigated the tenderness of beef as affected by roasting and pressure saucepan cookery. They found no difference in tenderness of the top round roasts cooked by the two methods to the same internal temperature.

In their study of the effect of braising and pressure saucepan meat cookery, Clark, et al. (37) found top and bottom round beef

steaks oven cooked to 80°C were more tender than paired steaks cooked to 112°C at 15 pounds pressure. Aldrich and Lowe (2) investigating the effect of extended cooking time on muscles from beef rounds, found an additional hour of cooking after the internal temperature of the roasts reached 90°C resulted in a slight increase in tenderness as shown by panel scores and shear force readings.

Factors Affecting the Juiciness of Meat

Two kinds of moisture are thought to be present in meat. One type is relatively free to run or be pressed out as juice. Sources of this juice may be the lymph and any liquid remaining in the blood vessels and perhaps some of the immobilized water. The other kind of moisture is adsorbed water. Some of it is probably released during heating for the relatively short periods during cooking. The amount remaining in the cooked meat may influence juiciness scores, according to Cover, et al. (53).

Composition of meat

In their study of the relationship between juiciness and fatness of beef ribs, Barbella, et al. (11) found a significant association between the quantity of juice and the degree of fatness. Branaman, et al. (25) reported results in agreement with this.

Thille, et al. (186) cooked beef ribs at 210°C to an internal

temperature of 65°C. Analysis of their data showed fat-surfaced roasts were less dry than lean-surfaced roasts.

Tuma, et al. (189) and Bowman, et al. (21) found no correlation between percentage of fat and juiciness. Both studies used steaks from the longissimus dorsi muscle of beef. Day (59), Masuda (134), and Walter, et al. (196) reported similar results.

After a study of differences among beef steaks, Cover (48) concluded the juicier steaks had tougher connective tissue. The data showed this relationship was not significant for loin steaks but was significant for bottom round steaks.

Using a pressometer to measure the press fluid in standing and rolled rib beef roasts, Child and Esteros (34) concluded standing rib roasts contained a larger quantity of juice than rolled rib roasts. Juiciness scores correlated with pressometer readings.

In determining the relationship of the biochemical properties of pork to quality, Kauffman, et al. (111) concluded loin and round muscles with a relatively high pH were more juicy than muscle tissue with a low pH.

Animal characteristics

Tuma, et al. (189) studied the influence of animal age on factors associated with beef quality. The taste panel scores obtained in their study indicated no relationship between juiciness and animal

age. Simone, et al. (1976) came to the same conclusion.

Investigating the effect of animal maturity on palatability characteristics, Walter, et al. (196) reported juiciness decreased with advancing maturity of the animal. The investigators used 72 beef carcasses representing 3 age groups for their study.

Preliminary treatment of the meat

Meyer, et al. (1938) studied the quality of grain-finished and grass-finished beef as affected by aging and found juiciness scores showed no difference due to aging. Tuma, et al. (1989) reported similar results.

In an investigation of the effect of storage conditions on the palatability of beef, Griswold and Wharton (1978) found that meat from animals refrigerated from 37 days at 1.1°C was somewhat less juicy than meat held for 9 days at the same temperature.

Deatherage and Hamm (1961) reported quick-freezing (-50°C) caused a significant increase in the water holding capacity of beef, probably by a mechanical loosening of tissue structure due to the formation of tiny ice crystals inside the cells. Slow freezing (-15°C) caused a significant decrease in the water holding capacity of meat, probably due to some destruction of protein structure by formation of large ice crystals between the cells.

After studying the effect of freezing temperature and storage

time on organoleptic characteristics of beef, Guenther, et al. (79) concluded neither freezing temperature ranging from -9.4 to -34.4°C , nor storage times of 1, 4, 8, and 12 weeks, affected the juiciness scores and press fluid of steaks taken from the longissimus dorsi muscle of beef.

Method and extent of cooking

In their early study, Cline, et al. (40) showed that searing did not hold in the juices of meat. However, Child and Satorius (36) found no difference in pressometer measured press fluid in beef roasts cooked at 150°C after searing for 20 minutes at 260°C and at constant oven temperatures of 150 and 200°C .

Felder, et al. (68) compared the effect of four cooking methods on juiciness of steaks taken from the semitendinosus and longissimus dorsi muscles of beef. The results indicated deep fat and electronic cooking reduced juiciness more than oven roasting or broiling. Bollman, et al. (19), Headley and Jacobsen (85), and Marshall (131) also reported electronically cooked roasts were dry and lacking in juiciness when compared to conventionally cooked roasts. The results of Lukianchuk's (126) study showed roasts cooked conventionally at 149°C were juicier than roasts cooked in deep fat at 115°C when measured by subjective and objective means.

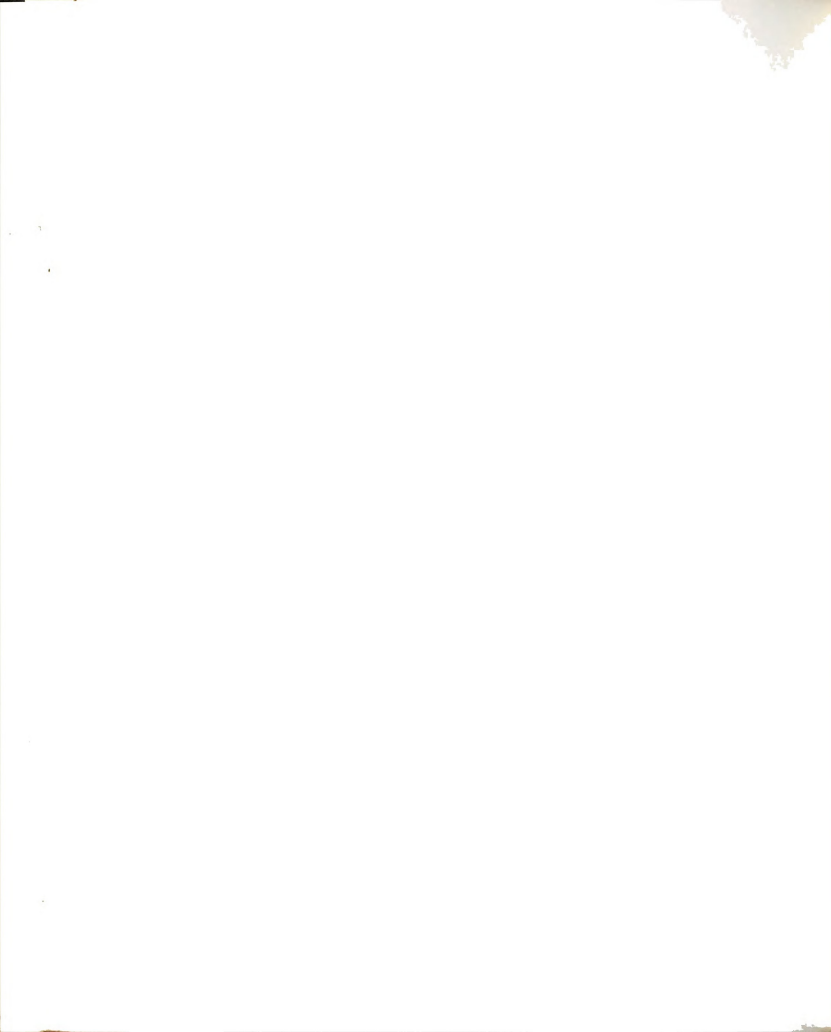
Comparing the effect of extremely low rates of heat penetration

on beef quality, Cover (47) roasted three cuts of meat to the well-done stage using oven temperatures of 80 and 125°C. She concluded standing rib, arm bone chuck, and bottom round beef roasts cooked for long periods at 80°C were drier than similar cuts roasted at 125°C. Conversely, Bramblett, et al. (23) noted beef rounds, wrapped in aluminum foil and cooked at 68°C for 18 hours yielded less press fluid and lower scores for juiciness than similar cuts cooked at 63°C for 30 hours.

Studying the effect of cooking method on beef roasts, Hood, et al. (92) concluded dry heat cooked roasts were juicier than roasts cooked by moist heat methods. The investigators used roasts from the triceps brachii muscle for their study.

Noble, et al. (145) found beef rib roasts cooked to 61°C juicier than comparable roasts cooked to 75°C. According to their findings, beef rounds yielded more juice than rib roasts at both degrees of doneness.

Satorius and Child (168) reported a decrease in press fluid in the semitendinosus muscle of beef by increasing the internal temperature from 67 to 75°C during cooking. However, they obtained no decrease in press fluid by increasing the internal temperature from 58 to 67°C.



Subjective Methods of Evaluating Palatability

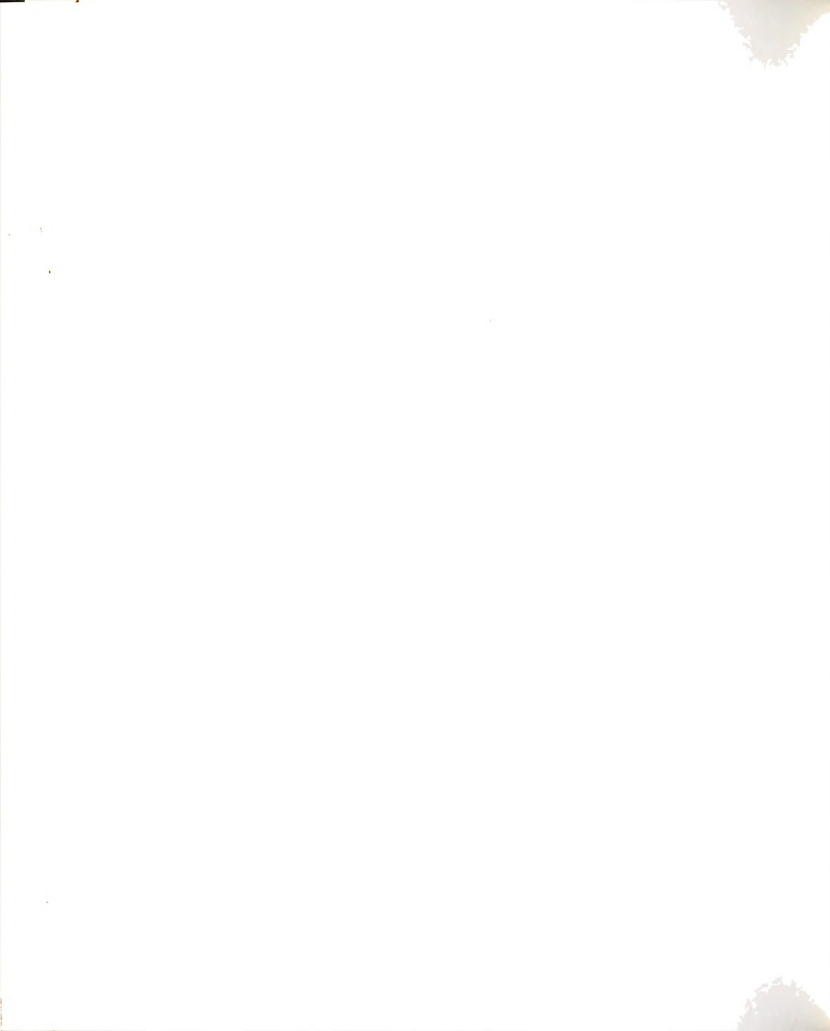
The acceptance or rejection of a food is based largely on the stimulus given the sense organs of an individual (123). Sight, smell, and taste are important senses in food evaluation.

Scoring tests

In subjective methods of evaluating palatability, the quality characteristics under consideration are assessed according to the opinions of the judges. According to Lowe (123), scoring tests are more frequently used than other sensory tests.

The factors most commonly evaluated in meat by taste panel scoring are color, flavor, odor, tenderness, and juiciness. In using a scoring test, the quality characteristics of the meat sample may be assigned a numerical score, such as from 1 to 7 arbitrary points, qualified by descriptive terms (123). One of the most widely used scoring tests is the 7-point scale of the Cooperative Meat Investigations (43).

In their discussion of problems in meat research, Satorius and Child (169) stated that the scoring method was an accurate measure of tenderness. The investigators based this conclusion on high correlations obtained between scores and mechanical shear values. The factors of palatability measured by the grading sheet were found



interrelated. Such an interdependence existed between flavor and aroma; quantity and quality of juice; flavor, aroma, and juiciness; texture and tenderness; flavor, aroma, and tenderness; and tenderness and juiciness.

Chew counts

A partly subjective and partly objective method of comparing tenderness of different samples of meat is the chew count, based on the number of chews required to masticate a sample of meat of uniform size to a determined end point. The end point of mastication is standardized with a score chart (123).

Harrington and Pearson (82) used chew count as a measure of tenderness in pork loins with various degrees of marbling. Mean chew counts showed a high correlation with mean shear values.

Cover's approach to tenderness

In 1957, Cover, et al. (49) obtained scores for tenderness of muscle fibers and for tenderness of connective tissue. Two years later, Cover (48) reported a study in which tenderness scores were divided into three component parts: softness, friability of the muscle fiber, and amount and quality of connective tissue. Softness was described as the sensations from the tongue and cheeks and by the ease with which the teeth sank into the meat at the first bite. Friability was used to designate the ease with which the muscle fibers broke and

whether they were crumbly or rubbery. Tenderness of the connective tissue was rated by the quantity and its resistance to chewing.

Later Cover and co-workers (54, 53, 52, 51) divided tenderness into six separate components. These were tenderness of connective tissue, juiciness, softness to tooth pressure, softness to tongue and cheek, ease of fragmentation and adhesion, and mealiness.

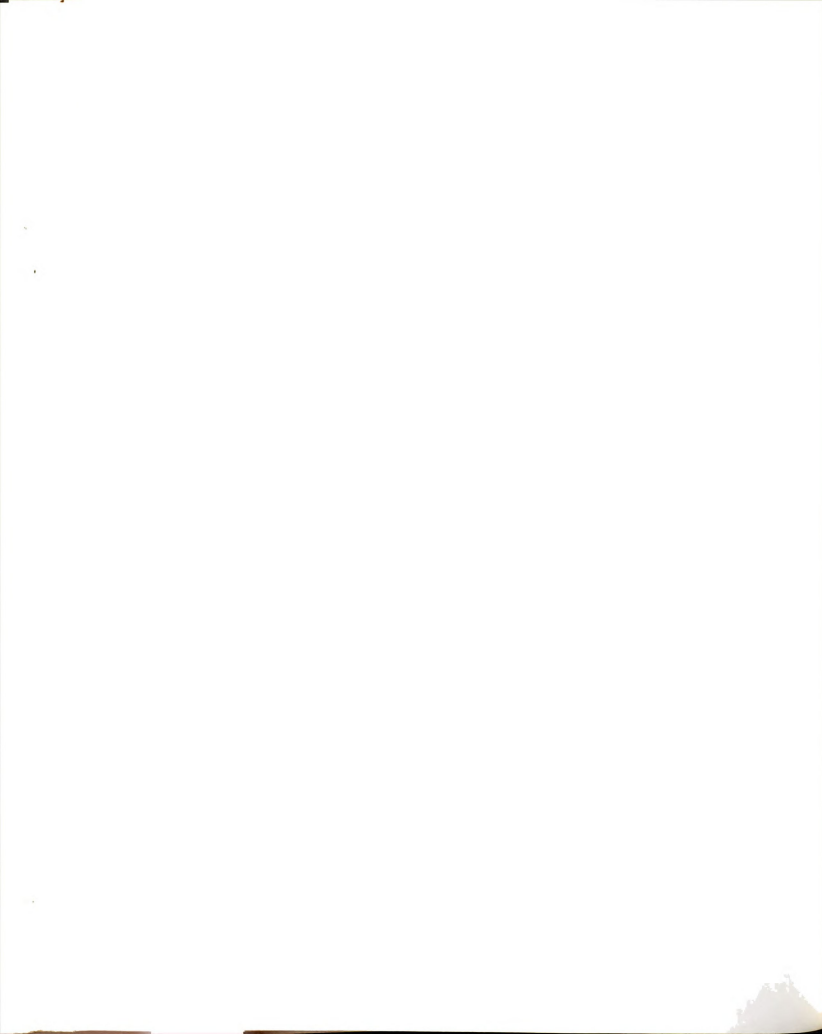
Objective Methods of Evaluating Palatability

Meat quality is determined by the total effect of its physical and chemical characteristics. Since certain organoleptic properties of meat obviously depend upon physical and chemical properties, attempts have been made to measure these properties objectively.

Tenderness

Several mechanical devices have been developed for objective measurement of tenderness. As early as 1907, Lehman (120) developed two such instruments. One determined breaking strength and the other measured the force necessary to shear meat between two cutting edges.

Warner (199) reported briefly to the American Society of Animal Production in 1928, on the developmental stages of a shearing device. Three years later, Black, et al. (17) reported more extensive studies on the apparatus which consisted of a steel blade 0.03



inch thick, cut with a square hole slightly larger than the sample of meat used. The test sample, removed from the piece of meat with a cylindrical steel core similar to a cork borer, was placed in the perforation in the steel blade and the blade pulled through a wooden miter box by means of a hand-driven screw. The following year, Bratzler (27) modified and improved this shear apparatus. The shear device, now known as the Warner-Bratzler shear, makes use of a triangle-shaped hole in the blade, a rigidly supported opening made by two steel plates and just wide enough to allow free passage of the blade, and a gear system powered by a constant speed motor.

The major difficulty of the widely used Warner-Bratzler shear is that it does not take into account the time-load effect but gives only the load for shearing. A time-load curve reflects more accurately the work required in chewing, according to Hurwicz and Tischer (99), and would, therefore, be expected to be more closely related to tenderness.

The Cutting Gage of Tressler, et al. (187) determined the pressure needed to cut or puncture meat. The instrument consisted of a Schrader tire pressure gage connected to a blunt penetrating instrument. The puncturing device was a metal rod 2.50 inches long and 0.31 inches in diameter with a symmetrically tapered end. In use, a sample of meat 3 inches square and 1 inch thick was clamped at its periphery, thereby allowing the puncturing device to perforate the

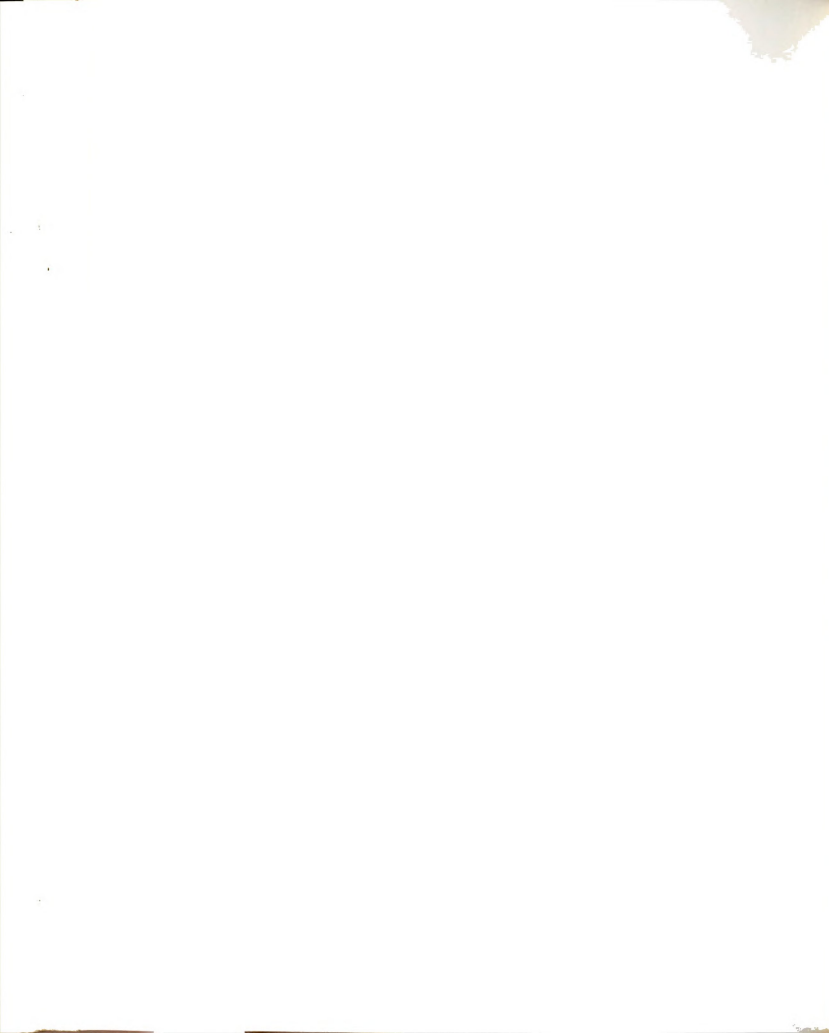
meat without obstruction. The values obtained from 8 readings were converted to pounds force. A later modification of the instrument added a driven motor (188).

Tressler, et al. (187) also used a penetrating needle 1.38 inches long and 0.15 inch in diameter with a rounded point of 0.07 inch radius to measure meat tenderness. In operation, the needle point was brought to rest in a vertical position on top of the meat. A weight of 255 grams was then placed over the needle and held for 15 seconds. The distance of penetration in millimeters was recorded on a dial geared to the movement of the needle.

Child and Satorius (36) used an instrument similar to the Warner-Bratzler shear. The Child-Satorius shear recorded the number of pounds force on a gage as shearing bars were pulled across a dull blade with a triangular opening through which the sample was placed.

In 1938, Volodkevich (195) described an instrument in which metal wedges or artificial teeth were used. The meat was placed between the wedges, one of which was stationary and the other movable by mechanical means. Movement of the wedge was recorded on a revolving drum, thereby giving a continuous recording of the pressure on the meat. The slope of the curve and the area under the curve were used to calculate a value for meat tenderness.

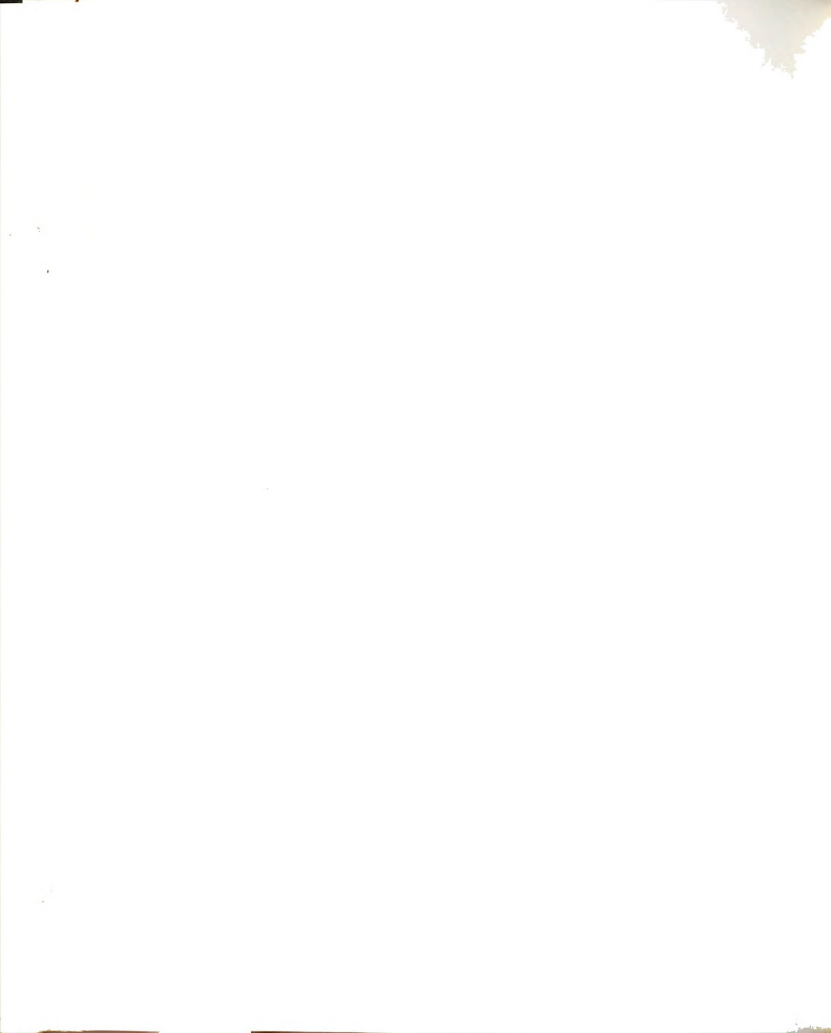
Miyada and Tappell (140) modified a Christel Texturemeter



by attaching an electric motor and reduction gears and used this device for measuring meat tenderness. The total work and maximum shear force required to force shearing prongs through a cylindrical sample of meat were recorded. Maximum shear readings were obtained from the peak of the force-distance diagram. The area under the curve represented the total work involved.

By wiring the motor of a grinder in series with an AC ammeter and recording the ampere readings at 5-second intervals, Miyada and Tappel (140) plotted the power consumption in watts as a function of time to represent the total energy expended in grinding a meat sample. Theoretically, increased toughness of meat would produce a corresponding increase in current consumption by the grinder. In two studies on the longissimus dorsi muscle of beef, Bockian, et al. (18) obtained highly significant correlation coefficients of $-.59$ and $-.60$ between sensory evaluation and grinding measurements of meat tenderness.

In 1955, Proctor, et al. (159) reported the construction of an instrument making use of two dentures and simulating the frequency and motions of chewing. The instrument consisted of upper and lower dental plates fastened to an articulator with simulated cheeks, lips, and tongue. The upper dentures were movable and by means of a motor gave both vertical and lateral movements, while the lower dentures were stationary. A strain gage recorded the chewing action.



Proctor, et al. (160) later modified the instrument so a force penetration diagram could be obtained.

The Kramer shear-press (115), initially developed for quality evaluation of vegetables, measures the maximum pressure required to force a plunger through the sample material. By means of a sensitive mechanical pressure gage, which registers through a proving ring, and by connection of the pressure gage through an amplifier to a recording device, it is possible to make a continuous recording of pressure as the plunger plates pass through the product. The pressure-time curve obtained from the recording can be used for calculating the work required to penetrate the product. High coefficients of correlation between the shear-press and sensory evaluations of meat have been obtained by Bailey, et al. (10), Burrill, et al. (30), Bramblett, et al. (23), Rogers, et al. (165), and Tuomy and Lechnir (191).

Sperring, et al. (178) used the orifice method for measuring meat tenderness. This method made use of a Carver press with a modified cylinder and a base containing a hole 0.30 inch in diameter. When in use, the base was placed on top of a cutaway cylinder so the orifice in the base could be observed. Samples 0.50 inch in thickness and weighing approximately 30 grams were placed in the cylinder, and the pressure was raised until meat from the sample first extruded from the orifice. Theoretically, less pressure was required to

force tender meat through the orifice than was needed for tough meat.

Alsmeyer, et al. (5) used a materials testing instrument equipped with a special rod for puncturing meat and a shear device for determining meat tenderness. Values were obtained on the basis of either penetration force or shear force from the force-penetration curve. Alsmeyer, et al. (6) later reported highly significant correlations between the shear device and taste panel scores on the longissimus dorsi muscle of pork.

Recently, a patent (147) was issued for a tenderness-testing device in which the force necessary to penetrate a piece of meat was measured as well as the amount of recovery of the meat when the force was removed. This device was based on the concept that tough meat was difficult to penetrate and was very elastic.

Juiciness

Of the several methods proposed for determining the fluid content of meat, all involve the principle of pressure but differ in design. In 1905, Grindley and Emmett (75) extracted juice from raw beef by grinding and then pressing the meat in a compound screw press. A few years later, Bigelow and Cook (14) pressed small pieces of beef through cotton bags in a glycerine cylinder press. In 1912, as reported by Child and Fogarty (35), Botazzi ground raw ox muscle with diatomaceous powder and then applied pressure to determine the amount of fluid.

Child and Baldelli (33) reported the first mechanical method developed for the study of juiciness of cooked meats. By means of an apparatus called a pressometer, they subjected 2- to 3-gram samples of meat wrapped in unsized filter cloth, to a pressure of 250 pounds for 10 minutes. The amount of juice was determined by the difference in weight before and after subjecting the meat sample to pressure.

Tanner, et al. (182) used a hydraulic laboratory press equipped with plates electrically heated to 50°C and capable of producing up to 20,000 pounds pressure per square inch to measure juiciness of meat. Juice was collected in a receiver, thus facilitating subsequent determination of its fat content. Difference in weights of the sample before and after pressing represented the quantity of expressible fluid.

The Carver press has been used extensively for measurement of press fluid or juiciness. This hand operated, hydraulic press provides pressures up to 24,000 pounds per square inch. The material to be pressed is confined between separator plates and filter pads in a one piece metal cage. Vertical grooves carry liquid out to a series of collecting rings and thence to a spout.

Urbin, et al. (192) modified the Carver press by substituting an electrically driven centrifugal pump for the original hand operated pump. These investigators concluded a greater degree of standardization resulted with an electric pump.

Losses incurred during cooking may be an indication of

juiciness. From her studies in standardizing methods of roasting beef, Latzke (118) concluded juiciness in the meat can be predicted to some extent by the amount of losses during cooking. This inverse relationship between product juiciness and cooking losses was also observed by Bramblett, et al. (23) and Cover, et al. (53).

Texture, muscle extensibility and firmness

Szczesnick, et al. (181) recently described a new recording instrument, the Texturometer, used to determine the texture of foods. The instrument is an adaptation of the denture tenderometer developed by Proctor, et al. (159, 160). The device simulates certain aspects of the human chewing motion and records the results in terms of several parameters, thus giving a texture "profile." The parameters measured are hardness, cohesiveness, elasticity, chewiness, juiciness, and the rate of water release. The authors obtained very highly significant coefficients of correlation between scores of a specially trained texture profile panel and recordings from their instrument.

Analysis of the measurement of the extensibility of single muscle fibers and Warner-Bratzler shear force measurements showed a negative correlation, according to data presented by Wang, et al. (198). Saffle and Bratzler (166) found highly significant correlations between taste panel tenderness scores for pork loin chops and muscle fiber extensibility.

Pilkington, et al. (156) measured firmness of a 2-inch 11th and 12th beef rib steak using a modified Precision Penetrometer and a trained taste panel. Positive correlations existed between firmness and tenderness, as measured by the panel and the penetrometer. Their data suggested that, with fat content held constant, the softer muscle tissue tended to be more tender than firmer rib steaks.

Correlation with subjective methods

Conflicting reports appear in the literature regarding the correlation of subjective and objective measurements of palatability characteristics. Mackintosh, et al. (128), Palmer, et al. (148), Ramsbottom, et al. (163), Day (59), Cover and Smith (56), Paul, et al. (151), McBee and Naumann (136), Webb, et al. (201), and Burrill, et al. (30) found significant correlations between sensory evaluations of meat tenderness and Warner-Bratzler shear values. Conversely, Visser, et al. (194) reported correlations between sensory evaluations and Warner-Bratzler shear values were not significant. Significant correlations between Kramer shear-press values and sensory evaluations were obtained by Bailey, et al. (10), Shannon, et al. (173), Burrill, et al. (30), Bramblett and Vail (24), Rogers, et al. (165), and Tuomy and Lechnir (191).

The relationship between juiciness scores and Warner-Bratzler shear force values has been studied. Wellington, et al. (203) and Cover (48) reported highly significant correlations between

juiciness scores and tenderness as measured by the Warner-Bratzler shear.

Hydroxyproline values correlated significantly with Kramer shear-press values in a study by Parrish, et al. (149). Paul (150) calculated correlation coefficients between tenderness as measured by panel scores and percentage collagen, percentage elastin, and percentage fat. None of the coefficients was large enough to indicate that these chemical determinants would be useful as valid predictors of tenderness.

Satorius and Child (169) in their study on beef ribs, found no correlation between press fluid and the quantity of juice as judged by a grading sheet score. These findings were confirmed by Gaddis, et al. (69).

Microorganisms on or in Meat

During storage prior to cooking, meat is constantly acted upon by its enzymes, bacteria and their enzymes, and the environment in which the meat is held. Not all of the changes occurring in meat are undesirable. Enzymatic changes in meat, such as the reduction of glycogen to lactic acid, and those brought about in connection with controlled aging of meat are desirable. An example of desirable changes produced by bacterial action is the tangy flavor produced in certain sausages such as lebanon, thuringer, and in pork roll with

the use of harmless bacterial starters of the acidophilus type. On the other hand, bacterial changes occurring in meat which result in deterioration of quality and subsequent spoilage are undesirable.

The freshly slaughtered and dressed carcass of the meat animal is virtually sterile except for the lymph nodes, which may contain moderate numbers of bacteria (121). As the carcass is subjected to handling and processing, however, increasing numbers of microorganisms are introduced on the surface of the meat (108, 109, 130). The contaminating flora is extremely diverse (130, 102). The fate of the microorganisms and their effect on the meat are dependent on the physical and chemical environment which surrounds them.

Factors affecting growth of microorganisms

The food requirements of microorganisms vary. Some require only water, oxygen, carbon dioxide, minerals, and a simple source of nitrogen and carbohydrate. Others have more complex nutritive requirements necessitating many amino acids, vitamins, purines, and pyrimidines. Meat is an excellent source of most of these nutrients (67).

Microorganisms may be classified according to their temperature requirements for growth. Those growing at temperatures between 15 to 40°C are called mesophiles. Psychrophiles grow best at temperatures below 20°C, whereas temperatures best for the growth



of thermophilic bacteria range from 55 to 60°C. During the cooking and cooling process, meat or meat products are in the temperature range for growth of mesophilic and thermophilic microorganisms. Storage may be at temperatures conducive to rapid growth of psychrophiles (67).

Another classification of microorganisms is on the basis of their need for oxygen: anaerobic and aerobic. Between these two extremes are organisms, such as staphylococci and coliform bacteria, which can grow either in the presence or in the absence of oxygen. In the interior of meat, only anaerobic organisms can grow (67).

Most microorganisms grow over a pH range of 4.5 to 8.5 with the range for optimum growth between pH values of 6.5 and 7.5. There are exceptions, such as Acetobacter and Lactobacillus, which are usually regarded as being both aciduric and acidogenic. Depending on the glycogen content of the meat at the time of slaughter, the pH of fresh meat is generally between 5.3 and 6.0. Most types of microorganisms can initiate growth in this pH range, but meat with a pH of 6.0 will spoil more rapidly than meat with a pH of 5.3 (104, 110, 86).

The water content of meat is ideal for many varieties of microorganisms. If the bacteria are limited to the surface of the meat, drying the surface will restrict growth of most spoilage organisms.

Cured meat may contain sodium chloride, sodium or potassium nitrate and nitrite, sugar and phosphates as well as other ingredients contributing to their texture, color stability, or flavor. These ingredients may inhibit growth of microorganisms that normally cause spoilage of fresh meats. Their major effect is the change in moisture content due to the effect of the sodium chloride. The nitrate may be reduced to nitrite by bacteria, and nitrite is relatively toxic to many bacteria. Sugar may provide an additional substrate for fermentative types of bacteria that produce acids and lower the pH of the product. The effects of other curing ingredients are due to changes occurring in pH and moisture (67).

Significance of food poisoning organisms in meat

Meat has been implicated in food poisoning outbreaks (7, 73). Such food poisoning may be the result either of bacterial toxins formed in the meat prior to consumption or to bacterial infections resulting from the ingestion of viable pathogens with the meat. Adequate cooking destroys pathogenic organisms and some toxins (67). Improper handling of the meat after cooking may result in re-contamination, however (29).

The most serious type of food poisoning is botulism, caused by toxin produced by Clostridium botulinum. The causative organism is an anaerobic bacterium which produces a relatively heat labile toxin and heat resistant spores (67).

A more common type of food poisoning is caused by Staphylococcus enterotoxin, produced by Staphylococcus aureus. The organism is a facultative, nonspore-forming species, easily killed by heat. However, the toxin is very heat resistant. The foods most commonly involved in staphylococcal food poisonings are poultry products, cream-filled pastries, ham and potato salads (67).

Salmonellosis, caused by a bacterial infection resulting from ingestion of fairly large numbers of the causative organism, is another type of food poisoning. Salmonellae are facultative, nonspore-forming organisms of intestinal origin. Poultry products, particularly, are a frequent cause of salmonellosis, but meat products are occasionally involved (67).

In addition to these well-known types of bacterial food poisoning, other bacteria that are normally considered harmless are occasionally implicated in food poisoning outbreaks. These include Clostridium perfringens, Streptococcus faecalis, and Bacillus cereus (67).

Meat cooking and microorganisms

The literature contains few reports regarding time-temperature effects on bacteria in meat during cooking. Husseman and Buyske (102) reported on the survival of Salmonella typhimurium in chicken muscle. Forty per cent of the chick muscle samples contained viable

organisms after 45 minutes heating at 75°C , according to their study.

Iacono, et al. (103) studied the rate of bacterial growth during the roasting of 12- and 13-pound turkeys. An examination of the data showed the birds were in the optimum growth range for staphylococci and salmonellae too short a time to permit extensive growth of the organisms.

Castellani, et al. (32) injected stuffed turkeys with Streptococcus faecalis, Staphylococcus aureus, and Salmonella pullorum. The turkeys were cooked at 149°C to an internal temperature of 74°C , as indicated in the center of the stuffing. The resulting time-temperature relationship killed the organisms present and allowed a safety margin.

Barnes, et al. (12) studied the behavior of a food poisoning strain of Clostridium perfringens in beef. The results of the study showed the majority of spores failed to germinate in meat stored at 1, 5, 10, and 15°C for 13 days. Slow multiplication occurred at 20°C but at 25 and 37°C growth was rapid.

Dymit (66) reported bacteriological findings of delayed service cookery. According to his report, no problem existed if the temperature of the holding cabinet was not allowed to fall below 60°C . He did stress the importance of browning the meat well, however, since this procedure would eliminate any danger from microorganisms initially present on the surface of the meat.

METHOD OF PROCEDURE

To compare the effect of four cooking methods on heat penetration rates, cooking losses and palatability factors, 24 loin cuts from 6 pairs of U.S. Choice grade beef loins were used. Each loin cut of beef selected for cooking by delayed service with a 6-hour and an 18-hour holding period, forced convection, and conventional roasting, was based on a predetermined plan. Procedures used for roasting and objective and subjective evaluations of the samples were developed through preliminary investigations.

Procurement of Samples

U.S. Choice grade, Range 2, regular short loins or Item No. 173 of the Institutional Meat Purchase Specifications for Fresh Beef -- Series 100 (105), were secured 6 days after slaughter through a local wholesaler. The tenderloin, protruding edge of the chine bone and flank edge were removed resulting in Item No. 179 of the above mentioned specifications. Each strip loin (bone-in) cut was then halved, making two roasts from each short loin of the six pairs.

The roasts were weighed and coded according to the animal from which they were obtained, the position of the cut, the side of the animal, and the cooking method to be used. The cuts were wrapped



in a double thickness of heavy, waxed freezer paper and blast frozen. They were stored at -34.4°C until defrosted in the refrigerator for roasting and subsequent evaluation.

The cooking method used for each sample was arbitrarily assigned so that one of the four cuts from each animal would be roasted by each of the four cooking methods. Samples from anterior and posterior positions and left and right sides were rotated according to a predetermined plan (Table 1).

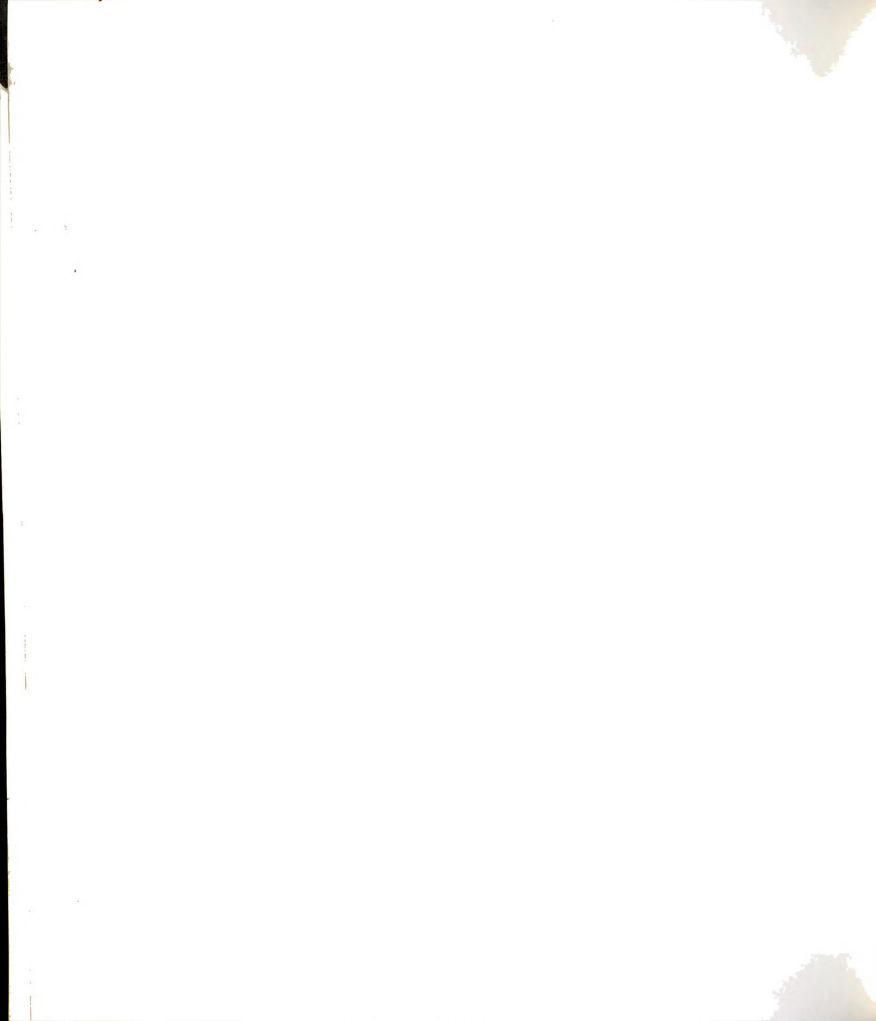
Table 1. Rotation plan for selection of meat cuts for each cooking method.

Cooking Method	Code and Rotation Plan Used for the Twenty-four Meat Cuts					
Delayed service, 6-hour	1AL	2PR	3AR	4PL	5AL	6PR
Delayed service, 18-hour	1PL	2AL	3PR	4AR	5PL	6AL
Forced convection	1AR	2PL	3AL	4PR	5AR	6PL
Conventional	1PR	2AR	3PL	4AL	5PR	6AR

Code: Animal, 1 to 6; Position, A Anterior, P Posterior; Side of animal, L Left, R Right.

Preparation of Samples for Roasting

After removal from the freezer, the samples were unwrapped and weighed, using a 5-kilogram capacity torsion balance. Weight losses during freezing were determined as the difference between



this weight and the original weight of the sample. After rewrapping in Saran, each sample was defrosted for 36 to 50 hours in a 5°C reach-in refrigerator.

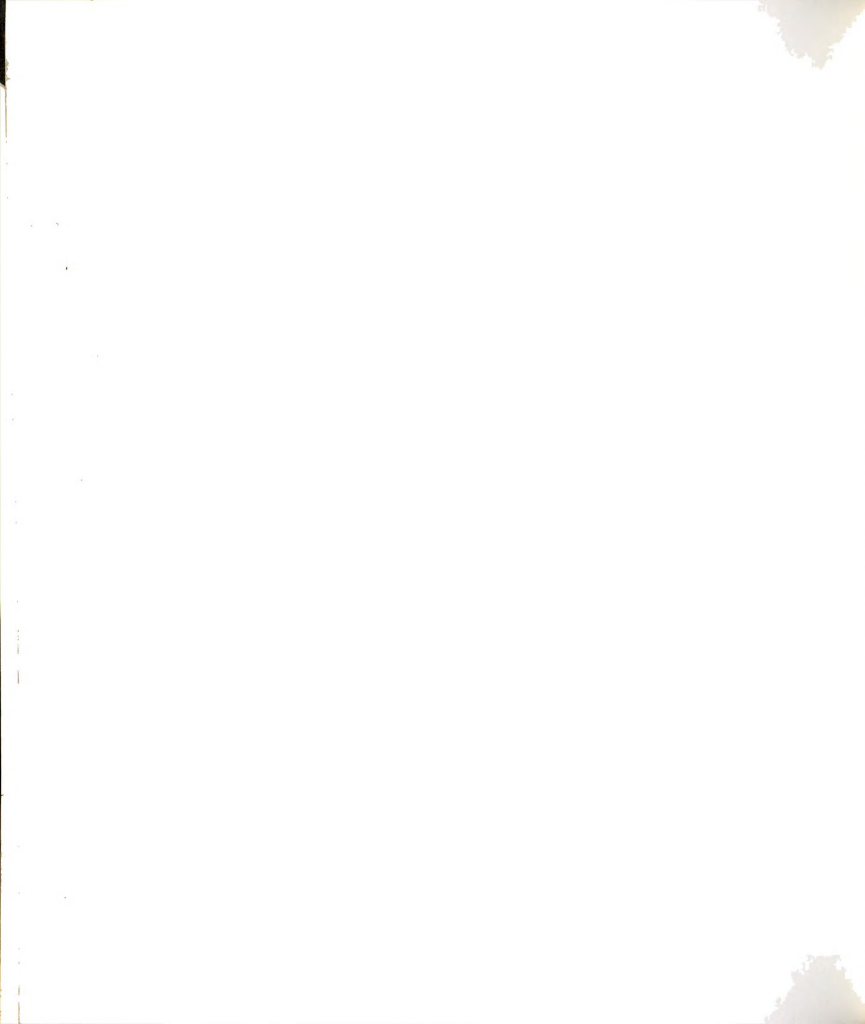
After defrosting, the sample was again weighed to determine weight loss during defrosting. The difference between this weight and the weight after freezing determined weight loss during defrosting.

The outer coating of fat was trimmed to 3/8 inch thickness; as measured with vernier calipers. Samples for chemical analysis were removed and the raw weight of the sample was obtained.

The oven-ready roast was positioned fat side up on an aluminum sheet roasting rack perforated with 0.19-inch holes at 0.75-inch x 0.50-inch intervals. The 18" x 9.50" x 1" roasting rack had previously been weighed in the 18.63" x 9.75" x 2.25" aluminum roasting pan.

Basis of the Heat Penetration Data

The time-temperature relationships at various positions were continuously recorded during oven cooking with a 12-point Brown Electronic Potentiometer High Speed Multiple Point Recorder. The recording from the potentiometer lead placed horizontally at the center of the roast from the back, was used to indicate the end cooking temperature of 52°C for all roasts.

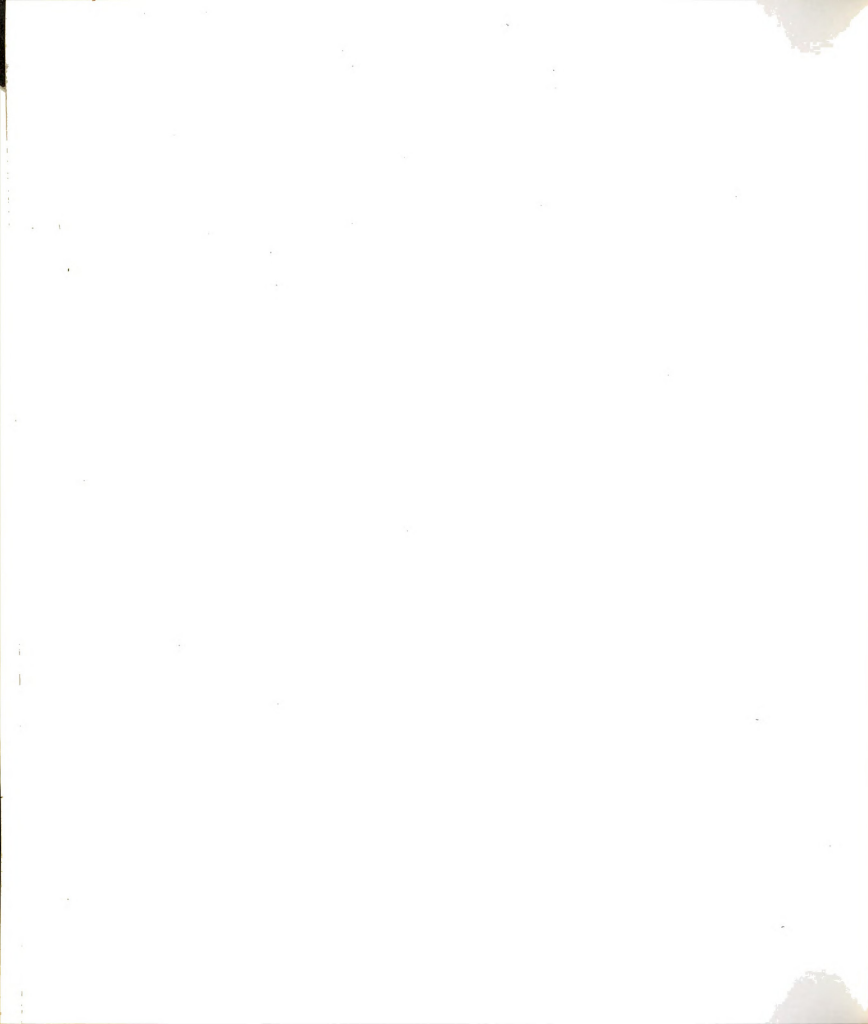


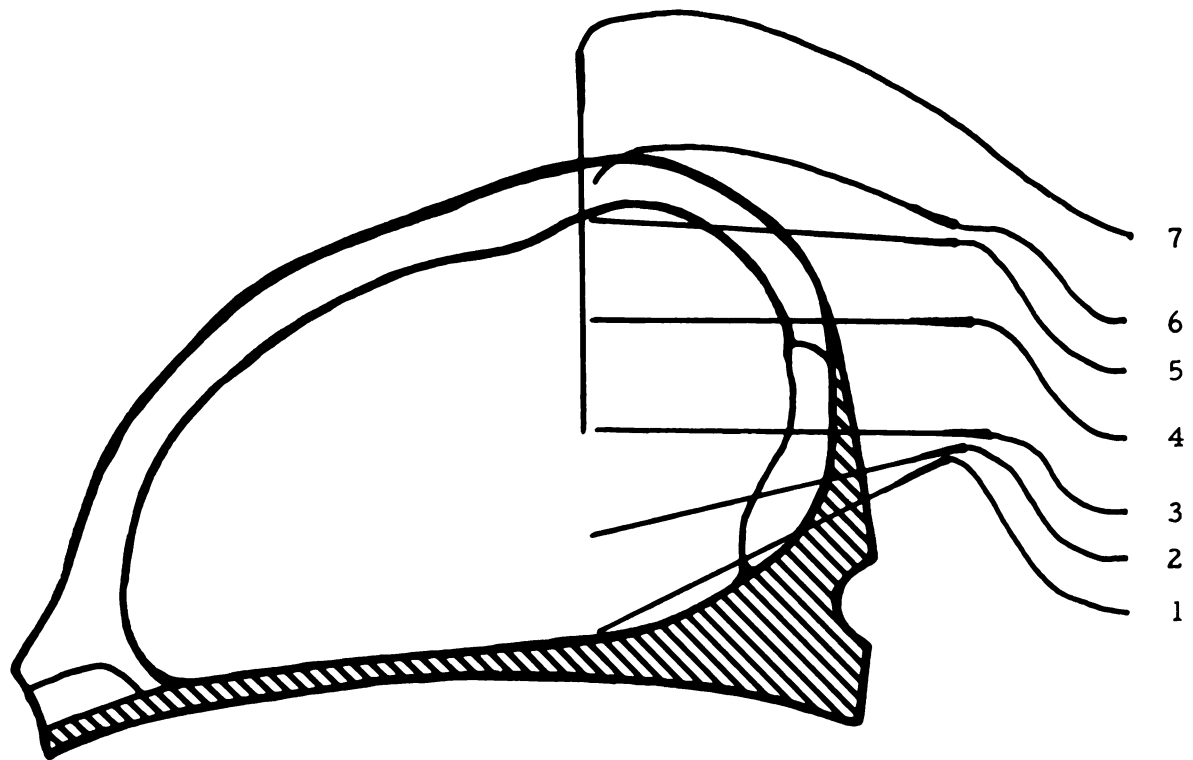
Potentiometer lead placement

Iron constantan thermocouples were positioned in the roast from the center of the back (Fig. 1). The positions of the potentiometer leads were: No. 1, at the bone and connective tissue-muscle interface; No. 2, midway between the bone, connective tissue-muscle interface and the center of the muscle tissue; No. 3, the center of the muscle tissue; No. 4, midway between the center of the muscle tissue and the fat, connective tissue-muscle interface; No. 5, just below the surface fat and the connective tissue sheath covering the muscle; No. 6, embedded approximately 0.13-inch into the surface of the fat; and No. 7, inserted from the top of the sample to the center of the muscle tissue. An eighth potentiometer lead, placed approximately 3 inches above the surface of the meat, was used to obtain a continuous record of the oven temperature during roasting.

Temperatures during holding

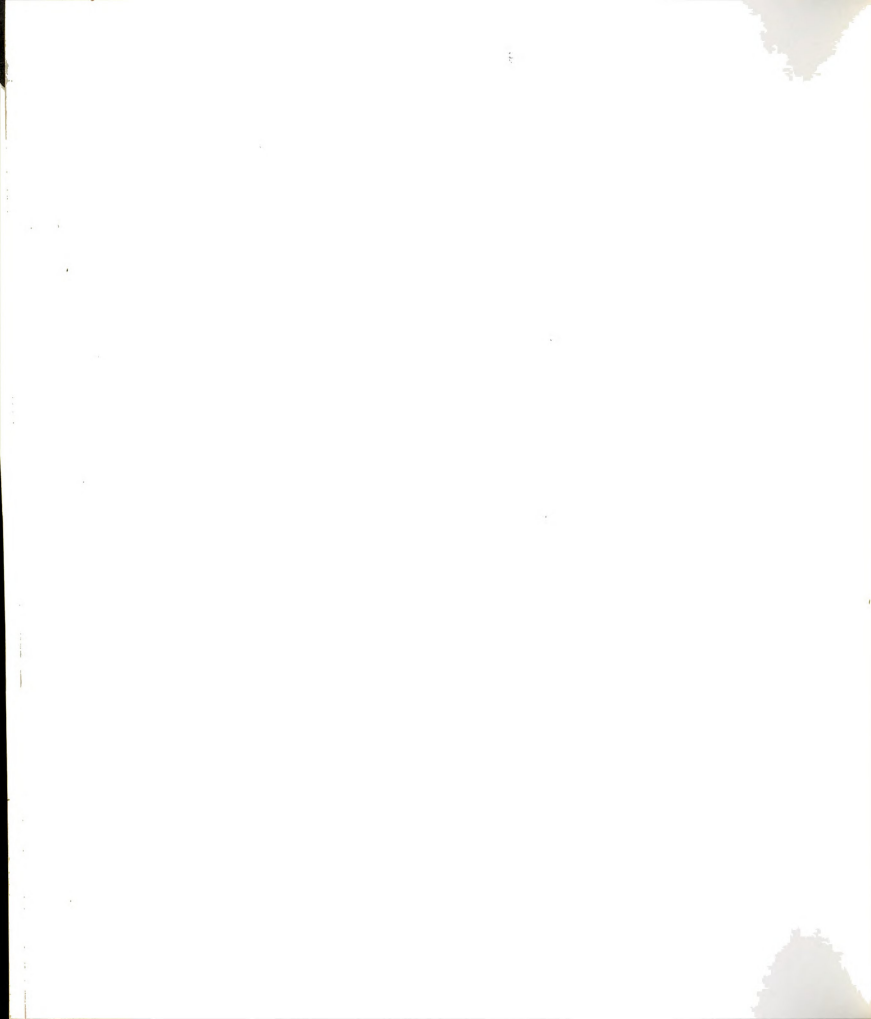
Temperatures during holding periods in the 60°C cabinet for delayed service cooked roasts were obtained with meat thermometers, one inserted to the center of the roast and a second to a point midway between the center and the surface. Initial and hourly thermometer readings were recorded for roasts held for six hours. For roasts held for eighteen hours, the initial temperature and the temperature at the end of the first hour were recorded. Beginning at the twelfth





1. Bone, connective tissue-muscle interface
2. Muscle tissue
3. Center of muscle tissue
4. Muscle tissue
5. Fat, connective tissue-muscle interface
6. Surface fat
7. Center of muscle tissue

Figure 1. Potentiometer lead positions for continuous recording of time-temperature relationships during roasting.



hour, the temperatures were again recorded hourly for the remainder of the holding period.

Roasting of Meat

Preliminary investigations established cooking end point temperatures and holding periods for delayed service cooked roasts. For conventional roasting, an oven temperature of 149°C was used. The same temperature of 149°C was selected for forced convection roasting to facilitate a direct comparison of heat penetration rates, cooking losses, and palatability factors, with those for conventional roasting.

Delayed service cooking

Delayed service cooking procedures had suggested browning temperatures ranging from 177 to 232°C . In preliminary studies, 204°C was found to yield roasts with a desirable degree of browning in the comparatively short period of time originally suggested for this procedure.

Holding periods for delayed service cookery were based on preliminary studies. Roasts held for 36 hours were extremely dried and their surfaces were hardened. Further studies confirmed the adverse effects of long holding periods. Hence, a maximum holding time of 18 hours was used. Also, the practicality of the holding times for the institutional setting was considered. It was reasoned the meat



could be oven roasted in the morning hours and then placed in the holding cabinet until needed for evening service, a period of about six hours. Or, after ovens were freed from evening meat preparation, meat could be oven roasted and placed in holding cabinets for service the following noon, 12 to 18 hours later.

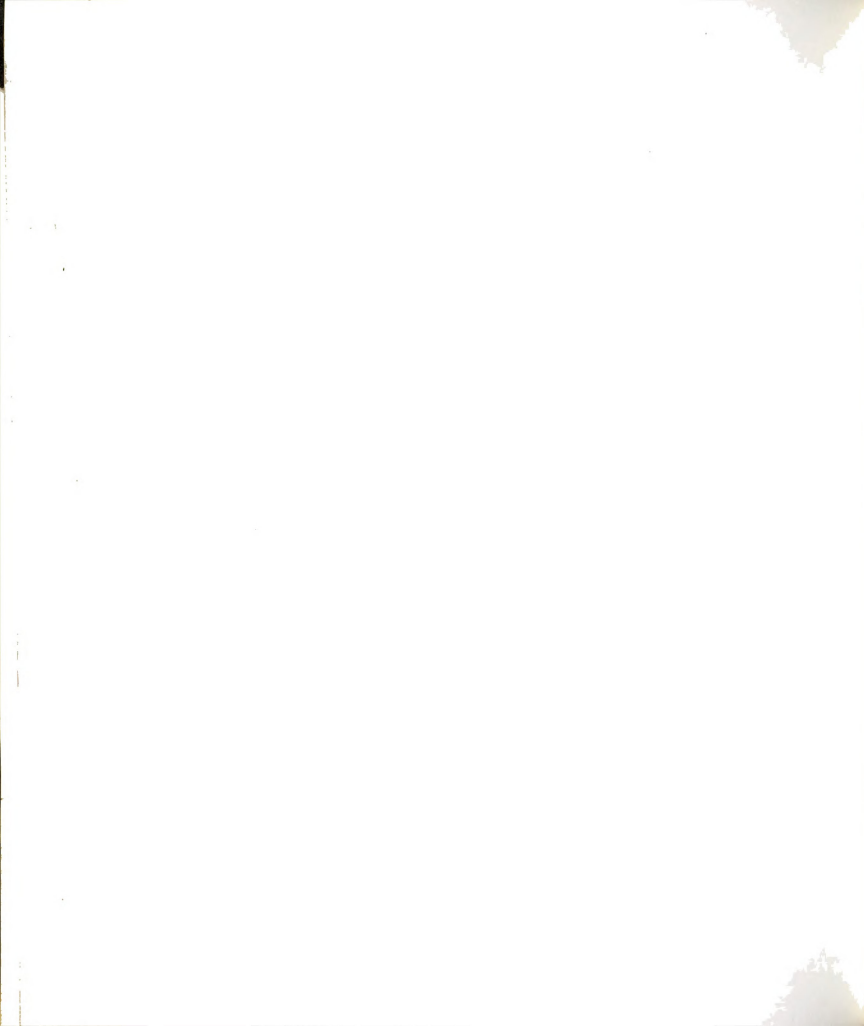
End cooking temperature

Preliminary investigations showed a temperature rise of approximately 10°C in the longissimus dorsi muscle after removal from the 149°C conventional oven at an end internal temperature of 52°C . An end point temperature of 52°C was selected, so the meat would be rare after the additional rise following removal from the oven.

Equipment

A General Electric 30-inch compact, heavy duty oven, model CN16, was used for oven roasting of delayed service and for the conventionally roasted samples. The center deck was removed from the oven during roasting, thus obtaining the depth necessary for the oven-ready sample. The oven was preheated to and maintained at the specified temperature $\pm 20^{\circ}\text{C}$ during roasting, with the grids set on medium and the damper half closed. ✓

A Metal Cabinet, Cenco Forced Circulation Incubator, set and maintained at $60^{\circ}\text{C} \pm 2^{\circ}\text{C}$, was used as a holding cabinet for samples



cooked by the delayed service method. An inner glass door on the incubator permitted thermometer reading and subsequent recording without causing any fluctuations in the interior temperature.

An ETCO oven, Model 186, was used for samples roasted by forced convection. The thermostat was set to maintain a temperature of 149°C , $\pm 10^{\circ}\text{C}$, during roasting. A pan 15.50" x 12.50" x 2.50", filled to a depth of 1 inch with three liters of boiling water was placed on a lower shelf in the air-tight oven just before the sample was put into the oven.

Treatment after Removal from Oven

Data from the cooked samples were collected prior to and after holding periods for the delayed service method. Data for forced convection and conventionally cooked samples were collected immediately after a 30-minute holding period following their removal from the oven.

Delayed service

Immediately after removal from the oven, the potentiometer leads were removed and the sample was weighed. The meat was then transferred to a clean, weighed roasting pan and rack. After insertion of meat thermometers, the sample was placed in the holding cabinet for the appropriate period.

Oven cooking losses were determined as the difference in raw and cooked weight. The weight of the drippings was obtained by



subtracting the known weight of the roasting pan and rack from the total weight of the pan, rack and drippings. Volatile losses were calculated as the difference between the raw sample weight and the combined weights of the cooked roast and the drippings.

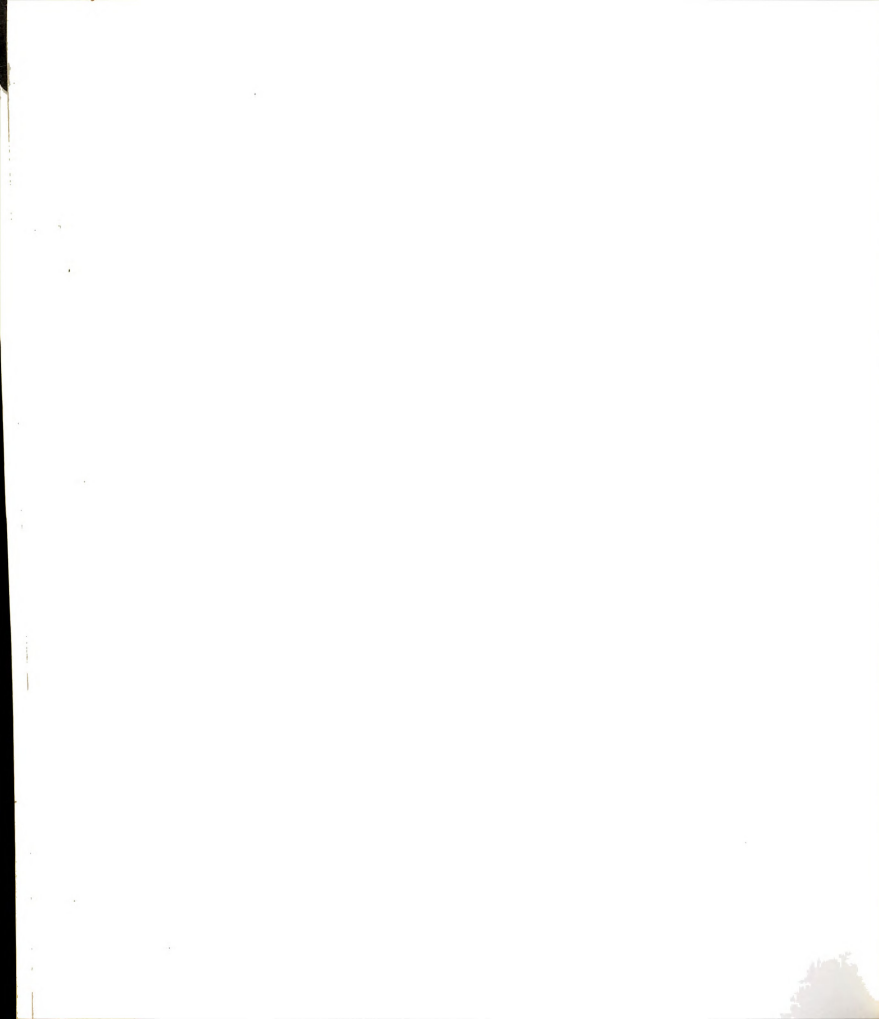
Additional losses incurred during holding were calculated in the same manner. Total losses included both oven cooking losses and the holding losses. At the end of the holding period, roasts were boned and the edible portion, defined as cooked sample minus bone, determined.

Conventional and forced convection

After removal from the oven, the samples were allowed to stand undisturbed at room temperature, ranging from 26 to 36°C, for 30 minutes. Time-temperature relationships were continuously recorded during this period. At the end of the period, the potentiometer leads were removed and each roast was weighed. Cooking losses and edible portion were determined as for roasts cooked by delayed service.

Subjective Evaluation of Palatability Factors

The external appearance of the cooked roasts was rated subjectively by the investigator prior to boning and slicing. Six palatability characteristics of the samples were evaluated subjectively by a taste panel of seven members.



Subjective evaluation

Prior to further preparation for sensory evaluation or objective measurement, the cooked roast was rated for the over-all appearance and the appearance of the fat and lean surfaces. A check form was used to simplify and speed the evaluation. The over-all appearance was rated as excellent, very good, medium, fair, poor, or very poor. Descriptive terminology applicable to the appearance of the fat was crisp, pale, browned, burned, moist, dried, and very dried. The lean surface was evaluated as browned, burned, moist, dried, or very dried. Additional comments were added when applicable.

Sensory evaluation

The boned roasts were sliced with a model 410 Hobart slicer, set at 30 to provide the 0.30-inch slices for sensory evaluation and objective measurements. Each of the seven trained judges was served a slice of the roast from the same relative position in the roasts obtained from the posterior and anterior sections of each loin (Fig. 2).

The meat was evaluated as soon as possible after the cooking and holding periods, using Dri-Heat hot plates to keep the samples warm. The hot plate assembly consisted of a stainless steel, double-walled lower shell which held an aluminum alloy pellet and serving plate, and the stainless steel cover with a vent-hole, 0.50-inch in diameter, in the center. In theory, the heat was released from the

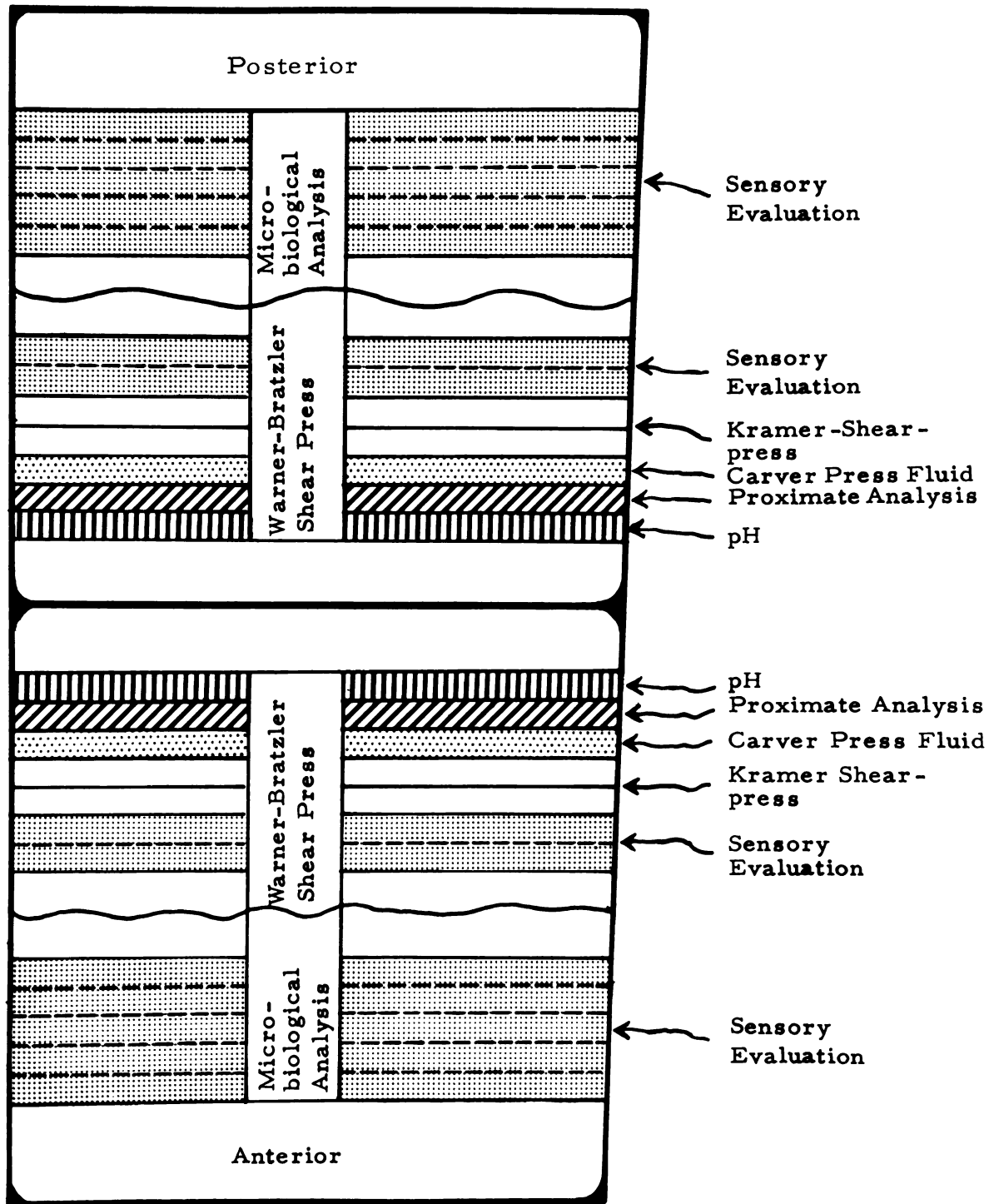


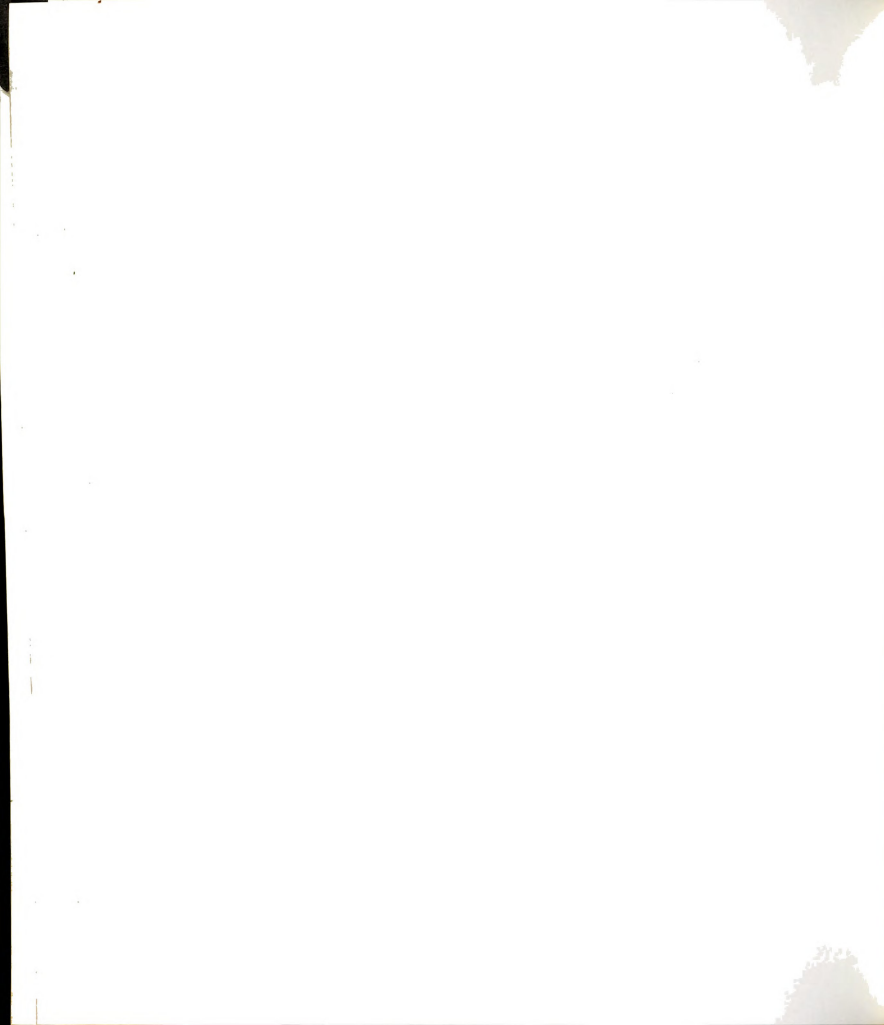
Figure 2. Location of samples for objective and subjective evaluation of cooked roasts from the anterior and posterior positions.

heat-retaining pellet slowly enough to prevent the temperature of the food from rising. The pellets were preheated in a 190°C oven and the lower shell, serving plate, and cover were heated in a 66°C oven for one hour. As the meat was sliced it was placed in the assembled hot plate and served to the judges within 15 to 20 minutes.

Glasses of water at room temperature were provided for panel members. Salt-free soda crackers were available to eliminate fat and flavors from the mouths of panelists between evaluations of the two samples served at each session. The panel was served in a special taste panel room so lighting and surroundings were constant for each session.

The panel scored the samples for aroma, color of lean, flavor of lean, flavor of fat, juiciness of lean, tenderness, and chew count (Appendix, Table 14). Scoring was based on a 7-point scale. A score of 1 indicated unacceptable quality and a score of 7 was excellent quality. Each numerical score was qualified with descriptive terminology to aid the judges in assigning a score for each palatability factor. Comments of the judges were summarized and applied to the interpretation of the data. The panelists were asked to consider each sample independently without reference to the other.

Chew counts were determined on a 1-inch circle, precut from the meat slice. The panelists were asked to count the number of chews required for the meat circle to disappear from their mouths



without conscious swallowing. A "chew range" table for each judge was developed in preliminary taste panel sessions by determining the number of chews corresponding to a particular tenderness score. This table was then used by the panelist for scoring tenderness throughout the panel sessions.

Objective Measurement of Palatability Factors

Cooked samples for objective measurement were taken from the same relative positions in each roast (Fig. 2). After removal from the roast, samples for press fluid and Warner-Bratzler shear were coded, wrapped in Saran, and allowed to cool to room temperature before measurement. Samples for the Kramer shear-press were wrapped in freezer paper, coded, and frozen and stored at -34.4°C until analysis.

Juiciness

The Carver press was used to determine juiciness of cooked samples. Two samples were obtained from the previously indicated slice (Fig. 2) and weighed to the nearest 0.0 gram. The 8- to 10-gram samples were placed between canvas and felt pads and simultaneously subjected to 15,000 pounds pressure per square inch for 10 minutes. After pressing, samples were separated from the pads and reweighed using the same 2-kilogram capacity, trip balance. The

press fluid was calculated as the difference between the initial and the pressed weight of the sample. The two values obtained were averaged.

Tenderness

Tenderness was objectively measured with the Warner-Bratzler shear and with the Kramer shear-press. The Warner-Bratzler shear measured in pounds the force required to cut through a 1-inch diameter cylinder of cooked meat. Five readings were taken from each core, 3 inches in length. The readings were averaged.

For tenderness measurements by the Kramer shear-press, model SP12, four 1-inch circles, 0.30 inch in thickness, were cut from each previously designated frozen meat slice. They were covered with Saran and aluminum foil and allowed to defrost at room temperature for 2 hours before testing. Samples ranging between 15.50 and 19.70 grams, were weighed on a 120-gram capacity torsion balance to the nearest 0.00 gram. A 30-second downstroke, 1000-pound range, and 250-pound pressure were used with the 3000-pound electronic ring. The sample, consisting of the four 1-inch circles, was sheared after being symmetrically arranged in the center of the cell. Pounds force per gram required for shearing was obtained by the prescribed formula:

$$\frac{\text{Range X Maximum force reading}}{\text{Sample weight}}$$

The two values obtained from each roast were then averaged.

Heat Penetration Data

Throughout the oven cooking, progressive time-temperature relationships at seven points within the roast were recorded by a potentiometer. Mean progressive time-temperature relationships during oven cooking were determined for each cooking method. The initial temperature readings from each of the seven points within the six roasts cooked by forced convection and conventionally, and the twelve roasts cooked by the delayed service method were averaged. At 10-minute intervals throughout the oven cooking period, temperature readings from each of the seven points were averaged. When the internal temperature of the roast reached 52°C , as recorded from the lead horizontally positioned at the center of the roast, the temperature readings were no longer included in the mean progressive time-temperature relationships for oven cooking. The averaging process was continued, however, until all replications of each cooking method had reached the desired end internal temperature.

Mean progressive time-temperature relationships were also determined for the seven recording points during the 30-minute holding period of conventional and forced convection cooked roasts. During the holding periods for delayed service cooked roasts, time-temperature relationships were recorded at two depths within the

roast. These relationships were averaged in the same manner for the 6- and 18-hour holding periods.

The average temperature at a given percentage of the total cooking time was calculated for each of the seven measured points. The total cooking time for each sample was divided into ten units each representing 10 per cent of the total. The recorded temperature at the end of each particular unit of time was noted. The unit temperatures for all the replications of each cooking method were averaged. The range of temperatures recorded for each replication at the particular time unit was also determined.

Chemical Analysis

Raw meat samples for chemical analysis were removed from the posterior end of roasts cut from the front half of each loin and from the anterior end of roasts cut from the back half of each loin. Cooked meat samples were taken from the same relative positions in the roast (Fig. 2).

pH

Readings of pH were recorded for slurries of both raw and cooked samples. Twenty grams of sample were combined with 100 milliliters of distilled water and blended for 3 minutes in an Osterizer blender. The mixture was strained through a fine sieve into two 150 milliliter beakers to permit duplicate readings for each sample.

Proximate analysis

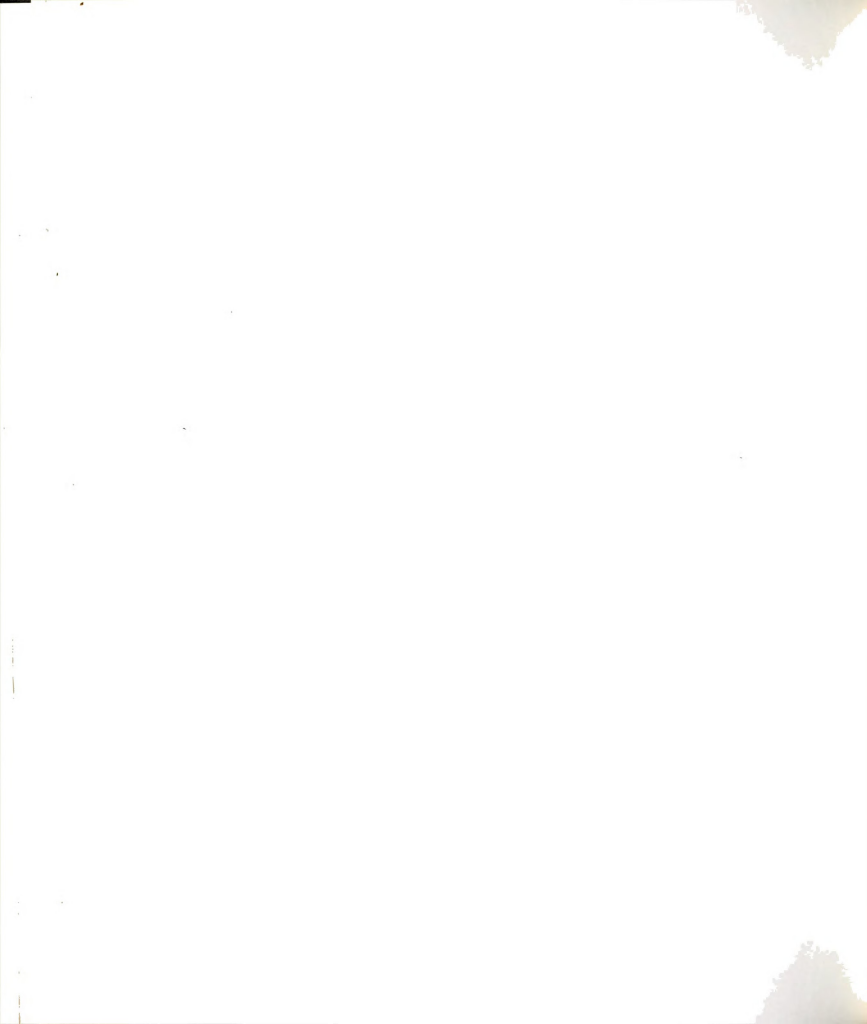
Samples for proximate analysis were placed in coded sample jars and frozen at -34.4°C until analyzed. At the end of the storage period, the samples were defrosted at room temperature for 1 to 2 hours. Each sample was thoroughly blended to a pasty mass for 3 to 5 minutes in an Osterizer blender. By means of a stainless steel chemical spatula, the blended samples were returned to covered sample jars until weighed. All samples for proximate analysis were weighed on a Mettler balance, type H15 to the nearest 0.0000 gram.

Moisture. Moisture was determined on duplicate samples ranging in weight from 1.30 to 1.50 grams. Each sample was spread on the bottom of an aluminum-foil weighing dish. Samples were dried in a vacuum oven at 90°C and 28 inches of mercury for 5 hours. After cooling in a desiccator, the samples were reweighed and the percentage of moisture calculated as follows:

$$\frac{\text{Initial sample weight} - \text{Dried sample weight}}{\text{Initial sample weight}} \times 100$$

Two values were averaged.

Crude fat. Crude fat was determined on the duplicate dried meat samples used in the moisture determinations. The aluminum-foil weighing dish containing the dried sample was loosely rolled and inserted into the extraction thimble. Using anhydrous ethyl ether,



the fat was extracted for 7 hours with the heaters set on high on a Goldfish extractor, model 1138. The percentage of crude fat, on a wet basis was calculated as follows:

$$\frac{\text{Weight of fat}}{\text{Initial sample weight}} \times 100$$

Two values were averaged.

Protein. Nitrogen was determined in duplicate on samples ranging in weight from 0.90 to 2.50 grams, by the boric acid modification of the Kjeldahl-Gunning method (172). The percentage of nitrogen was calculated from the following formula:

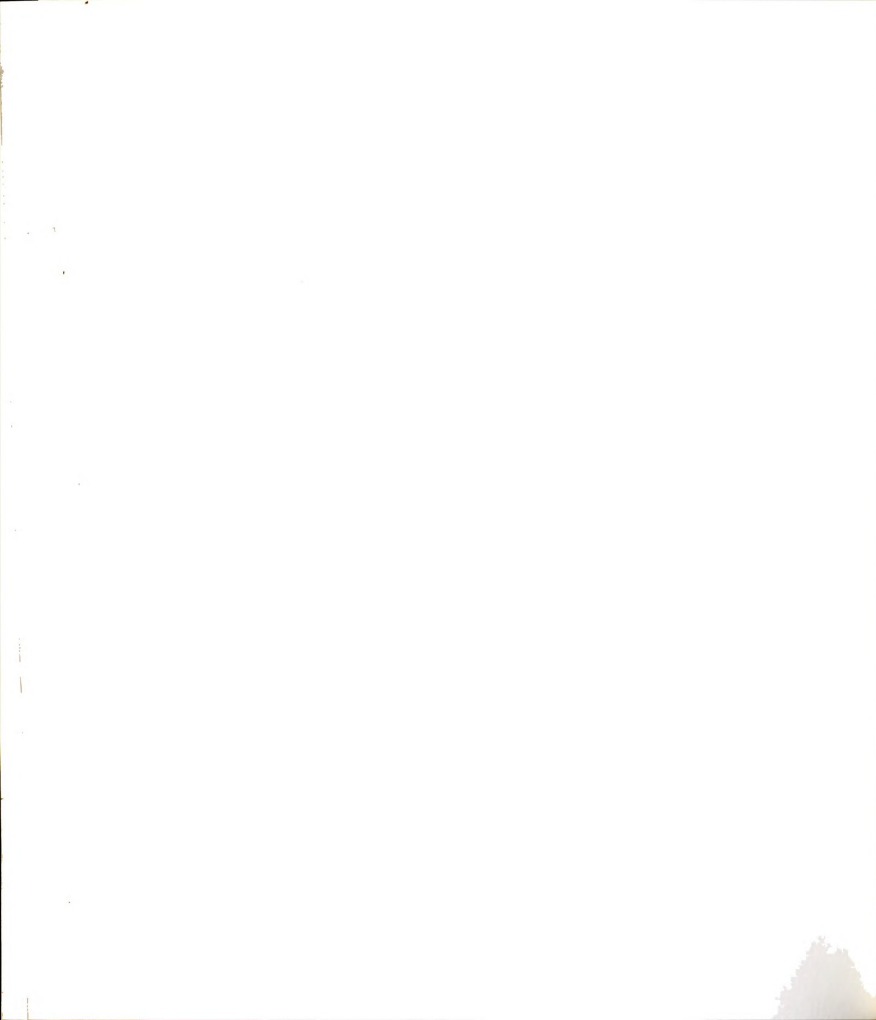
$$\frac{\text{Volume of acid} \times \text{Normality of acid} \times .014}{\text{Sample weight}} \times 100$$

Using a conversion factor of 6.25, the protein content was calculated from the nitrogen. The two values were averaged.

Ash. Ash was determined in duplicate on the dried, defatted meat samples. After preliminary burning, the sample was ashed in a muffle oven at 550°C for 4 hours. The cooled sample was reweighed and percentage ash, on a wet basis, calculated as follows:

$$\frac{\text{Weight of ash}}{\text{Initial sample weight}} \times 100$$

The two values were averaged.



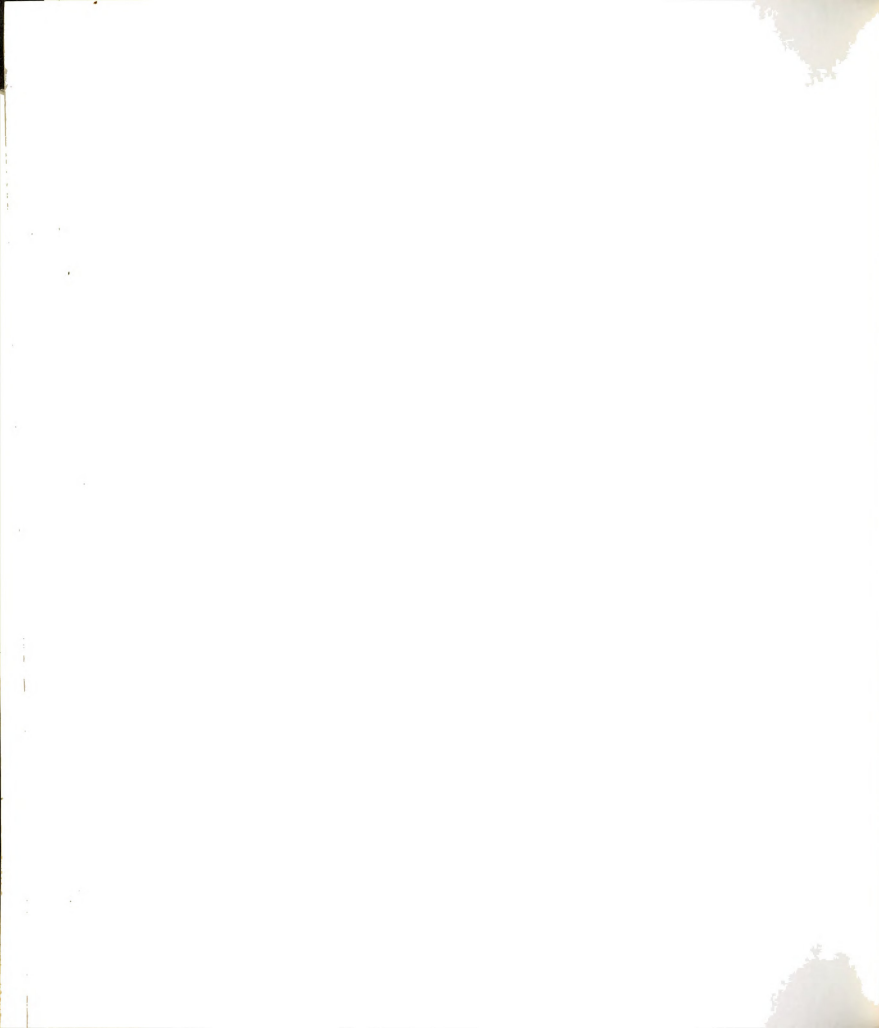
Microbiological Analysis of Delayed Service Cooked Roasts

Since delayed service cooked roasts were held for long periods of time in the temperature range favorable for thermophilic bacterial growth, preliminary investigations established the safety of roasts cooked by the delayed service method for taste panel evaluation. Loin roasts similar to those used for the main study were cooked and held according to the delayed service method. Samples were aseptically removed from the center of the roasts for microbiological analysis. The results of these tests showed no viable organisms in the cooked meat held at 60°C for 24 hours.

Roasts used for panel evaluation

Microbiological analysis were conducted on all roasts cooked by the delayed service method. After the bone was removed from the roast, a 3-inch section was aseptically cut from the roast by using a sterile knife for each of the two necessary cuts. With a sterile 1-inch corer, a sample for microbiological analysis was obtained from the center of this section. The sample was placed in a sterilized jar and refrigerated at 4°C until analyzed.

Aliquants from a 1:3 dilution, prepared with the meat sample and phosphate buffer, were plated on tryptone glucose extract agar (Difco) and incubated at 30°C for 48 hours. A second set of plated samples prepared from eight roasts were incubated at a second temperature of 4.5°C for 14 days.



Injected roasts

To further investigate the safety of meat cooked by the delayed service method, two defrosted roasts (not to be used for other tests) were injected with Salmonella seftenberg organisms before cooking. With a hypodermic needle, 8 cc. of a culture, with a concentration of over 1×10^9 organisms per milliliter, were injected into the center of each roast. The roasts were cooked in the same manner as other delayed service roasts to an internal temperature of 52°C . They were then transferred to the holding cabinet and held for 18 hours. At the end of this time, the roasts were wrapped in aluminum foil and refrigerated at 4°C for 2 to 4 hours until microbiological analysis could be conducted.

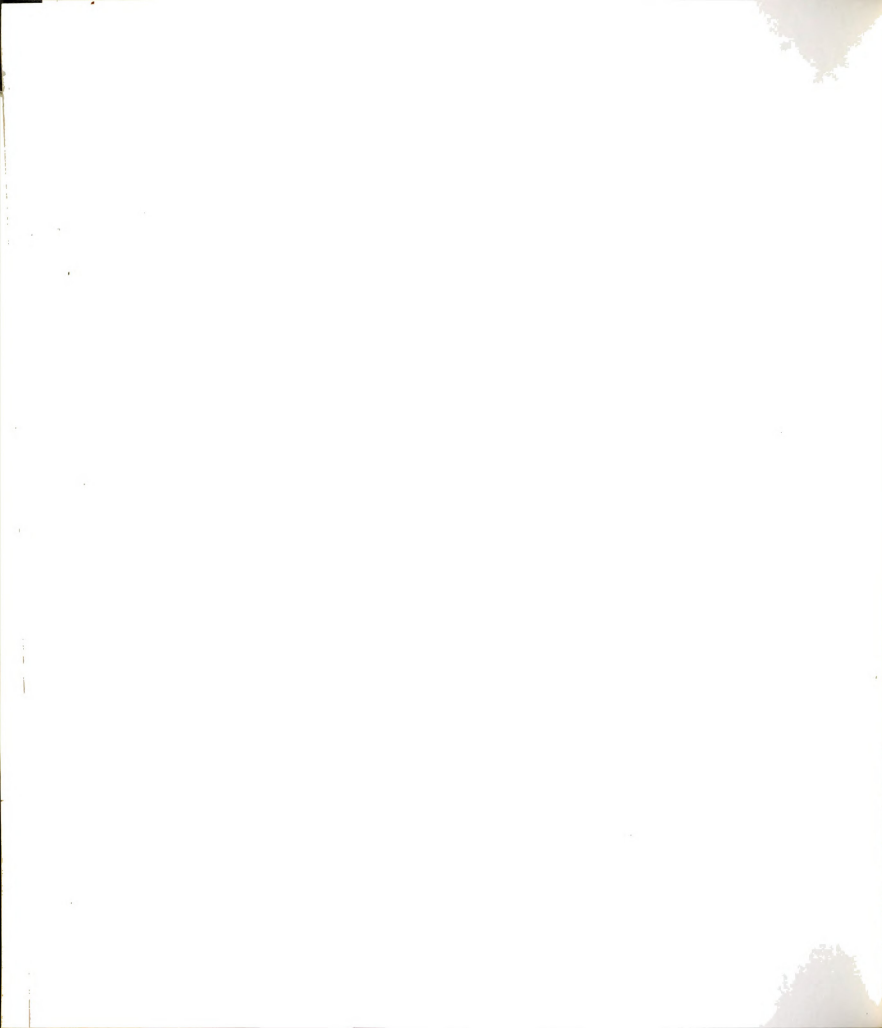
Analysis of the Data

Analysis of variance, to determine differences attributed to cooking method, was used for statistical evaluation of the objective data. Because of possible animal variations, the data were also analyzed for differences among animals rather than differences attributable to replication. To minimize variance due to judges, scores of all judges for each palatability characteristic were combined and averaged for each roast. Analysis of variance, based on the mean taste panel scores, was computed to determine any differences due to cooking method or animal.

Duncan's Multiple Range Test (64) was used to pin-point further the sources of the significant differences.

Correlation coefficients were determined for all possible combinations of tenderness evaluation, shear measurements, proximate analysis, and press fluid. Combinations of press fluid, total cooking losses, subjective juiciness, and proximate analysis were also analyzed for possible correlations.

Statistical tables used with analysis of variance and correlation data were from Dixon and Massey (63).

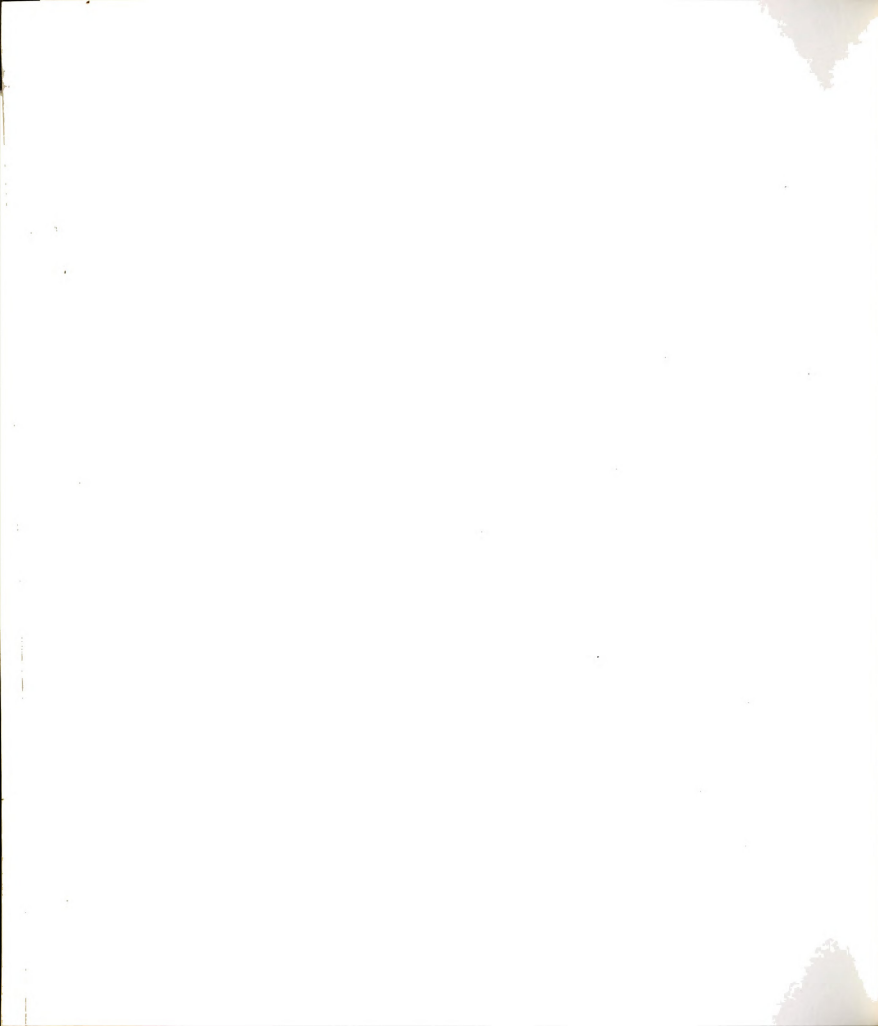


RESULTS AND DISCUSSION

The purpose of this investigation was to determine effect of method of cookery on palatability, cooking losses, physical and chemical attributes, and rate of heat penetration. The four methods were: delayed service with 6- and 18-hour holding periods, forced convection, and conventional. U.S. Choice loin cuts were cooked by each method according to procedures established in preliminary trials. Data were statistically analyzed for significant differences due to cooking method. The statistical results were examined for patterns in differences. Correlation coefficients and subjective evaluations were considered in the interpretation of the data.

Time-temperature relationships during cooking by the four methods were compared for differences. The effect of meat composition on the rate of heat penetration related to the different methods was examined.

The microbiological aspects of loin cuts cooked by the delayed service method were studied. Two roasts were injected with viable organisms, prior to cooking by delayed service, to further investigate the safety of this method.



Heat Penetration Rates

Potentiometer leads were placed at seven points within each roast (Fig. 1, page 69). The reading of the lead positioned horizontally at the center of the roast was used to determine the end internal temperature of 52°C for all methods. During roasting oven temperatures were continuously recorded at a point approximately 3 inches above the surface of the roast.

Mean progressive time-temperature relationship curves

Mean progressive time-temperature relationships from data obtained during the oven cooking period from the seven potentiometer leads positioned within the roast and for the oven temperature were plotted for 12 roasts cooked by delayed service, for the 6 roasts cooked by forced convection, and the 6 roasts cooked by conventional roasting (Fig. 3). Mean progressive time-temperature relationships during the 30-minute holding period of forced convection and conventionally cooked roasts and during the 6- and 18-hour holding periods for delayed service cooked roasts were also plotted.

When the progressive time-temperature relationships were examined for each roast all curves, except that for the surface fat, showed a continuous rise. However, when the averaged data for the roasts cooked by each method were plotted, dips or irregularities in the curves occurred during the latter part of the cooking period. This



is explained by the variation in the oven cooking time since a roast was no longer included in the averaging process after the center internal temperature had reached 52°C . The temperatures recorded within the roasts cooking in a short period of time increased the averages. The remaining roasts cooked by the same method were at lower temperatures in relation to the particular time period.

The thermostat of the oven was set to maintain an average temperature of 204°C for delayed service cookery and 149°C for conventional roasting. However, the normal cycling process during roasting resulted in fluctuations of $\pm 20^{\circ}\text{C}$. While similar fluctuations occurred with the forced convection oven, the smaller range of $\pm 10^{\circ}\text{C}$ indicated the forced convection oven maintained a more uniform temperature during roasting (Fig. 3).

Holding periods were graphed separately, since the same definite beginning and end existed for the replications cooked by each method. Changes in the scale for graphing time-temperature relationships during holding periods for delayed service were necessary because of the length of time the roasts were held. The thinner lines in parentheses, plotted for the 6- to 12-hour holding period, represent assumed heating curves, since no data were collected for this period.

Oven cooking. All temperature curves for roasts cooked in the 204°C oven used for the delayed service method, rose at a more rapid

rate than those for roasts cooked in the 149°C oven by the conventional method. Temperatures at all time points increased at a more rapid rate in the 149°C forced convection oven than in the conventional oven at the same temperature setting.

In all roasting methods, the temperature at the surface rose rapidly (Fig. 3). The rate of rise was dependent on the oven temperature, with the lowest and slowest temperature rises recorded for the 149°C conventional oven. At the end of the first 10 minutes of roasting, the average temperature of the surface fat of conventionally cooked roasts was 49.5°C; for delayed service roasts cooked in a 204°C oven, 84°C; and for the 149°C forced convection oven, 76.5°C (Fig. 3). The maximum surface temperature recorded for the 204°C oven was 133°C; for the 149°C forced convection oven, 108.5°C; and for the 149°C oven, 103°C (Fig. 3).

Although the fat surface of the meat heated rapidly, the recording from the potentiometer lead placed under the connective tissue sheath covering the muscle tissue did not show the same rapid time-temperature pattern. The heat penetration rates slowed considerably by the time surface heat reached a depth of approximately 3/8-inch (Fig. 3). The connective tissue sheath and/or the external fat layer apparently slowed the rate of heat penetration at this point in the roast.

During the first part of the cooking period of delayed service

and conventionally cooked roasts, heat penetrated the roast more rapidly through the exterior fat and connective tissue sheath than through the bone and connective tissue sheath. After 20 minutes cooking time in the 204°C oven, higher temperatures were recorded from the potentiometer lead positioned at the bone, connective tissue-muscle interface than from the potentiometer lead positioned at the exterior fat, connective tissue-muscle interface and this continued throughout the remainder of the cooking period (Fig. 3-A). In the 149°C conventional oven, approximately 53 minutes cooking time elapsed before the bone, connective tissue-muscle interface temperature exceeded that of the fat, connective tissue-muscle interface (Fig. 3-C). When the forced convection oven was used, higher temperatures were recorded from the potentiometer lead positioned at the bone, connective tissue-muscle interface than were recorded from the potentiometer lead positioned at the fat, connective tissue-muscle interface throughout the cooking period (Fig. 3-B).

The bone side of all roasts was placed directly on the perforated aluminum sheet roasting rack and since metal is a better conductor of heat than air, more rapid heat conduction through the bone, connective tissue-muscle interface would be expected after the metal was heated. Apparently, forced convection removed the stagnant air film normally adhering to the roasting pan thus permitting faster heating of the metal than was possible in a natural convection

oven. After the metal was hot, heat penetrated through the bone of the meat at a rate related to the oven temperature.

These results are in disagreement with data reported by Thille, et al. (186). However, a smaller portion of the bone would have been in direct contact with the roasting rack since the natural curvature of the standing rib roasts used in their study, was greater than curvature of the loin roasts used in this study.

During the first part of the roasting period, heat penetrated into the interior of the muscle tissue more rapidly from the top of roasts cooked in 204° and 149°C conventional ovens than from the bottom or bone side. As the roasting progressed, more heat came from the bone side of the roast than from the top as indicated above. The muscle tissue of forced convection cooked roasts heated more rapidly through the bone side of the roast than through the fat covered side during the entire cooking period (Fig. 3).

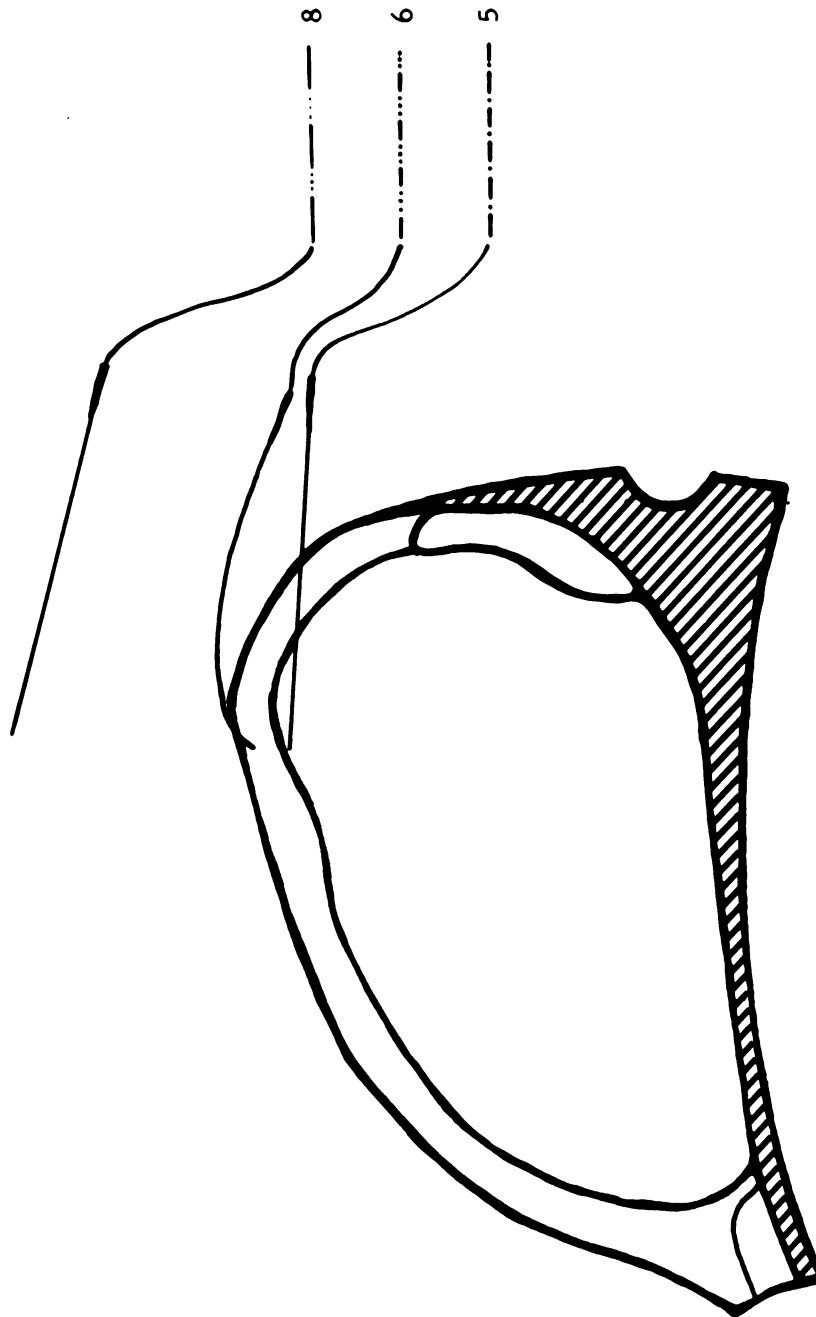
The mean progressive time-temperature relationships recorded from the potentiometer leads positioned vertically to the center of the roast were consistently lower than those recorded from the potentiometer lead positioned horizontally to the center of the roast. This difference was less for roasts cooked in a 149°C oven. Perhaps the hole formed by inserting the lead from the top permitted melted fat and moisture to seep down along the potentiometer lead, thus lowering the temperature. It may also be that lack of precision in potentiometer

lead placement is a partial explanation for this difference.

In all roasts, the potentiometer lead embedded approximately 0.13-inch into the fat surface, followed the oven temperature fluctuations (Fig. 3). This fluctuation in temperature was not recorded by the potentiometer lead placed just under the connective tissue sheath covering the muscle tissue. Apparently, the connective tissue sheath and/or the external fat layer buffered the effect of the oven temperature fluctuations.

Since average progressive plotting of the time-temperature relationships tended to mask this phenomenon, the curves for one roast cooked at 204°C were plotted (Fig. 4). The same sharp fluctuations apparent in oven temperature, were recorded from the potentiometer lead embedded in the surface fat. Again, these marked temperature fluctuations were not recorded by the potentiometer lead positioned under the connective tissue sheath.

Holding periods. All roasts were removed from the oven when the recording from the horizontally positioned potentiometer lead registered 52°C . Mean progressive time-temperature relationships were continuously recorded while conventionally and forced convection cooked roasts were held at room temperature for 30 minutes. For delayed service cooked roasts, time-temperature relationships were obtained from thermometer readings at specified intervals during the holding period.



Key showing the types of broken lines used for graphing the time-temperature relationships from the three different potentiometer lead positions.

- · — · — · — 5. Fat, connective tissue-muscle interface
- 6. Surface fat
- 8. Over

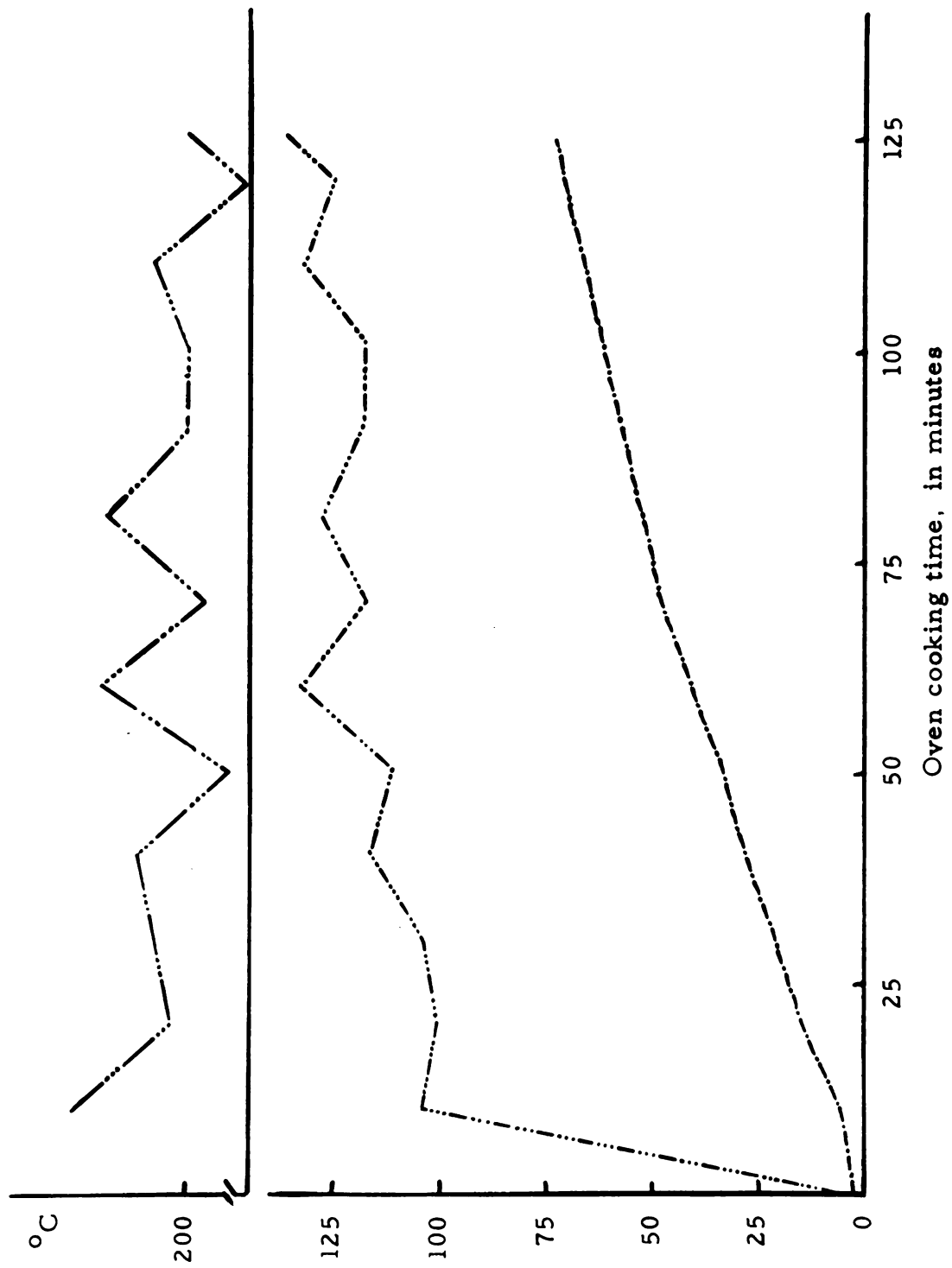


Figure 4. Progressive time-temperature relationships for oven temperature, surface fat and beneath connective tissue sheath for one roast cooked in an oven set at 204°C.

During the 30-minute holding period for conventionally and forced convection cooked roasts, the surface temperature fell rapidly. Temperature declines at the bone, connective tissue-muscle interface also occurred. In the conventionally cooked roasts, the temperature of the fat, connective tissue-muscle interface showed a slight decline, but in the forced convection cooked roasts, it did not. As expected, temperatures recorded within the muscle tissue showed increases during the holding period because of the continued penetration of the surface heat. The average internal temperature of conventionally cooked roasts rose to 62°C (Fig. 3-C). The 10°C temperature rise is in agreement with data reported by Latzke (118) for beef ribs cooked in a 149°C oven. The internal temperature rise of roasts cooked by forced convection averaged 11°C , hence, a maximum of 63°C was recorded for these roasts (Fig. 3-B).

For delayed service cooked roasts, the average maximum temperature of 68.5°C was recorded one hour after the roasts were placed in the $60^{\circ} \pm 2^{\circ}\text{C}$ holding cabinet (Fig. 3-A). The recordings of time-temperature relationships during cooking indicated higher temperatures on the outer layers of loin cuts roasted in the 204°C oven than in roasts cooked at 149°C (Figs. 3A and 3C). While a portion of this heat was lost to the holding cabinet into which the roasts were transferred, more heat was still available to continue to penetrate to the interior of the roast and, hence, the total rise in

temperature was greater.

Two thermometers were placed in each roast held for 6 or 18 hours for delayed service, one was at the center and the other at a point midway between the center and the surface. By the end of the first hour and throughout the remainder of the holding periods both thermometers showed the same readings. By the end of the sixth hour, the internal temperature of the roast had dropped to 56°C . No temperature fluctuations were recorded for the remainder of the 18-hour holding period.

Average temperature at percentage of cooking time

The average temperature at specified percentage intervals of the total cooking time was plotted for the 12 roasts cooked by delayed service, 6 roasts cooked by forced convection, and 6 roasts cooked conventionally (Fig. 5).

Average temperatures recorded at the center of the muscle tissue of meat cooked by each method rose at a constant rate during the last half of the oven cooking time. After reaching an internal temperature of approximately 50°C , recordings from potentiometer leads positioned 0.63 to 0.75 inch on either side of the center showed a decrease in the rate of temperature rise. This phenomenon has been attributed to the endothermic processes of evaporation and protein coagulation. According to Lowe (123) some protein coagulation probably occurs below 60°C . As coagulation of the protein



occurs, the internal temperature of the meat rises at a slower rate. Lowe further stated that when meat is cooked at low oven temperatures, such as 80 to 120°C, the internal temperature rise of the meat may remain stationary for several minutes between 75 and 80°C.

Average maximum temperatures reached within the muscle tissue ranged from 56°C for forced convection, 57°C for conventional roasting to 58.5°C for delayed service cooked roasts. This higher temperature was expected in roasts cooked in the 204°C oven. The maximum temperature within the muscle tissue was recorded from the potentiometer leads positioned midway between the center and the bone, connective tissue-lean interface.

Recordings from other potentiometer leads positioned in the delayed service cooked roasts showed higher temperatures than those noted in forced convection or conventional roasting. Bone, connective tissue-lean interface average maximum temperatures for delayed service cookery were 83.5°C; for forced convection, 67°C; and for conventional, 76.5°C. Fat, connective tissue-lean interface average maximum temperatures for delayed service cookery were 75°C; for forced convection 65°C; and for conventional 67°C (Fig. 5).

While an average of 109 minutes was required for 100 per cent oven roasting time of delayed service cooked roasts, the time ranged from 90 to 120 minutes among the 12 roasts cooked in this manner (Fig. 5-A). The average cooking time for the conventional oven

roasting period was 141 minutes. The range among the 6 individual roasts was from 120 to 160 minutes for the horizontally positioned center potentiometer lead to reach 52°C (Fig. 5-C). One hundred per cent of the cooking time for forced convection cooked roasts averaged 119 minutes, with a range of 102 to 137 minutes (Fig. 5-B). Total cooking times for the 6 replications of each cooking method are recorded in the Appendix, Table 15.

The range of oven cooking times for the 6 replications within a cooking method was probably due in part to weight differences among the loin cuts from the 6 animals. A coefficient of correlation ($r = .48$), significant at the .01 level of probability, existed between the raw weight and oven cooking time. As the weight of the roast increased, a longer time was required to cook it to an end internal temperature of 52°C .

Analysis showed the difference in oven cooking times required to cook roasts by delayed service, forced convection and the conventional method to be very highly significant. Further analysis showed time differences between oven cooking time in the 204°C oven used for delayed service and the 149°C forced convection oven were not significant. Highly significant differences were found in oven cooking times in the 204°C oven used for delayed service and the 149°C conventional oven. Significant differences in total oven cooking time also existed between the forced convection and the conventional oven

even though both ovens were maintained at the same temperature.

Roasts required an average of 10 minutes longer to cook in a 149°C forced convection oven than in a 204°C conventional oven with natural convection. And roasts needed an average of 22 minutes longer to cook in a 149°C conventional oven than in a forced convection oven at the same temperature. Three factors may have been involved in the explanation of the faster heat penetration rates in the forced convection oven. First, the velocity of circulating air tended to wipe off the stagnant air film adhering to the surface of the roast, thereby permitting the heat to penetrate at a rapid rate. Second, moisture was present in the oven during roasting. Cover (45) found less time was required for cooking in a poorly ventilated oven where the humidity was high than in the conventionally ventilated oven. Third, less temperature fluctuation occurred in the forced convection oven than in the 149 or 204°C conventional oven. Because of this factor, a more uniform source of heat may have been available to the roast.

The shorter cooking time in the 204°C oven was as expected. Other investigators have reported heat penetration rates increased as the oven temperatures increased (141, 118, 4, 45, 98, 23).

Relationship to meat composition

Total cooking time was correlated with composition factors of pH, moisture, fat, protein, and ash content of the raw meat. No

significant correlations resulted. Apparently other factors such as those mentioned above were responsible for differences in heat penetration rates.

Effect of Cooking Methods on Chemical Composition

The chemical composition factors of pH, moisture, fat, protein, and ash were determined on raw and cooked samples for each loin cut cooked by one of the four methods. The results of duplicate determinations were averaged for statistical analysis. The mean values for pH and the mean percentages of moisture, fat, protein, and ash are summarized in Table 2.

Table 2. Mean values for pH and mean percentages of moisture, fat, protein, and ash for six replications of four cooking methods.

State of Meat	pH	Proximate Analysis				
		Moisture	Fat	Protein	Ash	Total
Raw	5.7	66.75	11.67	20.15	0.97	99.54
Cooked						
Delayed service						
6-hour holding	5.8	58.24	14.62	25.29	0.90	99.05
18-hour holding	5.8	55.30	16.16	26.71	1.09	99.26
Forced convection	5.8	58.63	14.49	25.25	1.09	99.45
Conventional	5.8	58.84	15.99	23.68	0.94	99.43

Analyses of variance were computed for pH, percentages of moisture, fat, protein, and ash of the cooked meat to determine differences due to method and animal. Results of these analyses are summarized in Table 3.

Table 3. Analyses of variance for pH and proximate analysis of samples cooked by four methods.

Source of Variance	Degrees of Freedom	Mean Square Values				
		pH	Moisture	Fat	Protein	Ash
Total	23					
Animal	5	.022*	20.299**	42.696***	5.916***	.029
Method	3	.008	16.388*	4.689	9.192***	.058*
Error	15	.006	3.527	3.280	.720	.012

***Significant at the .001 level of probability.

**Significant at the .01 level of probability.

*Significant at the .05 level of probability.

pH

The pH values for raw and cooked samples, based on the mean of two readings, and changes in pH from the raw to cooked state for six replications of each cooking method are presented in the Appendix, Table 16. The pH of all raw samples ranged from 5.6 to 6.0, a significant difference among animals. Apparently, the glyco-gen content of the animal tissues at the time of slaughter varied since the pH attained is dependent on the lactic acid produced from available

glycogen. When the glycogen reserve is high, a large amount of lactic acid is produced, and the pH of the animal tissue is low. Conversely, when the glycogen reserve is low, little lactic acid can be produced and the resulting pH is high (123).

The changes in pH brought about by cooking were not significant. The pH values of the cooked meat were correlated with objective measurements and subjective evaluations of tenderness and juiciness. No significant correlations resulted.

Moisture

Moisture determinations for raw and cooked samples are presented in the Appendix, Tables 17 and 18, respectively. The average moisture content for all raw samples was 66.75 per cent. However, very highly significant differences in the percentage of moisture existed between animals. Animal averages ranged from 63.52 to 71.57 per cent moisture.

According to Lowe (123), the moisture content of muscle tissue varies inversely with the fat content of the muscle tissue. The very highly significant negative correlation coefficient ($r = -.95$) between the moisture and fat content of the loin cuts of beef used in this study also pointed out this inverse relationship.

When the meat was cooked by delayed service and held for 6 hours, the moisture content changed to 58.24 per cent. An 18-hour

holding period resulted in a decrease to 55.30 per cent. The moisture content of roasts cooked by forced convection was 58.63 per cent and by conventional roasting was 58.84 per cent. The percentages of moisture in cooked meat were significantly different at the .05 level of probability among the four methods of cooking. Further analysis of the data showed a significant difference in the moisture content of the delayed service cooked roasts with an 18-hour holding period and conventionally cooked roasts. No significant differences were found in moisture content of other possible combinations of the four cooking methods.

As indicated above, delayed service cooked roasts of both types had less moisture than forced convection or conventionally cooked roasts. Slightly more moisture was evaporated in the 204°C oven used for delayed service oven cooking than was evaporated in the 149°C ovens used for the forced convection and conventional oven roasting. Also, the delayed service cooked roasts were held for 6 or 18 hours in a 60°C holding cabinet and moisture evaporated from the roasts during this period.

Percentage moisture of the cooked meat was correlated with objective measurements of juiciness. A significant negative correlation coefficient ($r = -.44$) existed between moisture content and volatile losses occurring during cooking and holding, showing as expected, that as volatile losses increased the moisture content of the

cooked sample decreased. The correlation coefficient between moisture content and total cooking and holding losses was not significant. The correlation coefficient between moisture content and press fluid, as measured by the Carver press, was not significant.

Percentage of moisture was also correlated with subjective evaluations of juiciness and tenderness. Neither correlation was significant.

Crude fat

Crude fat determinations for raw and cooked samples are presented in the Appendix, Tables 19 and 20, respectively. While the average fat content of the raw meat samples was 11.67 per cent, animal averages ranged from 5.34 to 16.41 per cent. The difference in fat content among animals was very highly significant indicating the presence of more intramuscular fat in some of the animals than was present in others. Sampling errors may have been responsible for some of the variance since the small samples used for proximate analysis may have contained a larger portion of intramuscular fat than was representative of the roast. However, as previously indicated, the fat content of muscle tissue varies inversely with the moisture content and very highly significant differences in moisture content were found among animals.

For cooked meat, the fat content was 14.62 per cent for roasts cooked by delayed service with a 6-hour holding period, 16.16 per

cent for delayed service cooked roasts held for 18 hours, 14.49 per cent for forced convection cooked roasts and 15.99 per cent for conventionally cooked roasts. These percentages of fat in the cooked meat did not differ significantly. The differences among animals remained very highly significant, however, in the cooked samples.

The percentage of fat of the cooked samples was correlated with objective measurements and subjective evaluations of tenderness and juiciness. When percentage of fat was correlated with press fluid, as measured by the Carver press, a highly significant negative coefficient of correlation ($r = -.47$) was obtained, indicating that as the press fluid increased, fat content decreased. The correlation coefficient between percentage fat of the cooked samples and the subjective evaluation of juiciness was not significant.

The percentage of fat of the cooked sample and Warner-Bratzler shear values showed a very highly significant negative correlation coefficient ($r = -.52$). As the amount of fat in the cooked sample increased, the pounds force required to shear the meat by the Warner-Bratzler shear decreased indicating, by this measurement, more tender meat. However, neither the correlation coefficient between percentage fat of the cooked samples and the Kramer shear-press values nor that between percentage fat and the subjective evaluation of tenderness was significant.

The relationship between percentage fat of the cooked roasts

and the flavor scores of the lean portion of the roast was examined. The negative correlation coefficient was very low and not significant.

Protein

Protein determinations for raw and cooked samples are presented in the Appendix, Tables 21 and 22, respectively. The protein content of all raw meat samples averaged 20.15 per cent with a range of 18.91 to 21.78 per cent for the six animals. These animal differences were very highly significant. The differences were expected since animal differences existed in the moisture and fat content.

In the delayed service cooking method, the average protein content increased to 25.29 per cent with a 6-hour holding period and to 26.71 per cent with an 18-hour holding period. The protein values for roasts cooked by forced convection averaged 25.25 per cent and for conventionally cooked roasts, 23.68 per cent. The differences attributable to cooking method in protein content of cooked samples were very highly significant as were animal differences. The increase in percentages of protein in the cooked meat probably reflects a concentration of the roast by loss of moisture during the cooking process. Since moisture losses varied with the cooking method, differences in percentage protein were expected.

When the data were further analyzed using Duncan's Multiple Range Test (64), the protein content of forced convection cooked

roasts and delayed service cooked roasts with a 6-hour holding period was significantly higher than the protein content of conventionally cooked roasts. There was a very highly significant difference between the protein content of delayed service cooked roasts with an 18-hour holding period and conventionally cooked roasts.

The percentage of protein of the cooked meat was correlated with objective measurements and subjective evaluations of juiciness and tenderness. Very highly significant negative correlation coefficients between the percentage of protein and press fluid ($r = -.80$) and the percentage of protein and juiciness scores ($r = -.54$) were observed, indicating that as the percentage of protein increased, there was less press fluid and a decreased sensation of juiciness detected by the panel members. A highly significant correlation coefficient was observed between the percentage of protein and the Warner-Bratzler shear readings ($r = .51$). As the percentage of protein increased, the pounds force required for shearing the more compact cylinder of meat also increased. The correlation coefficients between percentage protein of the cooked meat/Kramer shear-press values and percentage of protein/tenderness scores were not significant.

Ash

The determinations for ash content of raw and cooked samples are presented in the Appendix, Tables 23 and 24, respectively. The

average ash content of the raw meat was 0.97 per cent with an animal range of 0.91 to 1.04 per cent. The difference among animals was highly significant, as expected, since animal differences existed in other composition factors.

The average ash content of roasts cooked by delayed service with a 6-hour holding period was 0.90 per cent. With an 18-hour holding period, the average ash content was 1.09 per cent. Forced convection cooked roasts had an average ash content of 1.09 per cent while conventionally cooked roasts averaged 0.94 per cent. An analysis of variance showed these differences were significant at the .05 level of probability.

The significant correlation coefficients between combinations of raw and cooked chemical composition factors and/or objective measurements and sensory evaluations of the cooked meat are summarized in Table 4.

Weight Losses

Percentage weight losses occurring during the frozen storage and defrosting periods for the 24 loin cuts used for this study were determined. Data pertaining to total, drip, and volatile losses were converted to percentages of the raw sample weight. Percentage total, drip, and volatile losses for 6 replications of each cooking method are recorded in the Appendix, Table 27. Mean percentage values for cooking losses are recorded in Table 5.

Table 4. Summary of significant correlation coefficients between chemical composition and objective measurements and sensory evaluations of raw and cooked samples of the longissimus dorsi muscle of beef.

Relationship	Correlation Coefficient
Percentage moisture of raw meat/ Percentage fat of raw meat	-.95***
Percentage moisture of cooked meat/ Volatile losses	-.44*
Percentage fat of cooked meat/ Press fluid values	-.47**
Percentage fat of cooked meat/ Warner-Bratzler shear values	-.52***
Percentage protein of cooked meat/ Press fluid values	-.80***
Percentage protein of cooked meat/ Juiciness scores	-.54***
Percentage protein of cooked meat/ Warner-Bratzler shear values	.51**

***Significant at the .001 level of probability.

**Significant at the .01 level of probability.

*Significant at the .05 level of probability.

Table 5. Mean percentage cooking losses for six replications of four cooking methods.

Cooking Method	Losses		
	Total	Drip	Volatile
Delayed service			
6-hour holding	23.82	8.25	15.57
18-hour holding	27.79	8.12	19.67
Forced convection	15.22	5.30	9.92
Conventional	12.49	4.09	8.40

Analyses of variance were computed for total, drip, and volatile losses to determine differences due to method and animal. Results of these analyses are summarized in Table 6.

Table 6. Analyses of variance for cooking losses of four cooking methods.

Source of Variance	Degrees of Freedom	Mean Square Values		
		Total	Drip	Volatile
Total	23			
Animal	5	4.923	3.863	.812
Method	3	308.837***	25.852***	162.268***
Error	15	3.423	1.544	1.523

***Significant at .001 level of probability.

Losses during freezing and defrosting

Percentage weight losses during frozen storage and defrosting are presented in the Appendix, Tables 25 and 26, respectively. The losses incurred during 100 to 146 days of frozen storage prior to cooking for evaluation, varied at the .001 level of probability, among animals. Drip and moisture losses incurred during the defrosting period ranging from 36 to 50 hours, were not significant.

Total cooking losses

Delayed service cooked roasts with a 6-hour holding period lost an average of 23.82 per cent of their weight during the oven

cooking and subsequent holding period. When the roasts were held for 18 hours, total cooking losses increased to an average of 27.79 per cent, showing that as the holding period increased in length, the total cooking losses also increased. Average total cooking losses for conventionally cooked roasts were 12.49 per cent whereas forced convection cooked roasts showed average total cooking losses of 15.22 per cent.

The high temperature of the 204°C oven and subsequent holding periods used with the delayed service method of cooking resulted in higher total cooking losses than occurred in the 149°C forced convection and conventional ovens. The final internal temperature reached in delayed service cooked roasts was higher than that reached in forced convection or conventionally cooked roasts. This may have been a factor in determining the high total cooking losses of delayed service cooked roasts.

Total cooking losses were higher when roasts were cooked in a forced convection oven than when roasts were cooked in a natural convection oven at the same temperature. The circulating fan apparently dried the surface of the meat thereby increasing losses. Also, a pan of water was placed in the forced convection oven during the meat roasting period. Other investigators have reported the use of moist heat increased cooking losses as compared to dry heat cooking methods (76, 93).

The differences in total cooking losses among four methods of cooking were very highly significant. Animal differences were not significant. Further analysis of the data showed very highly significant differences in total cooking losses between roasts cooked by delayed service with 6- or 18-hour holding periods and either the forced convection cooked roasts or the conventionally cooked roasts. The differences in total cooking losses between delayed service cooked roasts with a 6-hour holding period and delayed service cooked roasts with an 18-hour holding period were significant at the .05 level of probability. Differences in total cooking losses between forced convection and conventionally cooked roasts were not significant.

Drip losses

Delayed service cooked roasts with a 6- and 18-hour holding period showed very little difference in drip losses. Roasts held for 6 hours averaged 8.25 per cent drip, and with an 18-hour holding period, the average loss was 8.12 per cent. Forced convection cooked roasts with an average of 5.30 per cent showed a greater drip loss than did conventionally cooked roasts with an average drip loss of 4.09 per cent.

Very highly significant differences in drip losses occurred among the four cooking methods. Animal differences were not significant. The 204°C oven used with delayed service cookery rendered

out more fat than did the 149°C forced convection or 149°C conventional ovens. When drip losses were analyzed further, the differences in drip losses between delayed service cooked roasts with 6- or 18-hour holding periods and forced convection cooked roasts were significant at the .05 level of probability. Differences in drip losses between delayed service cooked roasts with 6- or 18-hour holding periods and conventionally cooked roasts were highly significant. No significant difference existed in the drip losses between forced convection and conventionally cooked roasts.

Volatile losses

In delayed service cooked roasts, volatile losses increased as the length of the holding period increased. The calculated volatile losses for the 6-hour holding period averaged 15.57 per cent; for the 18-hour holding period, volatile losses averaged 19.67 per cent. Higher volatile losses occurred in the forced convection oven than in the conventional oven. Roasts cooked in the forced convection oven lost an average of 9.92 per cent through evaporation whereas conventionally cooked roasts lost an average of 8.40 per cent. The evaporation of the water which was placed in the air tight forced convection oven did not sufficiently saturate the air to reduce volatile losses below losses incurred in conventional roasting, as was claimed by the manufacturer (97).

Analysis of variance, applied to the volatile loss data, showed very highly significant differences due to cooking method. Animal differences were not significant. Further analysis of the data showed highly significant differences in volatile losses between delayed service cooked roasts with the 6-hour holding period and delayed service cooked roasts with the 18-hour holding period. The volatile losses of delayed service cooked roasts with 6- or 18-hour holding periods were significantly greater than volatile losses of forced convection cooked roasts and conventionally cooked roasts at the .001 level of probability. The 204°C oven used with the delayed service methods and the subsequent holding period increased volatile losses to a higher percentage than those of roasts cooked by forced convection or conventionally. The difference in volatile losses between forced convection and conventionally cooked roasts was not significant.

Total cooking, drip, and volatile losses were correlated with the objective measurement and subjective evaluation of juiciness. The correlation coefficients obtained between the total cooking, drip, and volatile losses and press fluid as measured by the Carver press were not significant. Very highly significant negative correlation coefficients resulted between juiciness scores/total cooking losses ($r = -.87$), juiciness scores/volatile losses ($r = -.88$), and juiciness scores/drip losses ($r = -.71$), showing that as the cooking losses increased, juiciness scores decreased.

Oven and holding losses for delayed service cookery

Percentages based on raw weight of sample, were calculated for total, drip, and volatile losses occurring during oven cooking and subsequent holding periods of delayed service cooked roasts. These data are presented in the Appendix, Table 28. The average losses incurred during oven cooking and holding periods are recorded in Table 7.

Table 7. Mean percentage oven cooking and holding losses for six replications of delayed service cookery.

Holding Period	Oven Cooking Losses			Holding Losses			Grand Total
	Total	Drip	Volatile	Total	Drip	Volatile	
6-hour	18.66	7.93	10.72	5.16	0.31	4.85	23.82
18-hour	19.69	7.81	11.88	8.10	0.31	7.79	27.79

Average drip losses of 7.87 per cent occurred during cooking in a 204°C oven used for delayed service. Since the 60°C temperature of the holding cabinet was too low to melt additional fat, average additional losses of only 0.31 per cent occurred during holding periods.

The data presented in Table 7 show the high total losses found in delayed service cooked roasts were due to volatile losses during the holding period. As the length of the holding period increased, greater losses occurred.

Oven cooking losses for delayed service roasts cooked in the 204°C oven were higher than those in either the 149°C forced convection oven or the conventional oven at the same temperature. The hotter oven rendered out more fat during cooking resulting in greater drip losses, and caused greater evaporation of volatile components of the meat.

Meat available for serving

The amount of servable meat, defined as cooked roast minus bone, available from the 24 roasts cooked by four methods is presented in the Appendix, Table 29. Based on the weight of raw meat, roasts cooked by delayed service and held for 6 hours, yielded 55.61 per cent servable meat. With an 18-hour holding period, the yield was reduced to 53.07 per cent. Forced convection roasting resulted in a 63.22 per cent servable meat and 65.17 per cent of the conventionally roasted meat was available for service. These differences were very highly significant. Animal differences were also highly significant. Since the animal differences in the raw weight of the roasts were also very highly significant, the differences among animals in the amount of servable meat was expected.

Further analysis of the data showed the difference in servable meat from delayed service cooked roasts with a 6-hour holding period and delayed service cooked roasts with an 18-hour holding period was not significant. However, very highly significant differences in the

amount of servable meat were found between delayed service cooked roasts with 6- or 18-hour holding periods and forced convection cooked roasts. The differences between delayed service cooked roasts with 6- or 18-hour holding periods and conventionally cooked roasts were also very highly significant. These differences were expected because of the greater cooking losses from the delayed service cookery method. Amounts of servable meat from forced convection and conventionally cooked roasts did not differ significantly.

Palatability Factors

Aroma, color of lean, flavor of lean, flavor of fat, juiciness, and tenderness were the palatability characteristics evaluated in studying the effects of delayed service, forced convection and conventional roasting. Sensory judgments were based on a 7-point scale, indicating a range from unacceptable to excellent quality. Scores of all judges were averaged for each of the six palatability characteristics of each replication. Average scores for each replication are presented in the Appendix, Table 30.

Based on the mean score of the palatability characteristics for each roast, grand averages for the cooking methods were computed. These data were compared (Table 8).

When the palatability data were analyzed for variance, different levels of significance were found. The analyses of variance data are summarized in Table 9.

Table 8. Grand average palatability scores¹ of seven judges for six replications of four cooking methods.

Palatability Characteristic	Cooking Method			
	Delayed Service		Forced Convection	Conven- tional
	6-hour Holding	18-hour Holding		
Aroma	5.1	4.9	4.4	4.5
Color of lean	4.6	4.5	5.4	5.8
Flavor of lean	5.2	4.6	5.0	5.3
Flavor of fat	5.0	4.3	5.1	4.9
Juiciness	5.0	4.4	5.6	5.6
Tenderness	5.6	6.0	5.9	6.0

¹Highest possible score, 7 points.

Table 9. Analyses of variance of palatability data for four methods of cooking.

Source of Variance	Degrees of Freedom	Mean Square					
		Aro- ma	Color of Lean	Flavor of Lean	Flavor of Fat	Juici- ness	Tender- ness
Total	23						
Animal	5	.221	.573	.531	.616*	.144	.537***
Method	3	.672*	2.456***	.591	.706*	1.901***	.184*
Error	15	.150	.202	.227	.141	.097	.045

***Significant at the .001 level of probability.

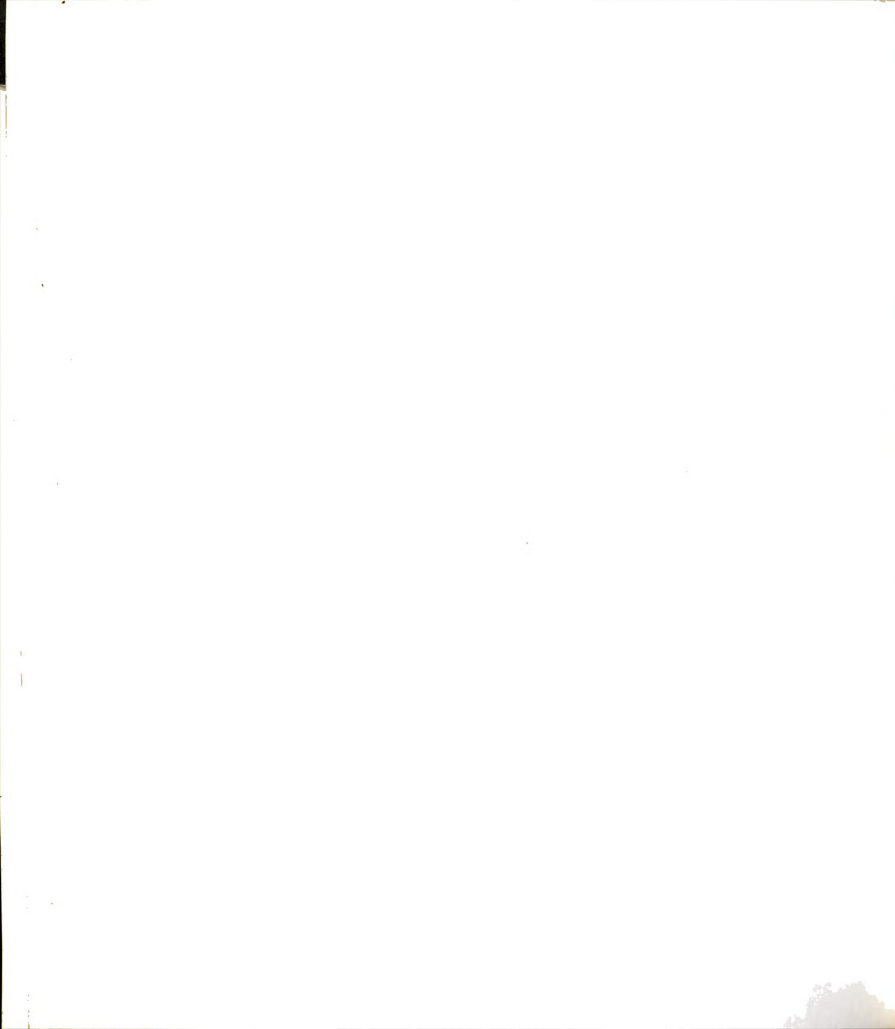
*Significant at the .05 level of probability.

Aroma

The grand average aroma score for delayed service cooked roasts with a 6-hour holding period was 5.1. This average was slightly higher than the grand average score of 4.9 received by the delayed service cooked roasts held for 18 hours. The descriptive term most often selected by the judges to describe the aroma was "good, full." Forced convection and conventionally cooked roasts received lower grand average scores of 4.4 and 4.5, respectively, indicating a good, but faint aroma for these samples.

The grand average scores indicated delayed service cooked roasts had more aroma. Perhaps the higher internal temperature reached in these roasts as compared to that of roasts cooked by forced convection or conventionally developed more compounds responsible for the characteristic aroma of roast beef. Analysis of variance computed on the mean aroma scores showed a difference, significant at the .05 level of probability, due to cooking method. Differences attributable to animals were not significant.

Further analysis of the data showed that the difference in aroma scores of the forced convection cooked roasts and the delayed service cooked roasts with a 6-hour holding period was significant at the .05 level of probability. Differences between other combinations of the four cooking methods were not significant.



Color of lean

Conventionally cooked roasts received the highest grand average score of 5.8 for color of lean. Most frequently, the outer area of the slices was described as light brown in color, shading to a pink color in the center of the slice. Less pink area was apparent in forced convection cooked roasts as indicated by their grand average score of 5.4. Slices from delayed service cooked roasts, scoring a grand average of 4.6 when held for 6 hours and a grand average of 4.5 when held for 18 hours, had very little pink color. This was as expected since the mean maximum internal temperature reached was 68.5°C . This temperature is in the upper portion of the range of 65 to 70°C suggested by Sprague and Grindley (180) for medium done beef. Thus, as the internal temperature increased, the pink color tended to disappear.

The maximum temperature recorded at the center of conventionally cooked roasts was 61°C , and at the center of forced convection cooked roasts, 60°C . Although these temperatures are within the temperature range suggested by Sprague and Grindley (180) for rare meat, judges' comments indicated the color of the lean of the samples was more indicative of medium cooked beef.

Judges also commented that only a small portion in the center of the slice seemed rare. Examination of the heat penetration data showed recordings from potentiometer leads positioned 0.63- to

0.75-inch at either side of the center reached 65°C for forced convection and 64°C for conventionally cooked roasts. Therefore, only a small portion of the muscle tissue remained in the temperature range for rare meat. The maximum temperature at a like position for delayed service cooked roasts was not recorded.

Analysis of variance showed very highly significant differences in the color of lean attributable to the method of cooking. The differences among animals were not significant. Further analysis of the data showed that the differences in color of lean between delayed service cooked roasts with 6- or 18-hour holding periods and conventionally cooked roasts were highly significant. The differences in color of lean between delayed service cooked roasts with 6- or 18-hour holding periods and that of forced convection cooked roasts were not significant. No significant difference existed in the color of lean in roasts cooked by forced convection and by conventional roasting.

Flavor of lean

No significant differences attributable to cooking method existed in flavor of the lean meat, nor were animal differences significant. Conventionally cooked roasts received a grand average score of 5.3 indicating a good, full flavor. The grand average score of forced convection cooked roasts was 5.0, still indicative of a good, full flavor, however. Scores for delayed service cooked roasts with a

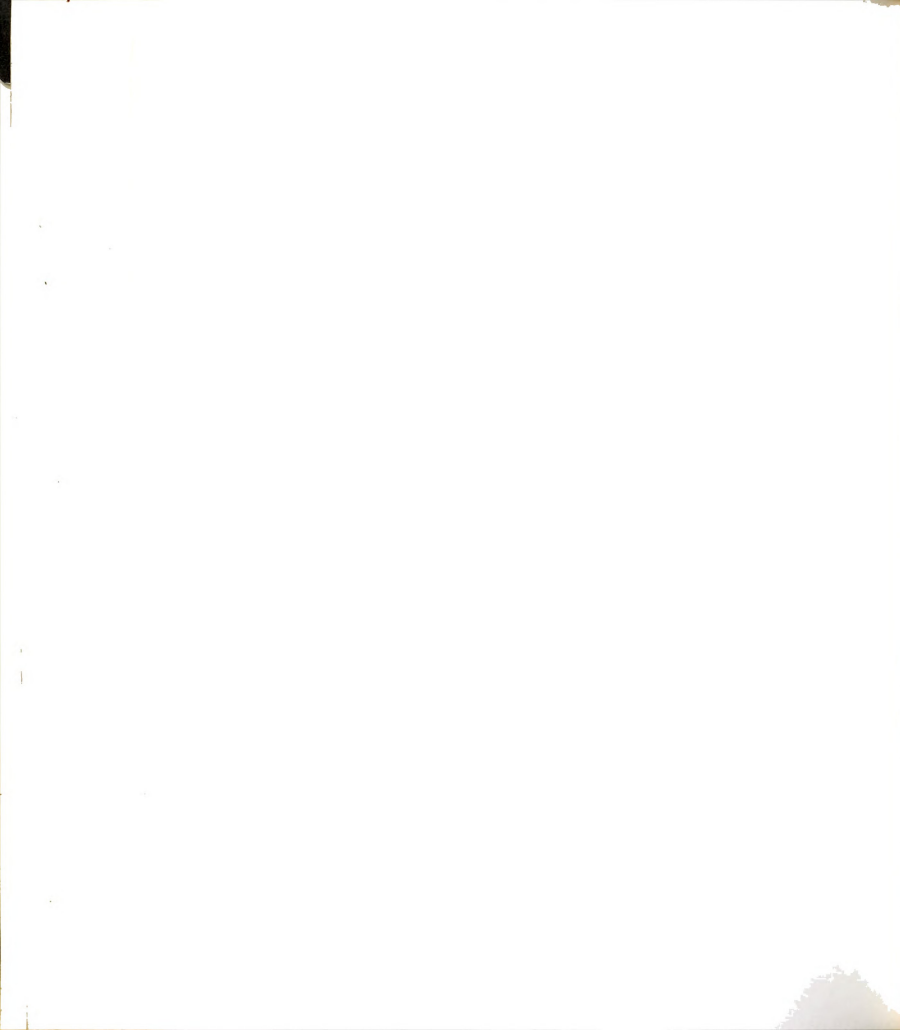
6-hour holding period had a grand average of 5.2. For roasts with an 18-hour holding period, the grand average score dropped to 4.6. Descriptive terminology going along with this score indicated the flavor was good, but faint.

The grand average scores for flavor of lean of delayed service cooked roasts are not in agreement with data reported by Dymit (65). The flavor of lean dropped slightly when the meat was held for 6 hours. With the increased holding period of 18 hours, the grand average score dropped 0.6 of a point. Comments made by the judges about delayed service cooked roasts indicated they regarded the flavor more typical of braised rather than roasted beef. They also commented that the samples tasted more well-done than rare.

A very highly significant correlation coefficient ($r = .63$) was obtained between flavor scores for lean and those for fat. The correlation coefficient ($r = .54$) obtained between flavor scores for lean and juiciness scores was also very highly significant, indicating flavor components of meat may be present in the juice.

Flavor of fat

Analysis of variance computed on the mean flavor scores of fat showed differences, significant at the .05 level of probability, attributable to cooking method. Animal differences for flavor of fat were also significant. Further analysis of the data showed that the differences in flavor of fat between forced convection cooked roasts



and delayed service cooked roasts with an 18-hour holding period were significant at the .05 level of probability. The same was true for the difference between delayed service cooked roasts with a 6-hour holding period and delayed service cooked roasts with an 18-hour holding period. Differences between other combinations of the cooking methods were not significant.

Samples from forced convection cooked roasts received a grand average score of 5.1 for flavor of fat. Delayed service cooked roasts with a 6-hour holding period received a grand average score of 5.0 for flavor of fat. Conventionally cooked roasts averaged slightly lower for flavor of fat with a grand average of 4.9. When an 18-hour holding period was used with the delayed service cooking method, the flavor of fat received a grand average score of 4.3.

The grand average scores for delayed service cooked roasts showed flavor of fat decreased when the meat was held in the 60°C holding cabinet for 18 hours. Judges' comments about the flavor of the fat from delayed service cooked roasts with an 18-hour holding period indicated a burned flavor. Surfaces of all delayed service cooked roasts were characterized as very brown by the judges.

Juiciness

Grand average juiciness scores were 5.6 for forced convection and conventionally cooked roasts, indicating "juicy" meat. Delayed



service cooked roasts with a 6-hour holding period had a grand average score of 5.0, and those with an 18-hour holding period had a grand average of 4.4. These scores indicated judges rated the samples as neither juicy nor dry. The juiciness scores are in agreement with moisture and cooking loss data. As the length of the holding period increased with the delayed service method of cooking, scores for juiciness decreased.

Juiciness scores showed very highly significant differences due to cooking method. Differences among animals were not significant. Further analysis of the data showed differences in juiciness scores between delayed service cooked roasts with a 6-hour holding period and forced convection or conventionally cooked roasts were significant at the .05 level of probability. The difference in juiciness scores between delayed service cooked roasts with an 18-hour holding period and forced convection or conventionally cooked roasts were very highly significant. No significant difference was found in the juiciness scores of delayed service cooked roasts with a 6-hour holding period and those with an 18-hour holding period.

Average press fluid yields for each replication of the four cooking methods are presented in the Appendix, Table 31. Average percentage press fluid, along with the corresponding average juiciness scores are recorded in Table 10.

Table 10. Average percentages of press fluid and juiciness scores¹ for six replications of four cooking methods.

Cooking Method	Juiciness Score	Percentage Press Fluid
Delayed service		
6-hour holding	5.0	60.42
18-hour holding	4.4	57.27
Forced convection	5.6	59.94
Conventional	5.6	60.50

¹Highest possible score, 7 points.

Delayed service cooked roasts with an 18-hour holding period yielded the lowest percentage of press fluid, 57.27 per cent. Other percentages of press fluid were 60.42, 59.94, and 60.50 for delayed service with a 6-hour holding period, forced convection, and conventional roasting, respectively.

The differences in the percentage of press fluid attributable to method of cooking were significant at the .05 level of probability. Duncan's Multiple Range Test (64) did not pinpoint where the significant differences were. As was true in percentage of moisture of cooked meat, very highly significant differences in percentages of press fluid existed between animals.

A significant correlation coefficient ($r = .42$) was found between juiciness scores and press fluid values. As the percentage of press fluid increased, judges indicated the meat samples were more juicy.

Tenderness

Tenderness scores were based on the number of chews required to completely masticate a 1-inch circle of meat. The grand average tenderness score of 6.0 was the same for delayed service with an 18-hour holding period and conventionally cooked roasts, indicative of very tender meat. Forced convection cooked roasts received a slightly lower grand average score of 5.9. The lowest grand average score of 5.6, indicative of tender meat, was noted for delayed service cooked roasts with a 6-hour holding period.

The differences attributable to cooking method were significant at the .05 level of probability. When the data were analyzed further, the difference in tenderness of delayed service cooked roasts with a 6-hour holding period and conventionally cooked roasts was significant at the .05 level of probability. Other possible combinations of the four cooking methods showed no significant differences in tenderness attributable to cooking method.

The data on delayed service cooked roasts are in agreement with data reported by Dymit (65). The longer holding period of 18 hours increased the tenderness of the loin cuts of beef more than did the 6-hour holding period. The data in this study indicate the 18-hour holding period was necessary to equal the tenderness obtained by conventional roasting. However, equal tenderness may have resulted with a holding period of less than 18 hours. Further investigation

would be necessary to determine the exact holding period at which the roasts cooked by the two methods score equally in tenderness.

Differences in tenderness scores among animals were very highly significant. Other workers (28, 83, 70) have reported tenderness varied from animal to animal within the same grade of meat.

Average shear values obtained with the Warner-Bratzler shear and the Kramer shear-press are presented in the Appendix, Tables 32 and 33, respectively. The mean shear values obtained with both instruments are recorded in Table 11 along with the corresponding tenderness scores.

Table 11. Average scores¹ for tenderness and mean shear force readings as measured by the Warner-Bratzler shear and Kramer shear-press.

Cooking Method	Tender- ness Scores	Warner-Bratzler Shear (lb. force)	Kramer Shear-press (lb. force/g)
Delayed service			
6-hour holding	5.6	10.83	13.28
18-hour holding	6.0	9.76	13.04
Forced convection	5.9	9.64	13.67
Conventional	6.0	9.63	14.40

¹Highest possible score, 7 points.

Forced convection and conventionally cooked roasts required almost the same average pounds force of 9.64 and 9.63, respectively, to shear the 1-inch cores used with the Warner-Bratzler shear. Only

slightly more force, 9.76 pounds, was required to shear the cores from roasts cooked by delayed service and held for 18 hours. The cores from delayed service cooked roasts with a 6-hour holding period required the largest number of pounds force, 10.83, to shear them. The differences, attributable to cooking method, were not significant.

Mean Kramer shear-press values in pounds force per gram of 13.28, 13.04, 13.67, and 14.40 were obtained for delayed service with a 6-hour and an 18-hour holding period, forced convection, and conventionally cooked roasts, respectively. The differences were not significant. These values follow neither the pattern established by tenderness scores nor the Warner-Bratzler shear. However, this method of measuring tenderness did detect highly significant animal differences, and animal differences were noted in tenderness scores.

A very highly significant negative correlation coefficient between tenderness scores and Warner-Bratzler shear readings was found ($r = -.55$). The negative correlation coefficient between tenderness scores and Kramer shear-press values was highly significant ($r = -.49$). These results were as expected since as the score received by the meat became higher, indicating greater tenderness, less force would be required for shearing. A very highly significant correlation coefficient existed between Warner-Bratzler shear values and Kramer shear-press values ($r = .66$). This would indicate both instruments were measuring the same thing. The correlations

between tenderness scores and juiciness scores and tenderness scores and press fluid were not significant.

The significant correlation coefficients between palatability factors and objective measurements are summarized in Table 12.

Table 12. Summary of significant correlation coefficients between palatability factors and objective measurements of loin roasts cooked by four methods.

Relationship	Correlation Coefficient
Flavor of lean scores / Flavor of fat scores	.63***
Flavor of lean scores / Juiciness scores	.54***
Juiciness scores / Press fluid scores	.42*
Tenderness scores / Warner-Bratzler shear values	-.55***
Tenderness scores / Kramer shear-press values	-.49**
Warner-Bratzler shear values / Kramer shear-press values	.66***

***Significant at the .001 level of probability.

**Significant at the .01 level of probability.

*Significant at the .05 level of probability.

Appearance of the cooked roast

The over-all appearance of the cooked roast was evaluated by the investigator prior to boning and slicing it for further analysis.



In comparison to conventionally cooked roasts, the fat surface and exposed lean surface of delayed service cooked roasts were browner and drier in appearance. As the length of the holding period increased, the dryness increased. Surfaces of roasts held for 18 hours were very browned and very dried in appearance. These results are in agreement with data reported by Gaines (70) in her study of delayed service cookery.

The fat surface of forced convection cooked roasts appeared pale or almost raw when compared to conventionally cooked roasts. The lean surface of the roasts was not as well browned as that of the conventionally cooked roasts. The browning of lean appeared striated on some roasts and spotty on others cooked by forced convection.

Temperature at which the meat was served

Meat slices used for palatability analysis were served warm to panel members using Dri-heat plate assemblies. The time-temperature relationships of the meat slices were recorded for five samples. The average temperature recorded was 50°C. During a 30-minute holding period, the temperature of the meat slice dropped 3.5°C.

Judges reacted favorably to samples served on the hot plates. No off-flavors attributable to the serving plates were reported. Meat slices did not dry out during the 15- to 20-minute holding period prior to taste panel evaluation.

Microbiological Aspects of Delayed Service Cooked Roasts

Samples for microbiological analysis were aseptically removed from the 12 roasts which were cooked by the delayed service method for this experiment. In a follow-up study two extra roasts were injected with cultures of Salmonella senftenberg prior to cooking and holding for 18 hours.

Roasts used for sensory evaluation

Culture plates made from all meat samples cooked by the delayed service method were incubated at 35°C for 48 hours. After the experiment had begun, the decision was made to incubate at a second temperature; hence, culture plates prepared from only 8 of the 12 meat samples were incubated at 4.5°C for a 14-day period. Zero to very low counts were obtained from all analyses and the results are presented in Table 13.

The number of viable organisms represent total counts. No attempt was made to identify the organisms present in some of the roasts. Errors in technique may have been responsible for part or all of the microorganisms.

Since such low numbers of microorganisms were present in the roasts cooked by the delayed service method, no food poisoning problem existed, according to a food microbiologist (129).

Table 13. Number of microorganisms present in twelve delayed service cooked roasts when incubated at two temperatures.

Holding Period	Replication Number	Viable Organisms after Incubation	
		35°C for	4.5°C for
		48 Hours	14 Days
		Number/gram	Number/gram
6-hour	1	0	--- ^a
	2	145 _b	--- ^a
	3	---	--- ^a
	4	---	--- ^a
	5	183	0
	6	28	28
18-hour	1	53	0
	2	55	0
	3	28	0
	4	0	0
	5	0	0
	6	0	0

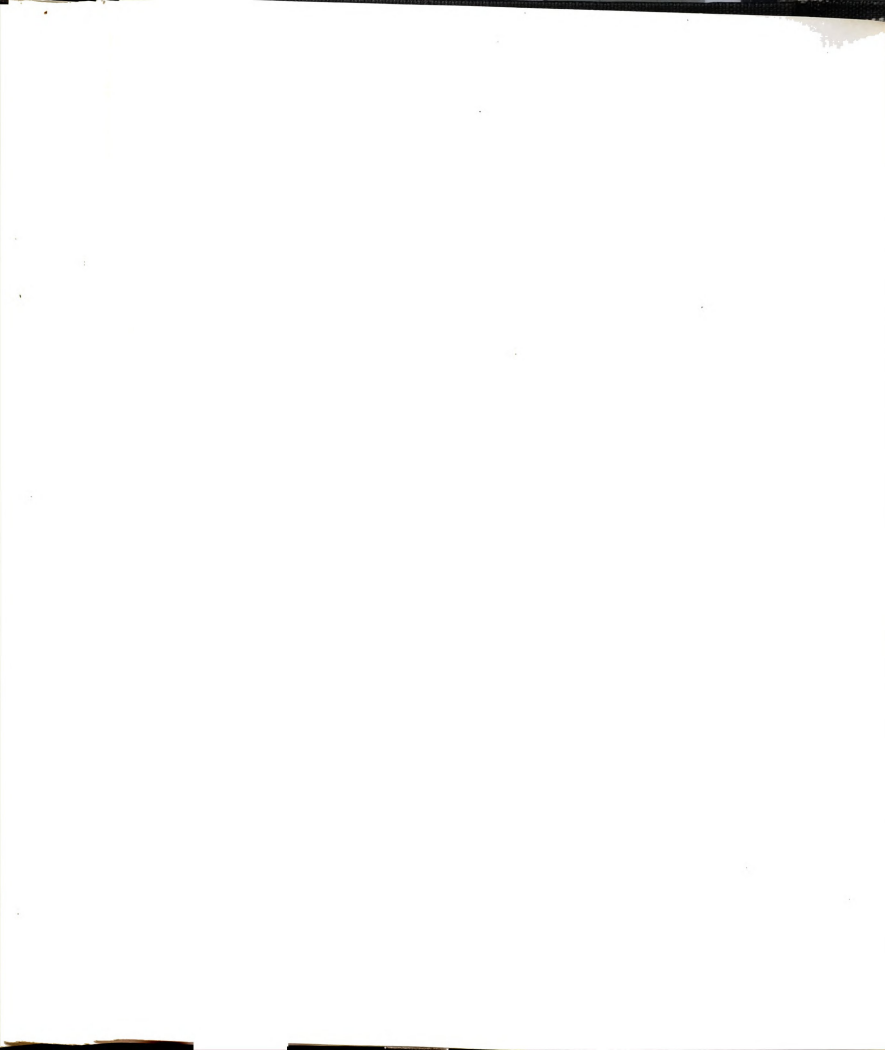
^aSamples not incubated at this temperature.

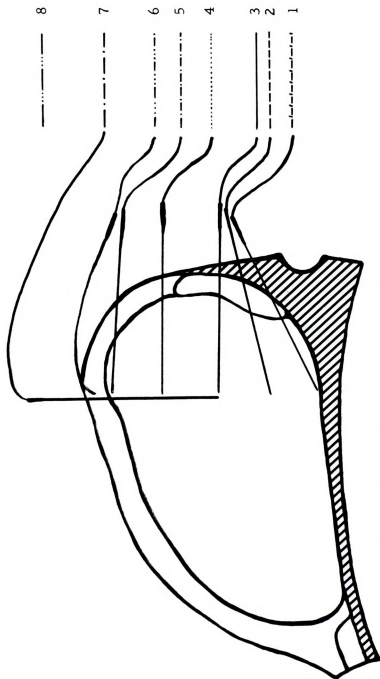
^bSamples discarded because of error in technique.

Injected roasts

Inoculated roasts were cooked in a 204°C oven to a center internal temperature of 52°C. The mean progressive time-temperature relationships were plotted for recordings from the seven potentiometer leads positioned within the roast (Fig. 6).

The microbiological analyses of the two roasts after cooking showed that no organisms were present. The maximum internal temperature reached at the center of the roast was 67°C, recorded one hour after placing the roasts in the 60°C holding cabinet. The





Key showing the types of broken lines used for graphing the time-temperature relationships from the eight different potentiometer lead positions.

- | | |
|-------|---|
| ----- | 1. Bone, connective tissue-muscle interface |
| ----- | 2. Muscle tissue |
| ----- | 3. Center of muscle tissue |
| ----- | 4. Muscle tissue |
| ----- | 5. Fat, connective tissue-muscle interface |
| ----- | 6. Surface fat |
| ----- | 7. Center of muscle tissue |
| ----- | 8. Oven |

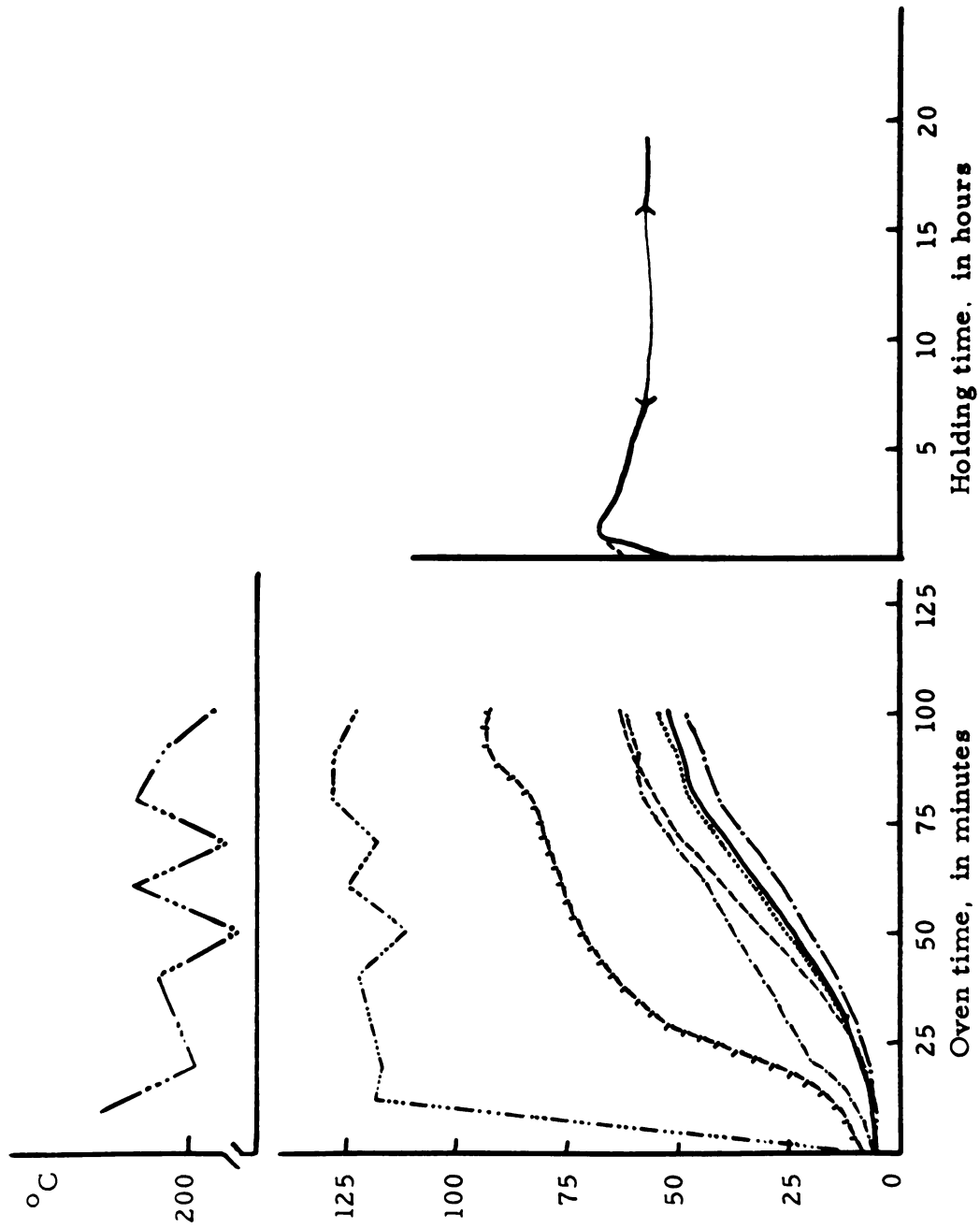


Figure 6. Mean progressive time-temperature relationships of inoculated roasts cooked by delayed service method with 18-hour holding periods.

temperature declined over a period of 6 hours to 56°C where it remained throughout the remainder of the holding period. Apparently, the Salmonella senftenberg organisms were destroyed at the time-temperature relationships recorded for these roasts.

Cooking Methods Related to the Institution Food Service Setting

A third objective of this study was the examination of the cooking methods for possible use in the institution food service setting. The methods will be discussed under the headings of delayed service roasting and forced convection roasting.

Delayed service roasting

Under the conditions of this study, 22 per cent less time was required to cook loin cuts of beef to an end internal temperature of 52°C in the 204°C oven used with delayed service cookery than was needed to cook roasts to the same internal temperature in the 149°C oven used with conventional roasting. With the use of holding periods in the actual food service operation, oven space for other purposes would be available. Holding periods could be adjusted to fit the needs of the particular food service operation.

The disadvantages of delayed service cookery should be considered along with the possibility of additional oven space. Total cooking losses, when a 6-hour holding period was used, were almost

twice as high as the losses from conventionally cooked roasts. When an 18-hour holding period was used, total cooking losses were almost two and one-fourth times as high as those of conventionally cooked roasts. The increased losses of delayed service cookery represented higher drip and higher volatile losses than were found with conventionally cooked roasts.

Because greater losses occurred with the delayed service cookery method, less meat was available for service than from conventionally cooked roasts. Hence, the cost per serving of meat would be higher for delayed service cooked roasts than for conventionally cooked roasts.

The palatability factors indicated another disadvantage of the delayed service cookery method. Color of lean, flavor of lean, and juiciness scored lower for delayed service cooked roasts than for conventionally cooked roasts. Comments made by panelists showed delayed service cooked roasts possessed a flavor more typical of braised than of roasted beef. When a 6-hour holding period was used with the delayed service method, judges scored tenderness lower than that of conventionally cooked samples. With an 18-hour holding period, the flavor of fat decreased in desirability. The decrease in quality factors of delayed service cooked roasts would mean a decrease in consumer satisfaction.

Forced convection roasting

When ovens of the same temperature were used, forced convection roasting was accomplished in approximately 18 per cent less time than was required for conventional roasting. This would represent additional oven capacity to the food service operator.

Total cooking losses of the forced convection cooked roasts, were about 20 per cent higher than losses from similar cuts cooked conventionally. Hence, the food service operator would be faced with higher costs per serving of meat when forced convection ovens were used in place of conventional ovens.

All palatability characteristics evaluated, except flavor of fat, scored slightly lower for roasts cooked by forced convection as compared with those prepared by conventional roasting.

SUMMARY AND CONCLUSIONS

The primary objectives of this study were to compare the effects of delayed service cookery using 6- and 18-hour holding periods, forced convection, and conventional roasting on heat penetration rates, palatability characteristics, and yield of loin roasts from U.S. Choice beef. Another objective of the study was to examine the methods of cookery in terms of efficiency of equipment use for the institution setting. Procedures used for roasting, objective measurements, and subjective evaluations of the samples were developed through preliminary investigations in the laboratory.

Strip loin (bone-in) cuts of beef were prepared from six paired short loins. Each strip loin cut was then halved, making the twenty-four roasts needed for this study. Codes were arbitrarily assigned to the roasts so that one roast from each animal was cooked by each of the four methods. Individual raw roasts were weighed, wrapped, frozen, and stored at -34.4°C until defrosted for roasting and subsequent evaluation.

Prior to cooking, each roast was weighed, defrosted, and reweighed. The external fat covering of the roast was trimmed to a uniform depth. Potentiometer leads were positioned horizontally and in a vertical plane at five points within each roast: at the bone or surface fat and connective tissue-muscle interfaces; at the center of

the muscle tissue; and within the muscle tissue at points 0.63- to 0.75-inch from the center. The sixth potentiometer lead was positioned vertically to the center of the roast. Another potentiometer lead was embedded approximately 0.13-inch into the surface fat of each roast. An eighth potentiometer lead was used to obtain a continuous record of the oven temperature during roasting.

All roasts were oven cooked to an end internal temperature of 52°C , as recorded by the potentiometer lead positioned horizontally to the center of the roast.

For oven roasting by the delayed service method, the oven was preheated to 204°C and this temperature $\pm 20^{\circ}\text{C}$ was maintained throughout the oven cooking period. After removal from the oven, the potentiometer leads were removed and the sample weighed. Thermometers were inserted, one to the center of the roast and a second to a point midway between the center and the surface. The roast was then placed in a forced circulation incubator set and maintained at $60^{\circ} \pm 2^{\circ}\text{C}$ which served as a holding cabinet. Initial and hourly temperatures were read throughout the holding periods for the roasts held for 6 hours. Temperatures for the roasts held for 18 hours were recorded initially, at the end of the first hour, and hourly from the twelfth hour through the remainder of the holding period.

Forced convection and conventionally cooked samples were

roasted in ovens preheated to 149°C and this temperature $\pm 10^{\circ}\text{C}$ and $\pm 20^{\circ}\text{C}$, respectively, maintained throughout the oven cooking period. A pan of water was placed in the forced convection oven during the roasting period. After removal from the oven, the samples were allowed to stand for 30 minutes before potentiometer leads were removed.

At the end of the holding periods, the roasts were weighed and prepared for evaluation. Warm samples were served to a seven member taste panel using Dri-Heat hot plates. Samples were scored for aroma, color of lean, flavor of lean, flavor of fat, juiciness, and tenderness. Measurements of press fluid, Warner-Bratzler shear, and Kramer shear-press were determined objectively. Proximate analysis and pH were determined on raw and cooked samples taken from each roast. Oven cooking and subsequent holding losses were obtained for each roast cooked by the delayed service method. Data pertaining to heat penetration rates were examined to evaluate differences attributable to cooking method.

Samples for microbiological analysis were aseptically removed from the center of all roasts cooked by the delayed service method. To further evaluate the safety of meat cooked by the delayed service method, two defrosted roasts were injected with a culture of Salmonella senftenberg prior to cooking. The roasts were cooked and held for 18 hours in the same manner as other delayed service cooked roasts.

All temperature curves for roasts cooked in the 204°C oven used for the delayed service method, rose at a more rapid rate than those for roasts cooked in the 149°C forced convection or conventional oven. Temperatures recorded at the surface of the roast rose at a rate dependent on the oven temperature and followed the normal cycling of the oven throughout the cooking period. By the time the heat had penetrated through the surface fat and connective tissue sheath covering the roast, the fluctuations in temperature were no longer evident.

During the first part of the delayed service and conventional cooking period, heat penetrated into the muscle tissue of the roast more rapidly through the surface fat than through the bone. This phenomenon was reversed after the first 20 minutes of the cooking period. Heat penetrated into the forced convection cooked roasts more rapidly through the bone than through the surface fat throughout the cooking period.

During holding, higher maximum internal temperatures were recorded for delayed service cooked roasts than for either forced convection or conventionally cooked roasts. In the delayed service cooked roasts, the maximum temperature declined over a period of six hours. From this time, the temperature remained constant throughout the remainder of the holding period.

Significantly less oven cooking time (.01 level of probability)



was required for delayed service and forced convection cooked roasts to reach the end internal temperature of 52°C than was needed for conventionally cooked roasts to reach the same end internal temperature.

Very highly significant differences existed among animals in the moisture, fat, and protein content of the raw meat. The ash content of the raw meat was also significantly different (.01 level of probability) among animals.

No significant differences due to cooking method were found in the pH or percentage of fat content of the meat. The percentage of moisture content of delayed service cooked roasts with an 18-hour holding period was significantly less than the percentage moisture content of conventionally cooked roasts. No significant differences were found in moisture content of other possible combinations of the four cooking methods. Very highly significant differences existed in the protein content of the meat cooked by the four methods. The differences in ash content attributable to cooking method were significant (.05 level of probability).

Percentage weight losses incurred during frozen storage varied at the .001 level of probability, among animals. Drip losses incurred during the defrosting period were not significant.

The total cooking losses of delayed service cooked roasts with a 6- or 18-hour holding period were significantly higher (.001 level of probability) than either the forced convection cooked roasts or the

conventionally cooked roasts. The 18-hour holding period of delayed service cooked roasts significantly (.05 level of probability) increased total cooking losses over those resulting from a 6-hour holding period of delayed service cooked roasts. Differences in total cooking losses between forced convection and conventionally cooked roasts were not significant.

Drip losses were the same for delayed service cooked roasts with either a 6- or 18-hour holding period. The drip losses from delayed service cooked roasts with 6- or 18-hour holding periods were significantly greater than drip losses from forced convection cooked roasts (.05 level of probability) or conventionally cooked roasts (.01 level of probability). No significant differences existed in drip losses between forced convection and conventionally cooked roasts.

Volatile losses for delayed service cooked roasts were significantly greater (.001 level of probability) for an 18-hour holding period than those incurred during a 6-hour holding period. The volatile losses of all delayed service cooked roasts were significantly greater (.001 level of probability) than volatile losses of forced convection and conventionally cooked roasts. The differences in volatile losses between forced convection and conventionally cooked roasts were not significant.

The difference in servable meat from delayed service cooked roasts with a 6-hour holding period and delayed service cooked roasts

with an 18-hour holding period was not significant. Significantly more (.001 level of probability) meat was available for service from either forced convection or conventionally cooked roasts than was available from delayed service cooked roasts with a 6- or 18-hour holding period. The amount of servable meat from forced convection and conventionally cooked roasts did not differ significantly.

Differences in aroma scores attributable to cooking method, were significant at the .05 level of probability. Higher grand average scores for aroma were obtained for delayed service cooked roasts than for either forced convection or conventionally cooked roasts.

Conventionally cooked roasts scored significantly higher (.01 level of probability) for color of lean than delayed service cooked roasts with 6- or 18-hour holding periods. The differences in color of lean between delayed service cooked roasts with 6- or 18-hour holding periods and that of forced convection cooked roasts were not significant. No significant difference existed in the color of lean in roasts cooked by forced convection and by conventional roasting.

No significant differences attributable to cooking method existed in the flavor of lean meat.

Flavor of fat scores were significantly higher (.05 level of probability) for forced convection or delayed service cooked roasts with a 6-hour holding period than for delayed service cooked roasts

with an 18-hour holding period. No other significant differences attributable to cooking method existed in flavor of fat scores.

Delayed service cooked roasts with a 6-hour holding period scored significantly lower (.05 level of probability) in juiciness than either forced convection or conventionally cooked roasts. When an 18-hour holding period was used with the delayed service method, juiciness scores differed at the .001 level of probability from the juiciness scores of forced convection or conventionally cooked roasts. Forced convection cooked roasts scored the same for juiciness as conventionally cooked roasts. Differences in the percentage of press fluid attributable to cooking method were significant at the .05 level of probability.

The conventionally cooked roasts scored significantly higher (.05 level of probability) in tenderness scores than roasts cooked by the delayed service method and held for 6 hours. No other significant differences attributable to cooking method existed in tenderness scores. Animal differences were very highly significant.

The differences attributable to cooking in the Warner-Bratzler shear readings and Kramer shear-press values were not significant. Highly significant differences among animals were detected by the Kramer shear-press, however.

Positive very highly significant correlation coefficients were found between flavor of lean scores/flavor of fat scores, flavor of

lean scores/juiciness scores, and Warner-Bratzler shear values/Kramer shear-press values. Positive correlation coefficients, significant at the .01 level of probability, were found between raw weight/oven cooking time and percentage protein of cooked meat/Warner-Bratzler shear values. At the .05 level of probability, the correlation coefficient between juiciness scores/press fluid values was significant.

Very highly significant negative correlation coefficients were found between percentage moisture of raw meat/percentage fat of raw meat, percentage fat of cooked meat/Warner-Bratzler shear values, percentage protein of cooked meat/press fluid values, percentage protein of cooked meat/juiciness scores, juiciness scores/total cooking losses, juiciness scores/volatile losses, juiciness scores/drip losses, and tenderness scores/Warner-Bratzler shear values. Negative correlation coefficients, significant at the .01 level of probability, were found between percentage fat of cooked meat/press fluid values and tenderness scores/Kramer shear-press values. The negative correlation coefficient between percentage moisture of cooked meat/volatile losses was significant at the .05 level of probability.

Zero to very low total counts of microorganisms were obtained from roasts cooked by the delayed service method. A food microbiologist indicated no food poisoning hazard existed when roasts

were cooked under the conditions of this study.

The microbiological analysis of the two roasts injected with cultures of the organism, Salmonella senftenberg and cooked by delayed service methods, showed no viable organisms were present after oven cooking and holding for 18 hours.

Under the conditions of this investigation the following conclusions are indicated:

1. Heat penetrated the roasts more rapidly in a 204°C oven than in 149°C ovens. Heat penetration rates were faster in a forced convection oven than in a natural convection oven. Twenty-two per cent less time was required to cook roasts in a 204°C oven than was required to cook similar roasts in a 149°C conventional oven. In a 149°C forced convection oven, roasting of loin cuts was accomplished in 18 per cent less time than was required to cook similar cuts in a natural convection oven at the same temperature.

2. Total cooking losses of delayed service cooked roasts with a 6-hour holding period were almost twice as high as the losses from conventionally cooked roasts. When an 18-hour holding period was used, total cooking losses were almost two and one-fourth times as high as those of conventionally cooked roasts. Total cooking losses of the forced convection cooked roasts, were about 20 per cent higher than those from similar cuts cooked conventionally.

3. In general, palatability factors scored lower for all delayed

service and forced convection cooked roasts. Differences between forced convection and conventionally cooked roasts were less than the differences between delayed service and conventionally cooked roasts.

4. Bacteriologically, no hazard existed when roasts were cooked by the delayed service method in this investigation. This factor was supported by data obtained from analysis of roasts injected with cultures of Salmonella senftenberg.

The results of this study show that although the delayed service cookery method reduced oven cooking time, increased total cooking losses and decreased palatability characteristics would mean higher food costs and lower consumer satisfaction for the food service operator than would be obtained from conventionally cooked roasts. Its use is therefore, not recommended.

Forced convection roasting reduced oven cooking time and increased total cooking losses when compared to roasting in a natural convection oven at the same temperature. The palatability scores of forced convection cooked roasts were slightly lower than those for conventionally cooked roasts. These factors would indicate natural convection roasting is to be preferred over forced convection roasting. Since the differences were small and limited data is available on the merits of forced convection roasting, perhaps other studies at different oven temperatures should be undertaken to further evaluate this method of meat cookery.

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APPENDIX



Table 14. Beef score card.

Date _____		Judge _____					Code No. _____	
Factors	7	6	5	4	3	2	1	
Aroma	Rich, meaty	Very meaty	Good, full	Good, faint	Fair	Fair, faint	Lacking____ or Unpleasant*_____	
Color of Lean	Light brown to deep pink	Light brown to pink	Medium brown to light pink	Medium brown to light gray	Gray throughout	Very gray throughout	Unnatural*_____	
Flavor of Lean	Rich, meaty	Very meaty	Good, full	Good, faint	Fair	Fair, faint	Lacking____ or Unpleasant*_____	
Flavor of Fat	Rich, typical full	Rich	Good, full	Good, faint	Fair	Fair, faint	Off-flavor____ or Unpleasant*_____	
Juiciness of Lean	Extremely juicy	Very juicy	Juicy	Neither juicy nor dry	Dry	Very dry	Too dry to swallow	
Tenderness and Chew Count	Extremely tender	Very tender	Tender	Slightly tough	Tough	Very tough	Extremely tough____	

*Describe
Comments



Table 15. Total oven cooking times for six replications of four cooking methods.

Method of Cooking	Animal (Replication)	Time, in Minutes
Delayed service		
6-hour holding	1	110
	2	101
	3	124
	4	92
	5	124
	6	107
Average		110
18-hour holding	1	108
	2	109
	3	112
	4	105
	5	106
	6	108
Average		108
Forced convection	1	127
	2	103
	3	137
	4	102
	5	130
	6	113
Average		119
Conventional	1	133
	2	135
	3	162
	4	134
	5	120
	6	163
Average		141



Table 16. Determinations of pH for raw and cooked samples and the change in pH for six replications of four cooking methods.

Method of Cooking	Animal (Repli- cation)	pH Readings ¹		
		Raw Samples	Cooked Samples	Change
Delayed service				
6-hour holding	1	5.7	5.9	0.2
	2	6.0	5.9	-0.1
	3	5.8	5.7	-0.1
	4	5.7	5.7	0.0
	5	5.7	5.7	0.0
	6	5.7	5.6	-0.1
Average		5.8	5.8	0.0
18-hour holding	1	5.7	5.9	-0.2
	2	5.8	5.8	0.0
	3	5.5	5.7	0.2
	4	5.8	5.8	0.0
	5	5.5	5.7	0.2
	6	5.7	5.9	0.2
Average		5.7	5.8	0.1
Forced convection	1	5.9	5.8	-0.1
	2	5.8	5.9	0.1
	3	5.7	5.8	0.1
	4	5.7	5.9	0.2
	5	5.5	5.7	0.2
	6	5.7	5.9	0.2
Average		5.7	5.8	0.1
Conventional	1	5.8	5.9	0.1
	2	5.9	5.9	0.0
	3	5.6	5.7	0.1
	4	5.7	5.9	0.2
	5	5.4	5.7	0.3
	6	5.6	5.8	0.2
Average		5.7	5.8	0.1

¹Based on 2 readings.

Proximate analyses were determined in duplicate on raw and cooked samples from each of the 24 roasts used in this study. For the few times the calculated results for moisture, fat, and protein did not agree within 1.0 per cent (based on 100 per cent) the analyses were repeated in duplicate. Ash determinations were repeated if calculated values did not agree within 0.2 per cent (based on 100 per cent). Values obtained from the original analysis were discarded and the values from the repeated analysis were reported.

Table 17. Percentage moisture determinations, averages, and standard deviations for the raw longissimus dorsi muscle of beef.

Method of Cooking	Animal (Repl-ication)	Determination		Average (%)	Standard Deviation
		1 (%)	2 (%)		
Delayed service					
6-hour holding	1	73.35	73.31	73.33	0.00
	2	69.15	69.02	69.09	0.00
	3	66.55	66.24	66.40	0.22
	4	62.17	62.38	62.28	0.14
	5	64.08	64.03	64.06	0.00
	6	62.25	62.05	62.15	0.10
Average				66.22	4.38
18-hour holding					
	1	70.00	70.04	70.02	0.00
	2	66.22	66.30	66.26	0.00
	3	70.36	70.84	70.60	0.35
	4	63.13	63.39	63.26	0.17
	5	66.58	66.62	66.60	0.00
	6	64.34	64.31	64.33	0.10
Average				66.85	2.96
Forced convection					
	1	71.95	71.92	71.94	0.00
	2	64.57	64.41	64.49	0.10
	3	71.04	71.24	71.14	0.14
	4	64.63	64.58	64.59	0.10
	5	66.97	66.93	66.95	0.10
	6	66.81	66.76	66.79	0.10
Average				67.65	3.20
Conventional					
	1	70.93	70.98	70.96	0.10
	2	65.45	65.45	65.45	0.00
	3	70.17	70.22	70.20	0.00
	4	63.94	63.97	63.96	0.10
	5	61.60	61.64	61.62	0.00
	6	65.55	65.53	65.54	0.10
Average				66.29	3.62
Grand Average				66.75	3.39



Table 18. Percentage moisture determinations, averages, and standard deviations for six replications of four cooking methods.

Method of Cooking	Animal (Repl-ication)	Determination		Average (%)	Standard Deviation
		1 (%)	2 (%)		
Delayed service					
6-hour holding	1	63.97	64.15	64.07	0.10
	2	56.67	56.58	56.63	0.10
	3	53.72	53.97	53.85	0.17
	4	57.31	57.46	57.39	0.10
	5	58.86	58.75	58.81	0.00
	6	58.67	58.74	58.71	0.00
Average				58.24	3.38
18-hour holding					
	1	58.04	58.19	58.12	0.10
	2	56.69	56.71	56.70	0.00
	3	53.31	53.36	53.34	0.00
	4	52.34	52.61	52.48	0.20
	5	56.71	56.81	56.76	0.00
	6	54.43	54.41	54.42	0.10
Average				55.30	2.22
Forced convection					
	1	61.08	60.97	61.03	0.10
	2	60.91	60.75	60.83	0.10
	3	59.81	59.91	59.86	0.10
	4	57.21	57.16	57.19	0.00
	5	56.80	57.11	56.96	0.20
	6	55.78	56.07	55.91	0.20
Average				58.63	2.21
Conventional					
	1	64.61	64.61	64.61	0.00
	2	58.10	58.03	58.07	0.00
	3	58.80	59.00	58.90	0.14
	4	55.55	55.72	55.64	0.10
	5	59.12	58.97	59.05	0.00
	6	56.76	56.79	56.78	0.00
Average				58.85	3.11

Table 19. Percentage fat determinations, averages, and standard deviations for the raw longissimus dorsi muscle of beef.

Method of Cooking	Animal (Replication)	Determination		Average	Standard Deviation
		1 (%)	2 (%)	(%)	
Delayed service					
6-hour holding	1	5.69	5.31	5.50	0.28
	2	9.75	9.60	9.68	0.10
	3	14.04	14.47	14.26	0.30
	4	18.99	19.54	19.27	0.39
	5	15.61	15.03	15.32	0.40
	6	16.10	16.39	16.25	0.20
Average				13.38	4.97
18-hour holding	1	6.58	6.22	6.40	0.26
	2	11.00	11.11	11.06	0.00
	3	7.62	7.58	7.60	0.00
	4	16.22	15.98	16.10	0.17
	5	10.48	9.88	10.19	0.41
	6	14.79	14.13	14.46	0.46
Average				10.97	3.78
Forced convection	1	5.51	4.61	5.06	0.64
	2	14.94	15.06	15.00	0.00
	3	6.32	7.32	6.82	0.70
	4	14.69	15.43	15.06	0.52
	5	11.47	10.71	11.09	0.53
	6	13.94	14.34	14.14	0.28
Average				11.20	4.31
Conventional	1	4.16	4.62	4.39	0.32
	2	12.48	12.07	12.28	0.28
	3	6.98	6.55	6.77	0.30
	4	14.75	15.65	15.20	0.63
	5	15.76	16.28	16.02	0.37
	6	11.79	12.11	11.95	0.20
Average				11.10	4.62
Grand Average				11.67	4.26

Table 20. Percentage fat determinations, averages, and standard deviations for six replications of four cooking methods.

Method of Cooking	Animal (Repli- cation)	Determination		Average (%)	Standard Deviation
		1 (%)	2 (%)		
Delayed service					
6-hour holding	1	7.92	7.94	7.93	0.00
	2	16.91	16.43	16.67	0.33
	3	18.20	17.86	18.03	0.24
	4	15.20	15.53	15.37	0.22
	5	14.56	14.79	14.68	0.14
	6	15.14	14.87	15.01	0.20
Average				14.62	3.50
18-hour holding	1	10.35	9.82	10.09	0.10
	2	14.80	14.13	14.47	0.48
	3	18.41	18.01	18.21	0.28
	4	21.01	21.04	21.03	0.00
	5	15.02	15.78	15.40	0.54
	6	17.91	17.58	17.73	0.24
Average				16.16	3.76
Forced convection	1	8.90	8.95	8.93	0.00
	2	14.65	14.01	14.33	0.45
	3	11.92	12.36	12.14	0.32
	4	17.63	17.73	17.68	0.00
	5	18.05	18.07	18.06	0.10
	6	15.59	15.98	15.79	0.28
Average				14.49	3.50
Conventional	1	9.29	8.96	9.13	0.22
	2	15.60	16.30	15.95	0.49
	3	16.33	15.95	16.14	0.26
	4	20.58	19.72	20.15	0.61
	5	16.14	16.55	16.35	0.28
	6	18.01	18.46	18.24	0.32
Average				15.99	3.73

Table 21. Percentage protein determinations, averages, and standard deviations for the raw longissimus dorsi muscle of beef.

Method of Cooking	Animal (Repl-ication)	Determination		Average (%)	Standard Deviation
		1 (%)	2 (%)		
Delayed service					
6-hour holding	1	21.63	21.81	21.72	0.14
	2	20.75	20.56	20.66	0.10
	3	19.19	19.06	19.12	0.10
	4	18.88	19.00	18.94	0.00
	5	18.88	19.00	18.94	0.00
	6	18.50	18.69	18.60	0.14
Average				19.66	1.24
18-hour holding	1	21.19	21.69	21.44	0.36
	2	20.63	20.88	20.76	0.17
	3	21.81	21.75	21.78	0.00
	4	18.94	18.88	18.91	0.10
	5	20.63	21.00	20.82	0.26
	6	19.44	19.69	19.57	0.28
Average				20.55	1.10
Forced convection	1	21.38	21.94	21.66	0.39
	2	18.88	19.00	18.94	0.00
	3	21.19	21.12	21.16	0.00
	4	19.56	19.50	19.53	0.00
	5	20.19	20.63	20.41	0.32
	6	19.19	19.38	19.29	0.14
Average				20.17	1.09
Conventional	1	21.63	21.63	21.63	0.00
	2	19.94	19.50	19.72	0.30
	3	21.63	21.63	21.63	0.00
	4	19.19	19.13	19.16	0.10
	5	19.75	19.63	19.69	0.10
	6	19.75	19.44	19.60	0.20
Average				20.24	1.10
Grand Average				20.15	1.11

Table 22. Percentage protein determinations, averages, and standard deviations for six replications of four cooking methods.

Method of Cooking	Animal (Repl-ication)	Determination		Average (%)	Standard Deviation
		1 (%)	2 (%)		
Delayed service					
6-hour holding	1	26.19	26.38	26.29	0.14
	2	24.69	24.56	24.63	0.10
	3	26.25	26.25	26.25	0.00
	4	25.13	25.25	25.19	0.10
	5	24.31	24.25	24.28	0.00
	6	25.19	24.94	25.07	0.17
Average				25.29	0.83
18-hour holding					
	1	29.88	29.69	29.79	0.14
	2	26.69	27.12	26.91	0.30
	3	26.00	26.38	26.19	0.26
	4	25.25	25.25	25.25	0.00
	5	26.06	26.25	26.16	0.10
	6	25.88	26.06	25.97	0.10
Average				26.71	1.60
Forced convection					
	1	27.00	28.00	27.50	0.71
	2	23.94	23.63	23.79	0.22
	3	25.44	25.56	25.50	0.00
	4	23.63	23.75	23.69	0.10
	5	23.18	24.13	23.97	0.67
	6	26.94	27.13	27.04	0.14
Average				25.25	1.70
Conventional					
	1	26.13	26.19	26.16	0.10
	2	23.69	23.25	23.47	0.32
	3	24.13	24.50	24.32	0.26
	4	22.56	22.44	22.50	0.00
	5	22.38	22.69	22.54	0.22
	6	23.19	23.00	23.10	0.14
Average				23.68	1.39

Table 23. Percentage ash determinations, averages, and standard deviations for the raw longissimus dorsi muscle of beef.

Method of Cooking	Animal (Replika- tion)	Determination		Average (%)	Standard Deviation
		1 (%)	2 (%)		
Delayed service					
6-hour holding	1	0.95	0.92	0.94	0.00
	2	0.96	0.95	0.96	0.10
	3	0.93	0.93	0.93	0.00
	4	0.90	0.95	0.93	0.00
	5	0.82	0.90	0.86	0.00
	6	0.81	0.82	0.82	0.00
Average				0.91	0.05
18-hour holding	1	1.03	1.04	1.04	0.00
	2	0.96	0.97	0.97	0.00
	3	1.13	1.05	1.09	0.00
	4	0.83	0.88	0.86	0.00
	5	0.93	0.94	0.94	0.00
	6	0.96	0.96	0.96	0.00
Average				0.98	0.08
Forced convection	1	1.11	1.10	1.11	0.00
	2	1.10	0.99	1.05	0.00
	3	1.12	1.03	1.08	0.00
	4	0.98	0.92	0.95	0.00
	5	0.99	1.01	1.00	0.00
	6	0.95	0.98	0.97	0.00
Average				1.02	0.06
Conventional	1	1.07	1.07	1.07	0.00
	2	0.96	0.95	0.96	0.10
	3	0.99	0.94	0.97	0.00
	4	0.86	0.92	0.89	0.00
	5	1.00	0.95	0.98	0.00
	6	0.87	0.87	0.87	0.00
Average				0.97	0.07
Grand Average				0.97	0.07

Table 24. Percentage ash determinations, averages, and standard deviations for six replications of four cooking methods.

Method of Cooking	Animal (Replication)	Determination		Average (%)	Standard Deviation
		1 (%)	2 (%)		
Delayed service					
6-hour holding	1	0.91	0.95	0.93	0.00
	2	0.91	0.92	0.92	0.00
	3	0.93	0.92	0.93	0.00
	4	1.06	1.08	1.07	0.00
	5	0.79	0.82	0.81	0.10
	6	0.78	0.72	0.75	0.00
Average				0.90	0.11
18-hour holding	1	1.22	1.04	1.13	0.10
	2	1.40	1.36	1.38	0.00
	3	1.28	1.12	1.20	0.10
	4	1.06	0.94	1.00	0.00
	5	0.83	0.90	0.87	0.00
	6	0.90	0.95	0.93	0.00
Average				1.09	0.19
Forced convection	1	1.16	1.20	1.18	0.00
	2	0.98	0.99	0.99	0.00
	3	1.10	1.12	1.11	0.10
	4	1.28	1.21	1.25	0.00
	5	1.10	1.02	1.06	0.00
	6	0.96	0.91	0.94	0.00
Average				1.08	0.12
Conventional	1	1.04	1.00	1.02	0.00
	2	1.04	0.94	0.99	0.00
	3	0.88	0.89	0.89	0.00
	4	0.84	1.00	0.92	0.10
	5	0.88	0.87	0.88	0.00
	6	0.95	0.87	0.91	0.00
Average				0.94	0.07

Table 25. Days in frozen storage and percentage weight losses during storage for six replications of four cooking methods.

Method of Cooking	Animal (Replication)	Days in Frozen Storage	Weight Losses During Storage (%)
Delayed service			
6-hour holding	1	100	0.41
	2	102	0.45
	3	107	0.20
	4	109	0.51
	5	114	0.38
	6	116	0.56
Average		108	0.42
18-hour holding	1	120	0.29
	2	122	0.29
	3	129	0.17
	4	131	0.44
	5	143	0.03
	6	145	0.95
Average		132	0.36
Forced convection	1	100	0.38
	2	102	0.35
	3	107	0.14
	4	109	0.68
	5	114	0.19
	6	116	0.52
Average		108	0.38
Conventional	1	121	0.40
	2	123	0.42
	3	130	0.29
	4	132	0.44
	5	144	0.35
	6	146	0.51
Average		133	0.40



Table 26. Defrosting hours and percentage weight losses during defrosting for six replications of four cooking methods.

Method of Cooking	Animal (Replication)	Hours To Defrost	Weight Losses During Defrosting (%)
Delayed service			
6-hour holding	1	42	0.58
	2	36	0.39
	3	38	0.14
	4	36	0.47
	5	39	0.02
	6	37	0.19
Average		38	0.30
18-hour holding	1	50	0.40
	2	48	0.07
	3	49	0.53
	4	48	0.28
	5	50	1.04
	6	48	0.34
Average		49	0.44
Forced convection	1	47	0.81
	2	41	0.03
	3	43	0.12
	4	41	0.38
	5	44	0.11
	6	42	0.27
Average		43	0.29
Conventional	1	44	0.51
	2	42	0.26
	3	43	0.52
	4	42	0.28
	5	42	1.02
	6	42	0.08
Average		43	0.45

Table 27. Total cooking weight losses for six replications of four cooking methods.

Method of Cooking	Animal (Repl-ication)	Raw Wt. (gm.)	Cooked Wt. (gm.)	Total Loss (gm.)	Total Loss (%)	Drip Loss (%)	Vola-tile Loss (%)
Delayed service							
6-hour holding	1	2772	2205	567	25.32	9.49	15.84
	2	2897	2375	522	23.02	7.59	15.43
	3	3290	2592	698	26.47	9.64	16.83
	4	2364	1926	438	19.84	7.66	12.18
	5	3003	2379	624	26.07	9.79	16.28
	6	2977	2591	386	22.17	5.31	16.86
Average		2884	2345	539	23.82	8.25	15.57
18-hour holding	1	3021	2395	626	28.40	8.90	19.50
	2	2463	1942	521	29.11	9.54	19.57
	3	3217	2611	606	26.51	6.65	19.86
	4	2281	1791	490	30.38	9.29	21.09
	5	3026	2481	545	26.04	6.38	19.66
	6	2684	2202	482	26.30	7.97	18.33
Average		2782	2237	545	27.79	8.12	19.67
Forced convection	1	3056	2527	529	17.31	7.19	10.12
	2	3042	2624	418	13.74	4.50	9.24
	3	3238	2705	533	16.46	6.64	9.82
	4	2504	2146	358	14.30	4.83	7.47
	5	3267	2766	501	15.33	5.75	9.58
	6	2899	2488	411	14.18	2.90	11.28
Average		3001	2543	458	15.22	5.30	9.92
Conventional	1	2641	2268	373	14.12	5.30	8.82
	2	2391	2116	275	11.50	4.14	7.36
	3	3529	3034	495	14.02	4.10	9.92
	4	2292	1967	325	14.18	5.24	8.94
	5	2835	2525	310	10.93	3.03	7.90
	6	3431	3082	349	10.17	2.71	7.46
Average		2853	2499	354	12.49	4.09	8.40



Table 28. Oven cooking losses and holding losses for six replications of two cooking methods.

Method of Cooking	Animal (Repl-ication)	Oven Cooking Losses			Holding Losses		
		Total (%)	Drip (%)	Vola- tile (%)	Total (%)	Drip (%)	Vola- tile (%)
Delayed service							
6-hour holding	1	20.45	9.27	11.18	4.87	0.22	4.65
	2	18.01	7.42	10.59	5.01	0.17	4.84
	3	21.22	9.33	11.89	5.25	0.31	4.94
	4	18.53	7.02	11.51	1.31	0.64	0.67
	5	20.77	9.45	11.32	5.30	0.34	4.96
	6	12.97	5.11	7.86	9.20	0.20	9.00
Average		18.66	7.93	10.72	5.16	0.31	4.85
18-hour holding	1	20.72	8.67	12.05	7.68	0.23	7.45
	2	21.15	9.17	11.98	7.96	0.37	7.59
	3	18.83	6.40	12.43	7.68	0.25	7.43
	4	21.48	8.90	12.58	8.90	0.39	8.51
	5	18.01	6.18	11.83	8.03	0.20	7.83
	6	17.96	7.53	10.43	8.34	0.44	7.90
Average		19.69	7.81	11.88	8.10	0.31	7.79

Table 29. Weight and percentage of servable meat available from six replications of four cooking methods.

Method of Cooking	Animal (Replication)	Weight of Servable Meat (Grams)	Percentage of Raw Weight
Delayed service			
6-hour holding	1	1450	52.31
	2	1564	53.98
	3	1740	52.89
	4	1379	58.33
	5	1704	56.74
	6	1769	59.42
Average		1601	55.61
18-hour holding	1	1584	52.43
	2	1273	51.68
	3	1695	52.68
	4	1127	49.41
	5	1683	55.62
	6	1519	56.59
Average		1480	53.07
Forced convection	1	1899	62.14
	2	1938	63.70
	3	1899	58.65
	4	1601	63.94
	5	2134	65.31
	6	1901	65.57
Average		1895	63.22
Conventional	1	1638	62.02
	2	1580	66.08
	3	2117	59.98
	4	1458	63.61
	5	1982	69.56
	6	2359	68.75
Average		1856	65.00

Table 30. Average palatability scores of seven judges for six replications of four cooking methods.

Method of Cooking	Animal (Replication)	Aroma	Color of Lean	Flavor of Lean	Flavor of Fat	Juiciness	Tenderness
Delayed service							
6-hour holding	1	5.6	5.1	5.7	5.0	4.6	4.9
	2	4.7	4.4	5.0	4.7	5.3	5.7
	3	4.9	3.9	4.1	4.9	4.6	6.1
	4	5.0	5.3	5.6	5.0	5.6	5.3
	5	5.4	4.1	5.6	4.9	5.1	5.9
	6	4.9	4.7	5.0	5.4	4.7	5.9
Grand average		5.1	4.6	5.2	5.0	5.0	5.6
18-hour holding	1	5.4	5.6	5.1	4.6	4.6	5.4
	2	4.0	3.8	3.8	3.3	4.0	6.2
	3	5.0	3.7	4.3	3.6	4.0	6.1
	4	5.0	4.8	4.0	4.3	4.5	5.5
	5	4.6	4.1	5.0	4.9	4.6	6.4
	6	5.3	5.0	5.4	5.1	4.7	6.1
Grand average		4.9	4.5	4.6	4.3	4.4	6.0
Forced convection	1	4.4	5.1	5.1	5.4	5.1	5.6
	2	4.1	5.7	5.6	4.6	5.4	5.9
	3	4.0	4.9	4.1	4.0	5.6	6.0
	4	4.1	5.7	5.1	5.3	5.6	5.7
	5	4.9	5.3	4.9	5.6	5.7	6.3
	6	4.6	5.7	5.4	5.4	6.0	6.1
Grand average		4.4	5.4	5.0	5.1	5.6	5.9
Conventional	1	4.9	6.3	5.0	4.9	5.4	5.6
	2	5.0	5.8	5.2	5.2	5.7	6.5
	3	4.1	5.4	5.0	4.4	5.4	5.7
	4	4.5	5.8	5.5	4.7	5.3	5.5
	5	4.6	6.3	6.0	5.1	6.0	6.6
	6	4.0	5.3	5.3	5.0	5.7	6.3
Grand average		4.5	5.8	5.3	4.9	5.6	6.0



Table 31. Percentages of press fluid, averages, and standard deviations for six replications of four cooking methods.

Method of Cooking	Animal (Replication)	Determination		Average	Standard Deviation
		1 (%)	2 (%)		
Delayed service					
6-hour holding	1	56.99	59.34	58.17	1.66
	2	64.13	63.16	63.65	0.69
	3	58.70	59.38	59.04	0.47
	4	56.84	61.90	59.37	3.58
	5	64.95	63.74	64.35	0.85
	6	54.44	61.46	57.95	4.96
Average				60.42	2.83
18-hour holding	1	52.58	53.33	52.96	0.53
	2	59.57	58.06	58.82	1.06
	3	55.38	56.38	55.88	0.70
	4	60.22	58.62	59.42	1.13
	5	60.00	55.78	57.89	2.98
	6	59.37	57.89	58.63	1.04
Average				57.27	2.44
Forced convection	1	56.82	53.68	55.25	2.22
	2	64.88	65.00	64.94	0.00
	3	58.43	58.51	58.47	0.00
	4	58.95	63.53	61.24	3.24
	5	62.63	61.70	62.17	0.66
	6	54.95	60.22	57.59	3.73
Average				59.94	3.50
Conventional	1	55.10	54.26	54.68	0.92
	2	62.64	62.50	62.57	0.10
	3	55.44	54.10	54.77	0.94
	4	64.84	62.77	63.81	1.46
	5	65.88	63.63	64.76	1.59
	6	63.44	61.38	62.41	1.45
Average				60.50	4.56



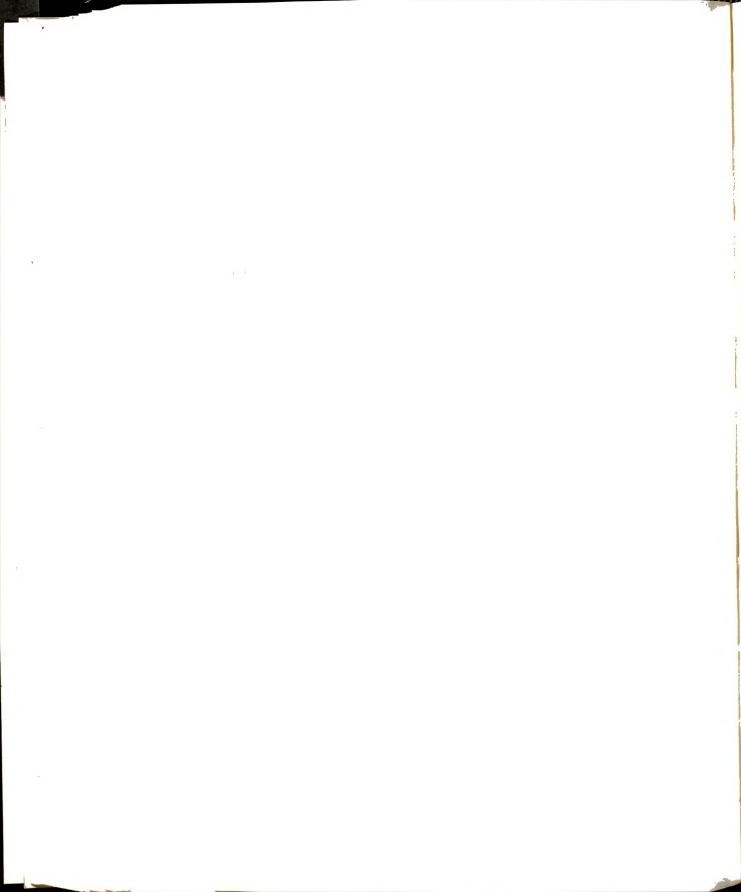


Table 33. Kramer shear-press readings,¹ averages,¹ and standard deviations for six replications of four cooking methods.

Method of Cooking	Animal (Replication)	Determination		Average	Standard Deviation
		1 (%)	2 (%)		
Delayed service					
6-hour holding	1	12.95	14.62	13.79	1.18
	2	12.38	13.28	12.83	0.63
	3	10.45	12.41	11.43	1.39
	4	15.35	15.20	15.28	0.10
	5	14.43	10.16	12.30	3.02
	6	13.41	14.71	14.06	0.92
Average				13.28	1.38
18-hour holding	1	17.88	18.11	18.00	0.14
	2	10.36	10.94	10.65	0.40
	3	12.85	12.37	12.61	0.33
	4	13.73	---	13.73	--
	5	12.69	11.49	12.09	0.85
	6	10.72	11.58	11.15	0.61
Average				13.04	2.66
Forced convection	1	13.81	17.18	15.50	2.38
	2	11.85	11.99	11.92	0.00
	3	12.88	13.08	12.98	0.14
	4	15.66	14.94	15.30	0.51
	5	11.63	14.22	12.93	1.83
	6	14.37	12.35	13.36	1.43
Average				13.67	1.43
Conventional	1	15.43	19.03	17.23	2.54
	2	12.57	13.37	12.97	0.57
	3	13.85	11.94	12.90	1.35
	4	16.03	12.89	14.46	2.22
	5	13.95	12.41	13.18	1.09
	6	15.64	15.64	15.64	0.00
Average				14.40	1.75

¹Expressed in pounds force per gram.



Statistical analyses of the data obtained from the objective measurements and subjective evaluations were calculated using two programs for the CDC 3600 computer at the Michigan State University Computer Center. The RAND Routine - Option 1 (randomized complete block) was used to calculate variance due to treatment and animals. The CORE Routine was used to calculate simple correlations.



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