EFFECT OF DRY AND MOIST HEAT TREATMENTS ON SELECTED MEASUREMENTS FOR EVALUATING THE QUALITY OF BEEF

by 45

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TABLE OF CONTENTS

INTRODUCTION

Differences among data from two or more laboratories studying similar problems related to the production and/or processing of beef often are reported in the literature. Ramsbottom et al. (1945) suggested that lack of uniformity in cooking methods, temperature, and time, as well as differences in muscles used, degree of fatness of the meat, and age of the meat, accounted for the varied results obtained by different investigators.

Ramsbottom et al. (1945), Harrison et al. (1949), and Paul et al. (1955) reported the use of deep fat as a cooking medium for experimental work on beef. Visser et al. (1960) discussed some of the problems encountered in studying degree of doneness of oven-roasted beef and beef cooked in deep fat.

Clark et al. (1955) braised top and bottom round steaks under 10 and 15 p.s.i.g. pressure and at atmospheric pressure to 80° and 112.2°C. The end point temperature to which the meat was cooked, rather than the method of cooking, was important in determining palatability and cooking losses of the steaks. The effects of rate of heat penetration and cooking time were important when the tenderness of deep-fat fried beef steaks and oven-roasted beef roasts was compared (Paul et al., 1952).

None of the studies reviewed was designed specifically to study the effects of heat treatment, or method of cookery, on laboratory measurements used to evaluate the quality of cooked beef.

It is important to know whether there are significant effects attributable to type of heat treatment (cooking medium) on the characteristics of cooked beef. If the cooking medium has significant effects on measurements used to evaluate cooked beef, research workers should know the nature of those effects. Such data exist mainly as by-products of experiments planned to study problems other than the effect of the cooking medium only. The objective of this study was to investigate the effects of dry and moist heat treatments on selected characteristics of cooked beef, to provide a guide for selecting the method of cooking for laboratory experiments with meat.

REVIEW OF LITERATURE

Effect of Heat on Selected Constituents and Characteristics of Beef Muscle

Cooking involves application of heat. The various constituents of skeletal muscle such as muscle fibers, connective tissue, fat, pigments, and precursors of flavor and odor, are affected by heat. Also, certain characteristics of this type of muscle such as moisture content, pH, flavor, tenderness, and juiciness are affected by cooking. The specific effects of heat on muscle constituents and characteristics have been reviewed comprehensively in recent literature (Lowe, 1955; Bunyan, 1958; Rogers, 1966). In general, those effects are applicable to skeletal muscle from most species. Selected studies concerning the effect of heat on beef muscle will be summarized here.

Beef muscle fibers

When beef was cooked to three internal temperatures (Satorius and Child, 1938) beef muscle fiber diameter decreased through coagulation with cooking to 67°C, but did not decrease further with cooking to 75°C. Thus, shrinkage of the fibers attributed to coagulation of the muscle plasma appeared to be complete at 67°C. Also, Ramsbottom et al. (1945) stated that heat denaturation and coagulation of beef fiber proteins cooked for short periods was accompanied by shrinkage and hardening of the fibers.

Tuomy et al. (1963) attributed the initial toughening of beef to heat denaturation of the fiber protein. As internal temperature increased, degree of toughening also increased. Cover et al. (1962) postulated that the toughening reaction could be a tightening of the protein network during denaturation. They suggested that tightening of the protein network occurred when new, stable cross-linkages formed between peptide chains.

The sarcolemma (plasmalemma) is a double-layered membrane that surrounds each muscle fiber (Bendall, 1966). Cover et al. (1957) found that fibers of beef biceps femoris muscle reacted differently to heat than did those of longissimus dorsi muscle. They suggested that the difference in the reactions of the fibers from the two muscles possibly might be attributed to differences in the reactions of the sarcolemmas from the two different muscles.

Connective tissue

The two main types of connective tissue (collagenous and elastic) differ in their response to application of heat. It generally is agreed that the tenderness of collagenous connective tissue is increased by cooking, whereas tenderness of elastic tissue is affected little by the commonly used methods of cooking.

Paul (1963) stated that collagenous connective tissue is solubilized partially or completely by cooking and that the extent of the change depends on the length of the heating period and the internal temperature that is reached in the center of the meat. Irvin and Cover (1959) pointed out that tendering of collagenous connective tissue by the conversion of collagen to gelatin often has been thought to require long cooking in moist heat. However, in their experiment, they found that at least some of the collagenous connective tissue was changed to gelatin even after a relatively short application of dry heat. They suggested that "some of the collagen is more easily affected by heat than was previously supposed." Cover (1943) also used dry heat (oven roasting at 80° and 125°C) to cook beef roasts for long periods of time. She theorized that long cooking (coagulation) time at low temperatures allowed the water of hydration to be released slowly from the beef muscle proteins so that it was used to convert collagen to gelatin.

Elastic connective tissue also is changed by heating, but the changes are not as evident as are those in collagenous connective tissue (Harrison, 1947). The main protein, elastin, is insoluble in hot water, and remains as a clear band throughout the muscle after heating (Andross, 1949).

Harrison (1943) postulated that volume increase in pieces of beef muscle at certain periods of cooking may be partly attributable to the effect of heat on the connective tissue. Her idea was based on data showing an increase in weight during heating of tendon (mainly collagen) and ligamentum nuchae (mainly elastin).

Fat

Fat content also is an important factor in determining the total reaction of a particular muscle to heat (Ritchey and Hostetler, 1964). Thille et al. (1932) explained that in adipose tissue some of the small sacs of collagenous connective tissue burst when heat is applied and the fat contained in them is set free. Other sacs resist the heat of both boiling and roasting until the membrane is transformed into gelatin; then the fat escapes.

Paul (1963) stated that the quantity of ether-extractable material (lipids) in lean tissue increased during cooking. However, Lowe (1955) found that the fat content of beef muscle tissue was the same both before and after cooking. She stated that the fat molecule is so large that it does not seem likely that much infiltration of fat occurs during cooking, particularly since the meat shrinks and soluble constituents are squeezed out.

Ramsbottom et al. (1945) stated that adipose tissue increased in tenderness during cooking.

Pigments

Raw beef muscle contains a relatively large amount of the chief muscle pigment, myoglobin. The depth of color depends on factors such as myglobin concentration, pH of the muscle, and exposure of cut surfaces to the air. The intense red color gradually is changed to a less intense red to pink, then to brown or gray as heat decomposes the myoglobin to hemichrome, a brown pigment (Lowe, 1955). The temperature of cooking affects the degree of conversion of the pigment (Lawrie, 1966). Temperatures of 65° to 70°C are necessary to initiate heat-decomposition of myglobin (Lowe, 1955). Below 65°C myoglobin denaturation may be initiated by enzymatic action or co-precipitation (Lawrie, 1966).

Precursors of beef flavor

Heat is necessary for the production of desirable cooked beef flavor (Hornstein and Crowe, 1964). However, desirable flavor is lost with prolonged heating (Crocker, 1948; Lawrie, 1966). The sweet, salty taste of blood is inherent in raw meat; beef cooked at low temperatures to the rare stage retains most of the salts and sugars, and thus has a taste similar to that of raw meat (Crocker, 1948).

Crocker (1948) postulated that meaty flavor is developed by chemical changes in the amino acids of muscle fibers. Similarly, Hornstein and Crowe (1960 and 1964) attributed the production of meaty flavor to a browning reaction between amino acids and reducing sugars present in the muscle.

Yueh and Strong (1960) and Hornstein and Crowe (1964) found in beef flavor precursors that were liberated by heating. The flavor that was produced by heating those precursors was largely odor, even though it was produced from essentially odorless precursors. Hornstein and Crowe (1964) stated that those precursors were water soluble, and that the insoluble fibers contributed little to meat flavor. Lawrie's (1966) view was that flavor may be produced during cooking by the interaction of fibers and meat juices.

Moisture

It generally is agreed that heating decreases the moisture content of lean beef tissue (Paul, 1963). Lowe (1955) related loss in weight of beef to loss in total moisture, particularly at higher cooking temperatures. Thille *et al*. (1932) found that cooked beef surfaces were drier than the centers of the same roasts; cooked centers were drier than the centers of similar raw roasts.

pH

Griswold (1955) stated that there was little difference between the pH of raw and cooked beef. Harrison *et al*. (1953) found the pH of cooked beef to be slightly higher than corresponding raw beef. Lawrie (1966) also found that heating beef increased pH. This may be attributed to loss of carbon dioxide during heating.

Tenderness

Harrison et al. (1959) stated that tenderness in cooked meat is the total effect of composition of muscle, aging before cooking, heat coagulation of muscle fiber proteins, and the changes that take place in the connective tissues. According to Tuomy et al. (1963), "The reactions that take place during cooking are not well understood in their relationship to the final tenderness of beef." However, they stated that the relative quantities of muscle fibers and connective tissue and their reaction to heat appear to determine the "inherent" tenderness of beef muscle. Differences in composition may explain why muscle responses to cooking differ among animals (Griswold, 1955) and among different muscles in one animal (Cover et al., 1957; Ritchey and Hostetler, 1965).

Harrison et al. (1959) reported that the major effect of heat on tenderness of beef muscles depended on the quantity of connective tissue present. Likewise, Sanderson and Vail (1963) stated that if a large quantity of connective tissue is present in muscle, total tenderness will increase if conditions permit softening of the connective tissue. However, if little connective tissue is present, the effect of heat on the fibers predominates, and the cooked muscle might be less tender. In a study of 25 beef muscles Ramsbottom et al. (1945) found that a decrease in tenderness was associated with denaturation and coagulation of muscle fiber proteins. In contrast, Hamm (1966) stated that tendering of meat during cooking cannot be attributed to tendering of muscle fibers because heat denaturation hardens the fibers and causes tightening of fiber structure. Therefore, tenderness probably results from solubilization of collagen.

Factors Affecting Rate of Heat Penetration

So many factors are involved in the relationship of heat penetration to degree of doneness and other characteristics of cooked meat that it is impossible to attribute the changes that take place during cooking to one factor alone. In cooking, heat is transferred from the heat source to the cooking medium and from the cooking medium to the surface of the meat by various means. In roasting, heat is transferred from the heat source to the air in an oven, and it flows through the air by convection. When hot air comes in contact with the surface of the meat, the heat is transferred to the meat. The surface of the meat next to the rack in the roasting pan receives some additional heat through conduction from the rack. In braising, heat also is conducted to the meat from contact with the cooking pan or with the rack in the pan, but most of the heat is transferred from steam that comes from volatilization of moisture in the covered pan. Pressure-braising involves a method of heat transfer similar to that of braising, except the temperature of the steam is higher because of the increased pressure in the pan. In deep-fat frying, heat is conducted from the pan to the fat; the heat then is transferred through the liquid fat by convection. Next the heat is conducted from the fat to the outer surface of the meat.

In the meat itself heat is transferred gradually by conduction from the outer surface to the center. When heat has been conducted into the meat and the changes in muscle constituents and characteristics reviewed in the previous section have taken place, the meat is "done." Those changes take place only in the parts of the meat to which heat has penetrated. In rare meat, which has a brown-gray surface with the characteristic dark pink or red center (Lowe, 1955), heat has penetrated only a short distance toward the interior of the meat. In well-done meat the heat has penetrated to the center of the piece, and the interior is an even brown-gray (Lowe, 1955).

Internal color at specific stages or degrees of doneness is related to the temperature at the center of the meat (Committee on Preparation Factors, National Cooperative Meat Investigations, 1942). Generally it is accepted that the relation of internal temperature to degree of doneness is more reliable than calculation of min/lb. Various internal end point temperatures for a specific degree of doneness have been suggested by different workers (Morgan and Nelson, 1932; Committee on Preparation Factors, National Cooperative Meat Investigations, 1942; Lowe, 1955; Marshall _et al_., 1960; Visser _et al_., 1960; Gilpin _et al_., 1965; Lawrie, 1966). Usually the temperatures suggested are within the ranges given by Lowe (1955), i.e. 55-65°C, rare; 65-70°C, medium-done; 70-80°C, well-done. However, she stated that stages of doneness are influenced by many conditions; thus, the arbitrary division into rare, medium-, and well-done stages is not always satisfactory.

Thermal conductivity of meat constituents

Heat flows through a mass such as meat from the area of highest heat concentration to the area of least heat by the conduction process (Boelter et al., 1965). The heat penetrates in a one-dimensional direction from particle to particle in its path. The rate at which heat flows, or penetrates, through a solid is measured as the amount of heat (kcal) transferred from the area of most heat to the cooler part of the substance. The quantity of heat is directly proportional to the cross-sectional area of the substance through which it passes, to the time necessary for heat to penetrate, and to the change in temperature of the sample. Quantity is inversely related to the distance between the locations of highest heat and lowest heat. Thus,

$$\text{Conductivity (k)} = \frac{\text{kcal}}{(\text{cm}^2)\ (\text{sec})\ ({}^{\circ}\text{C/cm})}$$

where cm^2 is the cross-sectional area of the planes of highest and lowest heat concentrations, sec. is time, and °C/cm is the change in temperature per unit of distance between the "planes," or temperature gradient (Lentz, 1961). The thermal conductivity constant (k) is specific for the type of substance being tested.

Thermal conductivity constants have been calculated for many substances, including ice, water, and various vegetable and animal foods. Thermal conductivity values are quoted in recent literature, in Btu/(hr) (ft) (°F), by Hill et al. (1967) and Woodams and Nowrey (1968).

The first mathematical formulas for the prediction of heat conductivity through a mass of a given substance were based on measurements of the heat conductivity of homogeneous masses (Boelter _et al_., 1965). Recent work by researchers interested in heat transfer in the freezing of foods, and of meat in particular, has recognized that prediction of heat conductivity through a heterogeneous mass like meat cannot be done simply by measuring the thermal conductivity of a single substance like protein, ice, or water (Lentz, 1961). Mathematical models that have been constructed as a theoretical means of predicting the behavior of meat undergoing transient heat processes have produced predictions that are in rather close agreement with experimental evidence (Hill _et al_., 1967). The experimenters have taken into consideration not only the heterogeneity of the meat, but also the effect of certain conditions such as the temperature of the meat, moisture content, and direction of heat transfer, parallel or perpendicular to the fiber (Lentz, 1961; Miller and Sunderland, 1963; Hill _et al_., 1967). All meats have common thermal conductivity characteristics (Hill _et al_., 1967). Heat conductivity of beef muscle constituents only is reviewed here.

Heat conductivity of beef muscle fibers. Hill _et al_. (1967) and Lentz (1961) reported that thermal conductivity of muscle fibers was much greater when measured parallel to the grain (longitudinal fiber axis) than when measured perpendicular to the grain. Thille _et al_. (1932) suggested that size and arrangement of fibers might influence rate of heat penetration. Lentz (1961) stated that the conductivity of beef did not appear to be related directly to moisture or fat content, but was dependent on the direction of the fibers. However, Miller and Sunderland (1963) and Hill et al. (1967) found that thermal conductivity values were higher in beef with higher moisture content. Awbery and Griffiths (1932) found that when thermal conductivity of raw beef was measured at various temperatures, thermal conductivity values decreased as the mean temperature of the meat increased. Hill et al. (1967) reported that at temperatures below freezing, conductivity was related inversely to temperature, but at temperatures above freezing, conductivity increased slightly as temperature increased.

Marshall et al. (1960) measured the temperatures at various positions in pieces of oven-roasted beef. They found that temperatures at different positions in individual roasts differed as much as 60°F after the first two to three hours of slow cooking, becoming more nearly uniform as cooking proceeded. When final internal temperature was reached, "the variation was approximately 20°F among the different roasts." The Committee on Preparation Factors, National Cooperative Meat Investigations (1942) stated that under certain conditions, as in very undernourished animals, lean meat may transmit heat more slowly than adipose tissue.

Thille et al. (1932) found that at the beginning of heating muscle fibers conducted heat faster than the other constituents of beef muscle, and that the rate of conductivity slowed down at approximately 50°C. Since some denaturation of fiber proteins takes place at temperatures below 60°C (Lowe, 1955; Hamm, 1966) and since coagulation of proteins is an endothermic process (Lowe, 1955; Visser <u>et</u> <u>al</u>., 1960), the abrupt slow-down of conduction and resultant flattening of related time-temperature curves probably are related to the absorption of heat that takes place as meat proteins are coagulated. Cover (1937) suggested that the flattening of time-temperature curves for beef at internal temperatures between 65° and 75°C was related to absorption of heat and liberation of water of hydration. Cover <u>et</u> <u>al</u>. (1957) also reported flattening of time-temperature curves between 65° and 70°C. Marshall <u>et</u> <u>al</u>. (1960) explained that the endothermic process caused less heat to be available for raising the internal temperature of beef roasts; thus, time-temperature curves suddenly flattened.

<u>Heat</u> <u>conductivity</u> <u>of</u> <u>beef</u> <u>fat</u>. Thille <u>et</u> <u>al</u>. (1932) studied the rate of heat conduction through fat. Heat conductivity through balls of solid beef fat was extremely slow with the first application of dry heat. As heating continued and the fat softened and neared its melting point, the rate of heat penetration increased. They suggested that melting of the surface fat increased the rate of heat penetration throughout the entire piece of meat. They further postulated that interior fat retards total heat penetration in muscle, because it remains solid through much of the cooking period. They concluded that fat is a poor conductor of heat when it is solid, but a good heat conductor when it melts. Thus, the location of the fat in a beef roast is important to the rate of heat penetration. The Committee on

Preparation Factors, National Cooperative Meat Investigations (1942) agreed that fat conducts heat more slowly than lean tissue but the rate of conduction is more rapid when the fat melts.

Siemers and Hanning (1953) stated that the heat of fusion of fat and its conductivity were major factors in reducing the rate of heat penetration in small samples of suet-covered beef. Thermal conductivity values for beef fat and lean beef are presented in table form in recent literature (Lentz, 1961; Miller and Sunderland, 1963; Hill _et al_., 1967; Woodams and Nowrey, 1968). Lentz (1961) quoted Cherneeva's values for conductivity of beef fat (7% water) of 0.487 kcal/(cm^2)(sec)(^{o}C/cm), and for conductivity of lean beef (74.5% water) of 1.14 kcal/(cm^2)(sec)(^{o}C/cm). Both values were measured at 0^{o}C. Cherneeva's values are similar to the values obtained by other researchers.

Heat conductivity of connective tissue. Connective tissue seems to influence total heat conductivity of meat (Thille _et al_., 1932). Siemers and Hanning (1953) found that the presence of connective tissue in small samples of suet decreased the rate of heat transfer in the suet. They reported that intact strands of connective tissue inhibited heat transfer more than connective tissue that had been minced with suet. Also, they reported that the heat conductivity of "rectangular volumes" of connective tissue was approximately the same as the heat conductivity of equal volumes of suet.

Cooking medium

Temperature of the cooking medium influences rate of heat transfer into the meat (Lentz, 1961). The higher the temperature of the medium in contact with the surface of the meat, the more rapidly heat will penetrate into the interior (Lowe, 1955). The results of several experiments showed that beef cooked at high temperatures takes less total time and less time per pound than that cooked at lower temperatures (Committee on Preparation Factors, National Cooperative Meat Investigations, 1942; Cover, 1943; Siemers and Hanning, 1953; Hunt et al., 1963; Weir et al., 1963).

Harrison (1943) stated that the specific heats of water, steam, oil, and air are 1, 0.48, 0.41-0.43, and 0.24, respectively. She found that roasts cooked in fat took less total cooking time than those cooked in air. However, roasts cooked in steam took longer to cook than was expected. She explained that the slightly longer distances to the centers of the steam-cooked roasts seemed to have a greater effect on cooking time than did the small difference in specific heat.

Visser et al. (1960) stated that liquid fat conducts heat six times faster than air. Paul et al. (1952) postulated that the rapid penetration of heat into meat cooked in deep fat coagulated the protein in unaged samples before rigor set in. In contrast, the slow rate of heat penetration into similar samples that were roasted in air induced the development of rigor. Cover (1941a) reported that heat penetration in meat cooked in water was much more rapid than in meat cooked in air in an oven. She suggested that the faster rate of heat penetration could be attributed to the fact that water is a better conductor of heat than air.

Rate of heat penetration in meat cooked by moist heat, such as in braising in a covered pan, is much more rapid than in meat cooked by some dry heat methods such as in roasting in an uncovered pan. Morgan and Nelson (1926) and Harrison et al. (1953) found that beef cooked in covered roasting pans took less cooking time than uncovered roasts. Hood (1960) stated that roasts cooked by a dry-heat method of cooking required a longer time to reach the desired internal temperature than those cooked by a moist-heat method.

Size and shape of the piece of meat

Weight, surface area, and shortest distance to the center of the thickest portion of a piece of meat affect total cooking time (Lowe, 1955). The Committee on Preparation Factors, National Cooperative Meat Investigations (1942) stated that the longer the distance that heat must travel to get to the center of the thickest part of a piece of meat, the greater the total cooking time. Ramsbottom et al. (1945) pointed out that the length of cooking time necessary to reach a specified internal temperature depends on the weight and thickness of a piece of meat. Bramblett and Vail (1964) found that small muscles required less total cooking time than larger muscles. Jacobson and Fenton (1956) reported that variations in cooking time were markedly decreased when roasts were uniform in size and shape.

Initial internal temperature

The rate of heat penetration is influenced by the temperature at the center of the meat when cooking begins (Committee on Preparation Factors, National Cooperative Meat Investigations, 1942; Lowe, 1955; Lentz, 1961). The Committee on Preparation Factors, National Cooperative Meat Investigations (1942) and Lowe (1955) agreed that the lower the initial internal temperature, the longer the total time required to cook the meat. Lowe (1955) added that meat that is frozen when cooking begins requires a long cooking time because part of the heat must be used to melt the ice before the temperature of the meat can rise above the freezing temperature.

Effect of Rate of Heat Penetration on Selected Characteristics of Beef

The relationship of length of cooking time to temperature of the cooking medium has been discussed. Cooking time also is related to the degree of doneness (internal end point temperature). This relationship affects the condition of the muscle fibers and connective tissue, which, in turn, has important effects on palatability characteristics of beef.

Fibers and connective tissue

Bramblett and Vail (1964) stated that both time and cooking temperature affect shrinkage of connective tissue and fibers. Hay _et_ _al_. (1953) postulated that shrinkage and change of shape of pieces of beef may be attributed partly to changes in the connective tissue that take place during long heating at low temperatures or for short heating periods at high temperatures. Lawrie (1966) suggested that time is more important than temperature for softening of collagenous connective tissue, whereas temperature is more critical in toughening of muscle fibers.

Cover (1943) cooked beef at extremely low temperatures for long periods of time. She found that a large amount of the connective tissue seemed to be changed completely from its native "hard, tough" state to a "moist, viscous state." She suggested that long cooking time is related to effective conversion of collagen to gelatin. Also, she found that muscle fibers that had been cooked for long periods of time at low temperatures were tenderized by the long heating period.

Bunyan (1958) explained that the temperature at which coagulation of the protein begins is dependent on the rate of cooking. Andross (1949) stated that heat-coagulated proteins form a layer on the surface of beef roasts; the faster the rate of heat penetration, the faster the formation of the layer. She explained that rapid formation of the layer on the surface of the meat inhibits loss of fluid, and thus lowers the percentage shrink.

Palatability

Tenderness. Many researchers have found that rate of heat penetration affects tenderness of cooked beef. Usually results indicate that slow heat penetration (low cooking temperatures for long periods of time) produces more tender beef than rapid heat penetration (Morgan and Nelson, 1926; Cover, 1937, 1938, 1941a,b, 1943; Lowe, 1955; Bramblett et al., 1959; Hood, 1960; Bramblett and Vail, 1964).

Cover (1937, 1941b) reported that flattening of heat-penetration curves seemed to be closely related to increase in tenderness of beef roasts. However, in comparing tenderness of broiled bottom round and loin beef steaks, Cover et al. (1957) found that marked flattening of heat penetration curves was not accompanied by a significant increase in tenderness. They added that under the conditions of the study, heat penetration did not appear to be associated with tenderization of broiled steaks. Tuomy et al. (1963) stated that neither total cooking time nor heating rate affected tenderness of cylinders of beef cooked at temperatures below 180°F. It appeared to them that the final tenderness of their samples was determined only by the "inherent tenderness" of the meat and the end point temperature to which the meat was cooked. However, at cooking temperatures above 180°F, the degree of tenderness depended on both time and cooking temperature.

Flavor. Lawrie (1966) suggested that both temperature and length of cooking time influence the nature and intensity of flavor. He stated that high temperature and absence of moisture at the surface of a piece of meat intensify flavor. Hood (1960) found that beef cooked for a long period of time had significantly higher flavor scores than beef cooked for a shorter time. However, Bramblett et al. (1959) found no significant difference between flavor scores of meat cooked at 63°C for 30 hours and those for meat cooked to the same internal temperature at 65°C for 18 hours.

Juiciness. Researchers do not agree about the effect of rate of heat penetration on juiciness of cooked beef. Several workers have reported that rapid heat penetration was accompanied by a decrease in juiciness (Morgan and Nelson, 1926; Siemers and Hanning, 1953; Hood et al., 1955; Lowe, 1955; Cover et al., 1957; Bramblett and Vail, 1964). In contrast, Hood (1960), Visser et al. (1960), and Lawrie (1966) stated that beef cooked by long, slow methods was juicier than comparable beef cooked more rapidly.

Cooking losses

In general, meat that is scored low for juiciness also has high total cooking losses (Morgan and Nelson, 1926; Thille et al., 1932; Cover, 1941b; Paul et al., 1952; Harrison et al., 1953; Siemers and Hanning, 1953; Hood et al., 1955; Cover et al., 1957; Bramblett and Vail, 1964). Conversely, juicy meat has been associated with low total cooking losses (Andross, 1949; Bramblett et al., 1959; Hood, 1960; Lawrie, 1966). Visser et al. (1960) noted that slow heat penetration in meat was accompanied by low cooking losses, whereas meat cooked at a faster rate had higher total cooking losses. However, they pointed out that meat with the lowest cooking losses did not always have the highest juiciness score.

Degree of doneness

As stated previously, heat changes the red muscle pigment, myoglobin, to brown hemichrome, and the amount of conversion of the pigment is related to changes in the apparent degree of doneness of cooked beef. Lawrie (1966) stated that the temperature of cooking affects the degree of conversion of pigments. Bunyan (1958) said that rate of cooking influences conversion of myoglobin; it affects the temperature at which myoglobin starts to coagulate. Lowe (1955) pointed out that the slower the rate of heat penetration, the more well done meat appears at a specific internal temperature. In a study of the effect of extremely low rates of heat penetration on tenderness of beef, Cover (1943) obtained rare beef at an internal temperature of 58-59°C when cooked in an 80°C oven, but at 63°C when cooked more rapidly in a 125°C oven. Thus, her findings also indicated that slow heat penetration produced beef that appeared more well done than that cooked rapidly. Conversely, Visser et al. (1960) reported that beef roasted in the oven at 300°F, 148.9°C, (slow heat penetration) appeared less well done at a given internal temperature than beef cooked in deep fat (rapid heat penetration).

EXPERIMENTAL METHOD

Twelve U. S. Good beef top rounds (18 to 22 lbs) were purchased from a local wholesale meat company. The fat was trimmed from each top round (Fig. 1), and the semimembranosus muscle (SM) was cut into four pieces (Fig. 2) as nearly alike as possible in

Fig. 1. Face of a beef round. Semimembranosus muscle is the upper-right section of the round.

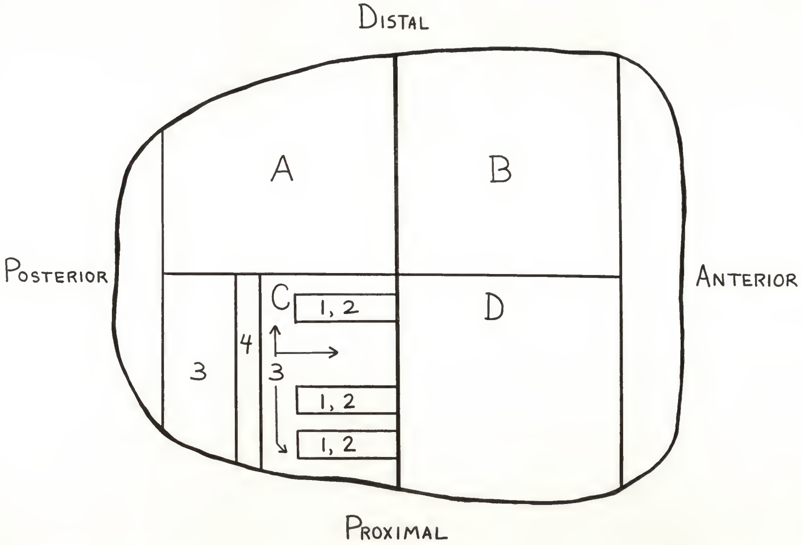

C04229

Fig. 2. Plan for sampling semimembranosus muscle.

A, B, C, D -- Portions of the muscle of similar weight and shape, each sampled as indicated in C.

1 -- Cores ($\frac{1}{2}$-in.) for shear value
2 -- Water-holding capacity (the center portion of each core)
3 -- Cubes ($\frac{1}{2}$-in.) for palatability scores were cut from area 3. Press fluid yield, pH, total moisture, and Gardner color-difference values were determined on samples of ground meat prepared from that remaining after the cubes for palatability evaluation were removed.
4 -- Slice for panel evaluation of degree of doneness.

Raw sample -- Ends of each muscle were used for: Cores ($\frac{1}{2}$-in.) for shear value; remaining muscle ground for determination of total moisture, pH, and Gardner color-difference values.


Distal
Posterior
Anterior
Proximal
A
B
C
D
1, 2
1, 2
1, 2
3
4
3

weight (approximately 820 g) and shape (11 x 11.5 x 6.5 cm). Each piece was wrapped in aluminum foil (gauge 0.0015) and frozen and stored at -17.8°C (0°F) in a household still-air freezer from 2 to 14 weeks.

Before cooking each wrapped piece was thawed for approximately 5 hours at room temperature (approximately 78°F) and an additional 19-20 hours in a refrigerator at 45°F. The internal temperature of thawed pieces was approximately 5 ± 2°C (Table 5, Appendix).

The design followed to cook and evaluate the effect of four heat treatments, i.e. cooking mediums, on pieces of SM was an incomplete block. There were 24 cooking periods (blocks) with two pieces, randomized by section of muscle, cooked at each period (Table 1).

Heat Treatments

All pieces were cooked to an end point temperature of 70°C (158°F) in the center. One-fourth of the pieces were deep-fat fried (DF). Each piece was placed on a rack in an electric deep fat cooker, covered with cottonseed oil preheated to 105°C (221°F), and held at 100 ± 2°C (212 ± 1°F) until the end point temperature was reached. After the cottonseed oil had been used once, it was filtered through four layers of cheesecloth and refrigerated until needed again. After the second use, the used oil was discarded, and only fresh oil was used the next time. One-fourth of the pieces were oven roasted (OR), uncovered on a rack in a shallow roasting pan, in a rotary hearth gas oven at

Table 1. Experimental design.[a]

Round	Blocks (Evaluation period)	Treatments and section of semimembranosus			
I	1	T_3	A	T_1	B
	2	T_2	C	T_4	D
II	3	T_1	A	T_4	B
	4	T_3	C	T_2	D
III	5	T_2	A	T_3	B
	6	T_3	C	T_4	D
IV	7	T_2	A	T_4	B
	8	T_2	C	T_1	D
V	9	T_3	A	T_1	B
	10	T_1	C	T_4	D
VI	11	T_4	A	T_3	B
	12	T_1	C	T_4	D
VII	13	T_2	A	T_1	B
	14	T_4	C	T_2	D
VIII	15	T_1	A	T_3	B
	16	T_3	C	T_2	D
IX	17	T_1	A	T_2	B
	18	T_4	C	T_2	D
X	19	T_4	A	T_3	B
	20	T_3	C	T_1	D
XI	21	T_1	A	T_4	B
	22	T_2	C	T_3	D

Table 1. (concluded)

Round	Blocks (Evaluation period)	Treatments and section of semimembranosus			
XII	23	T_1	A	T_2	B
	24	T_4	C	T_3	D

[a]The plan of Cochran and Cox (1957), plan 11.1, p. 471, repeated for a total of 24 blocks, 12 replications. t=4, k=2, r=12, b=24.

A, B, C, D -- Section of semimembranosus as designated in Fig. 1.

T_1 -- Deep-fat fried (DF)

T_2 -- Oven-roasted (OR)

T_3 -- Braised, atmospheric pressure (OB)

T_4 -- Braised, 10 p.s.i.g. (PB)

300°F (148.9°C). One-fourth of the pieces were oven braised (OB) at atmospheric pressure, on a rack in a Pyrex baking dish containing 30 ml tap water and covered with aluminum foil, in a rotary gas oven maintained at 300°F (148.9°C). The remaining one-fourth of the pieces were pressure braised (PB), with 30 ml water in a pressure frypan equipped with both a thermocouple and a thermometer, at 10 p.s.i.g. (115°C, 239°F).

Rate of Heat Penetration

A centigrade thermometer was inserted into the midportion of each piece of SM muscle for treatments DF, OR, and OB. The time required for each 5°C rise in internal temperature from initial to end point temperature was recorded. An iron-constantan thermocouple was inserted into the midportion of the PB pieces, the cover of the pressure frypan adjusted, and the thermocouple then connected to a Leeds and Northrup potentiometer which gave direct temperature readings in degrees Fahrenheit (Fig. 3). Steam was allowed to escape from the frypan for one minute to evacuate the air before the weight was placed on the vent. The time required for each 9°F (5°C) rise in internal temperature from initial to end point temperature was recorded.

Cooking Losses, pH, and Shear Values

Percentage total cooking losses was determined for all pieces of SM. In addition, volatile and dripping losses were measured for OR pieces.

The method described by Rogers et al. (1967) was used to determine pH of a distilled-water-ground-muscle slurry (Fig. 2). To obtain shear values, three ½-in. cores were cut with the grain of the tissue (Fig. 2) and sheared on a Warner-Bratzler shearing apparatus with a 25 lb dynamometer. Duplicate readings were made on each core.

Press Fluid Yield, Water-holding Capacity, and Total Moisture

Duplicate samples (25 g) of ground meat (Fig. 2) were pressed in a Carver laboratory press according to a standardized time-pressure schedule with a maximum pressure of 4,000 p.s.i.g.:

Fig. 3. Thermocouple inserted into center of semimembranosus muscle in pressure frypan, and connected to a potentiometer.

Minutes	Pressure (lb)
1	5,000
2	7,500
3	10,000
5	10,000
7½	12,500
10	15,000
11	16,000
15	16,000

The press fluid was collected in centrifuge tubes, and the volume of total fluid, serum, and fat was measured to the nearest 0.1 ml.

Water-holding capacity (WHC), Fig. 2, was measured on the center portions of the three cores from each sample according to the method described by Miller and Harrison (1965). Percentage total moisture (TM) was determined by drying 10-g samples of ground muscle (Fig. 2) in a C. W. Brabender Semi-Automatic Rapid Moisture Tester for 60 min. at 121°C.

Gardner Color-Difference Values and Palatability Factors

Ground meat (approximately 30 g), Fig. 2, was packed into each of two plexiglas cells in a standardized manner to avoid reflectance errors. Rd (reflectance), a+ (redness), and b+ (yellowness) of ground meat was measured on a Gardner Color Difference Meter. The instrument was standardized using a satin finish ceramic tile with calculated values of: 15.53 (Rd), +9.33 (a+), and +13.10 (b+).

Desirability of flavor, intensity of juiciness and tenderness, apparent degree of doneness, and over-all acceptability of each piece were scored by a laboratory panel of nine members on a 1- to 7-point scale (Form 1, Appendix). Samples ($\frac{1}{2}$-in. cubes of cooked muscle) were presented to the judges each day in small covered casserole dishes within 15 minutes after the meat had been removed from the oven. The temperature of the samples was room temperature (approximately 78°F). There was a sufficient number of cubes so that each judge could select at random and evaluate two cubes of muscle for each heat treatment. Scores for tenderness were based on the number of chews necessary to completely masticate the sample. Each judge rated a slice of muscle placed under a MacBeth Skylight as rare, medium-, or well-done (Fig. 2). Instructions for sensory evaluation were given to each judge before the first evaluation period (Form 2, Appendix).

Measurements on Raw Meat

To provide a reference point on which to base the effect of the heat treatments on the muscle, selected measurements were made on raw muscle from each round (Fig. 2) by the methods used for cooked muscle. Total moisture and Gardner color-difference values (Rd and a+) were measured on duplicate samples of ground meat and pH on ground meat slurries. Warner-Bratzler shear values were measured on three $\frac{1}{2}$-in. cores of muscle.

Statistical Analysis

Data for each measurement made to evaluate cooked and raw muscle samples were analyzed by analysis of variance, as for an incomplete block design (Cochran and Cox, 1957), to study differences attributable to heat treatments. Data were subjected to the following analysis of variance:

Source of Variation	d/f
Blocks (unadjusted)	23
Treatments (adjusted)	3
Intra-block Error	21
Total	47

When significant F-values occurred, least significant differences (LSD) at the 5% level were calculated. Also, correlation coefficients were determined to study relationships among measurements within each heat treatment.

RESULTS AND DISCUSSION

The results of this study indicate that it is important for meat researchers to consider the type of heat treatment (cooking medium) when planning experiments in which meat is to be cooked.

Initial Weight, Shape, and Temperature of Muscle Pieces

An effort was made to have all pieces of muscle used in this study as nearly alike as possible in both weight and shape. Analysis of variance indicated no significant differences among weights of the pieces (Table 2). Data for shape, or volume (length times width times height), of the pieces were not analyzed statistically. Irregularities in the shape of several of the top rounds, particularly at the posterior end, may account for some relatively low volume measurements (Table 5, Appendix).

Table 2. Means, F-values, and LSDs attributable to heat treatment for objective and organoleptic measurements.

Measurement	Heat treatment				F-value	LSD[a]
	OR(T_2)	OB(T_3)	DF(T_1)	PB(T_4)		
Initial weight, g	818.9	826.1	818.1	809.7	0.56	
Initial temperature, °C	3.2	4.3	4.8	* 7.1	4.04*	1.49
Rate of heat penetration, min/5°C	7.2	6.8	* 4.6	* 3.0	122.60**	0.49
Cooking time, total, min	101.2	94.7	* 65.6	* 42.9	115.19**	7.08
min/lb	56.0	52.0	* 36.6	* 24.1	97.45**	4.25
Cooking losses, total, %	23.5	* 27.9	28.7	* 33.2	35.84**	2.23
Total moisture, %	64.0	* 61.1	60.9	59.6	9.83**	1.87

Table 2. (continued)

Measurement	Heat treatment				F-value	LSD^{a}
	OR(T_2)	OB(T_3)	DF(T_1)	PB(T_4)		
Press fluid yield, ml/25 g	8.5	7.5	7.5	6.6	11.71**	0.73
WHC^{b}	0.64	0.61	0.57	0.55	6.28**	0.04
Shear value, lb/½-in. core	8.8	9.7	9.9	8.8	1.10	
pH	5.63	5.61	5.64	5.66	0.02	
Gardner color-difference						
Rd	22.00	21.08	21.03	20.26	0.41	
a+	7.31	6.92	6.75	6.81	0.20	
b+	12.77	11.79	12.25	12.13	0.09	
Organoleptic scores						
Flavor^{c}	5.8	5.6	5.7	5.6	0.76	
Tenderness^{c}	5.2	5.2	5.0	5.4	0.83	
Juiciness^{c}	5.8	5.3	5.0	4.5	6.49**	0.66

Table 2. (concluded)

Measurement	Heat treatment OR(T_2)	 OB(T_3)	 DF(T_1)	 PB(T_4)	F-value	LSD[a]
Over-all acceptability[c]	5.6	5.4	5.2	5.1	1.72	
Apparent degree of doneness[d]	2.2	2.9	2.8	2.7	4.40*	0.42

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

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

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

[d] 1 - rare, 2 - medium-done, 3 - well-done.

OR - Oven-roasted; OB - Braised, atmospheric pressure; DF - Deep-fat fried; PB - Braised, 10 p.s.i.g.

* $P < 0.05$.

** $P < 0.01$.

The mean initial internal temperature of PB pieces was higher ($P < 0.05$) than the mean temperatures of the pieces given the other heat treatments (Table 2). Abnormally high room temperatures on some days when meat was thawed for use in treatment PB resulted in several unusually high initial temperatures (Table 5, Appendix). This may explain, in part, the significant difference between the mean initial temperatures of PB and the other heat treatments.

Effect of Heat Treatment on Objective Measurements

Rate of heat penetration

Rate of heat penetration to the center of the pieces of muscle was affected significantly ($P < 0.01$) by the heat treatment (Table 2). Mean values for the minutes required for the temperature at the center of the pieces of muscle to rise 5°C indicated that each heat treatment differed ($P < 0.05$) from every other treatment, except that the two oven treatments (OR and OB) did not differ significantly from each other. The average rate of heat penetration was faster ($P < 0.05$) in PB pieces than in pieces given any of the other treatments. The order of the average rate of heat penetration in the other treatments was $DF < OB < OR$.

Time-temperature curves (Fig. 4) and data in Table 6 (Appendix) present a detailed picture of the effects of the four heat treatments on the rate of heat penetration to the center of the pieces of muscle. Treatments PB and DF caused heat to penetrate the muscle at a fairly constant rate after an internal

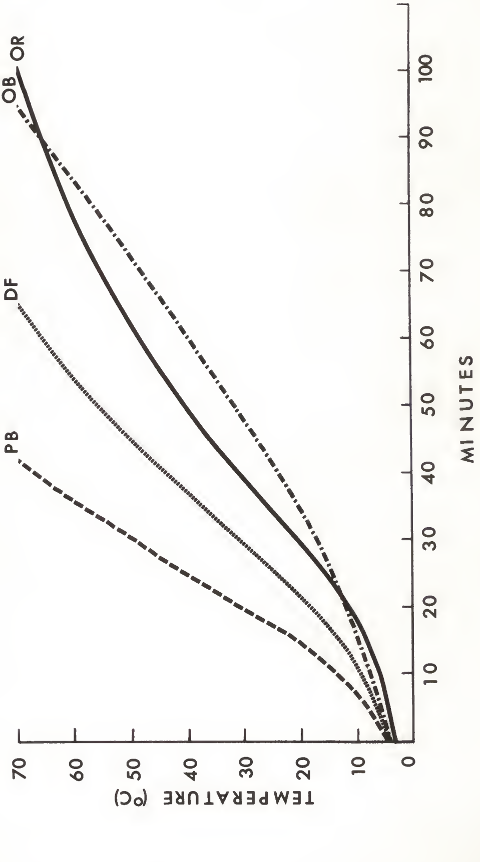
Fig. 4. Rate of heat penetration and total cooking time for semimembranosus muscle heated to 70°C in four cooking mediums.

PB - Braised, 10 p.s.i.g.

DF - Deep-fat fried

OB - Braised, atmospheric pressure

OR - Oven-roasted


TEMPERATURE (°C)
0
10
20
30
40
50
60
70
MINUTES
10
20
30
40
50
60
70
80
90
100
PB
DF
OB
OR

temperature of 10°C was reached; above 10°C the rate of heat penetration was faster than it was below that temperature. In OB pieces the rate of heat penetration was relatively constant after an internal temperature of 25°C was reached. Heat penetrated OR pieces most rapidly between internal temperatures of 10° and 50°C, slowing down slightly between 40° and 50°C. After 88 minutes of cooking, the internal temperature of both OB and OR pieces was approximately 65°C. Thereafter, the rise in temperature of OR pieces slowed down.

Other workers have reported data on heat penetration in beef similar to the data obtained in this study. In comparing oven roasting to pressure braising, Clark and Van Duyne (1949) also found that heat penetration in pressure-braised beef was more rapid and at a more constant rate than that in oven-roasted beef. Harrison (1943) stated that in mediums where heat penetration was rapid, the rate of temperature rise at the center of a piece of beef was approximately the same throughout the entire cooking period.

Time-temperature curves for beef deep-fat fried at 100°C and oven roasted at 300°F presented by Visser et al. (1960) were similar to those of this study. Also, both Harrison (1943) and Visser et al. (1960) reported a decrease in rate of heat penetration in oven-roasted beef at an internal temperature of approximately 50-55°C.

Rate of heat penetration appeared to be related to the initial internal temperature of the muscle (Table 2; Tables 5 and 6, Appendix), i.e. the lower the initial internal temperature, the slower the heat penetration. However, correlation coefficients (Table 3) for initial temperature vs rate of heat penetration were low except for OR pieces, where r = -0.72**. No significant relationship was found between initial temperatures and rates of heat penetration in DF, PB or OB pieces (Table 3). Hill et al. (1967) stated that the thermal conductivity of uncooked beef muscle fibers increases slightly as internal temperature (above $32^{o}F$) increases, and that at temperatures below $32^{o}F$ thermal conductivity varies inversely with temperature. However, they found that at $46.2^{o}F$ ($8^{o}C$) the thermal conductivity of pieces of canner and cutter grade inside round of beef (1.4% fat) was slightly higher than that at $63.4^{o}F$ ($17^{o}C$); there was faster heat penetration at a lower temperature. Although the temperatures at which Hill et al. (1967) measured thermal conductivity were higher than the mean initial temperature of the OR pieces in this study, the relationship of thermal conductivity to temperature in that instance is similar to the inverse relationship shown by the significant negative correlation (rate of heat penetration vs initial internal temperature) for OR pieces in this study.

Cooking time

Cooking time, on the basis of both total min and min/lb, was affected ($P < 0.01$) by heat treatment (Table 2). As might be expected, the effect of heat treatment on cooking time followed the same pattern as the effect of heat treatment on rate of heat penetration. Cooking time for each heat treatment differed ($P < 0.05$)

Table 3. Correlation coefficients for selected paired variates on the basis of heat treatment.

Paired variates	r-values[a]			
	Heat treatment			
d/f = 10	OR(T_2)	OB(T_3)	DF(T_1)	PB(T_4)
Initial temperature, °C, vs:				
Cooking time,				
total, min	-0.67*	-0.20	0.24	-0.28
min/lb	-0.65*	-0.20	0.12	-0.31
Cooking losses,				
total, %	-0.14	0.14	-0.37	-0.35
Rate of heat penetration, min/5°C	-0.72**	-0.20	0.24	-0.33
Rate of heat penetration, min/5°C, vs:				
Cooking time,				
total, min	0.98**	1.00**	1.00**	0.95**
min/lb	0.96**	0.91**	0.94**	0.96**
Cooking losses,				
total, %	0.36	0.17	0.40	0.91**
Total moisture, %	0.22	-0.21	-0.37	-0.66*
Press fluid yield, ml/25 g	-0.18	-0.20	-0.26	-0.78**
WHC[b]	-0.32	-0.07	-0.38	-0.51
pH	-0.06	-0.29	-0.24	0.06
Shear, lb/½-in. core	-0.16	-0.27	-0.04	0.10
Color-difference				
Rd	-0.20	0.05	-0.28	0.25
a+	0.25	0.01	0.42	0.18
b+	-0.55	-0.19	-0.13	0.24
Flavor score	0.10	-0.48	0.30	0.02
Tenderness score	0.32	0.30	0.40	-0.33
Juiciness score	-0.21	0.09	-0.37	-0.63*
Over-all acceptability	0.19	0.08	0.44	-0.46
Apparent degree of doneness score	-0.63*	-0.14	-0.27	0.79**

Table 3. (continued)

Paired variates	r-values^{a}			
	Heat treatment			
d/f = 10	OR(T_2)	OB(T_3)	DF(T_1)	PB(T_4)
Total moisture, %, vs:				
Cooking time,				
total, min	0.14	-0.21	-0.37	-0.63*
min/lb	0.16	-0.16	-0.35	-0.61*
Cooking losses, total, %	0.42	-0.18	0.11	-0.46
Press fluid yield, ml/25 g	0.50	0.18	0.56	0.74**
pH	0.71**	0.32	-0.35	-0.13
Press fluid yield, ml/25 g vs:				
pH	0.60*	0.33	-0.58*	-0.32
Cooking time,				
total, min	-0.31	-0.20	-0.26	-0.77**
min/lb	-0.34	-0.05	-0.21	-0.75**
Cooking losses, total, %	0.01	-0.44	-0.16	-0.72**
Shear, lb/$\frac{1}{2}$-in. core, vs:				
pH	0.65*	0.53	0.57*	0.70*
Tenderness score	-0.81**	-0.51	-0.40	-0.82**
Juiciness score vs:				
Cooking time,				
total, min	-0.26	0.09	-0.37	-0.66*
min/lb	-0.29	0.23	-0.33	-0.64*
Cooking losses, total, %	-0.70*	-0.09	-0.02	-0.81**
Total moisture, %	-0.65*	0.25	-0.24	0.21
Press fluid yield, ml/25 g	0.05	0.26	-0.13	0.54
WHC^{b}	0.44	0.62*	-0.34	-0.08

Table 3. (concluded)

Paired variates	r-values[a]			
	Heat treatment			
d/f = 10	OR(T_2)	OB(T_3)	DF(T_1)	PB(T_4)
Over-all acceptability score vs:				
Flavor score	0.73**	0.72**	0.54	0.24
Tenderness score	0.70*	0.47	0.94**	0.86**
Juiciness score	-0.14	0.39	-0.03	0.86**
Apparent degree of doneness score	0.02	0.17	-0.40	-0.54
Cooking losses, total, %	-0.25	0.15	0.56	-0.75**
Shear, lb/½-in. core	-0.79**	-0.52	-0.23	-0.80**
Apparent degree of doneness score vs:				
Cooking losses, total, %	-0.08	-0.07	0.21	0.82**
Flavor score	0.01	0.22	-0.74**	-0.05
Tenderness score	-0.05	0.43	-0.21	-0.27
Juiciness score	0.04	-0.35	0.16	-0.57*
Color-difference				
Rd	0.11	-0.07	-0.23	0.22
a+	0.17	0.42	-0.46	0.26
b+	0.09	0.34	-0.10	0.38

[a] Levels of significance: *, $P < 0.05$, $r = 0.567$; **, $P < 0.01$, $r = 0.708$.

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

OR - Oven-roasted

OB - Braised, atmospheric pressure

DF - Deep-fat fried

PB - Braised, 10 p.s.i.g.

from that of every other treatment with the exception of the two oven treatments, OR and OB, which were not significantly different from each other. Also, PB pieces of muscle required less ($P < 0.05$) time to cook than pieces given any of the other treatments; and the order of cooking time for the other treatments was DF<OB<OR (Table 2, Fig. 4). All correlation coefficients for rate of heat penetration and cooking time were extremely high (Table 3).

Differences in rates of heat penetration and cooking time attributable to treatment may be explained, in part, by differences in the heat conductivity of the four treatments (cooking mediums). As mentioned previously, the specific heats of steam, oil, and air are 0.48, 0.41-0.43, and 0.24, respectively (Harrison, 1943). In this study, the meat cooked in steam (highest specific heat) under pressure (PB) cooked faster than that cooked in oil (DF), which, in turn, cooked faster than that cooked in air (lowest specific heat), OR. OB pieces were oven-cooked in steam for less time than OR pieces, which were oven-cooked in air. Rate of heat penetration and cooking time for DF pieces were approximately two-thirds the rate of heat penetration and cooking time for OR pieces.

Morgan and Nelson (1926), Harrison _et al_. (1953), and Hood (1960) reported less cooking time for braised than for roasted beef. Visser _et al_. (1960) found that deep-fat fried beef required less cooking time than oven-roasted beef when cooked to internal temperatures of 55°, 70°, and $85^{\circ}C$.

Correlation coefficients for initial temperature vs cooking time for OR pieces were $r = -0.67^{*}$ (total min) and $r = -0.65^{*}$ (min/lb). Those values are similar to the coefficient for initial temperature vs rate of heat penetration for treatment OR ($r = -0.72^{**}$). Correlation coefficients for initial temperature vs cooking time and rate of heat penetration for the other three treatments were not significant (Table 3).

Cooking losses

Usually, for a given method of cooking, the cooking losses are related to cooking time, i.e. losses increase as time increases. As would be expected, in this study cooking losses, as well as cooking time, were affected ($P < 0.01$) by heat treatment (Table 2). The F-value for cooking losses was high, although not nearly as high as the F-values for rate of heat penetration and cooking time. Although cooking time was longer ($P < 0.05$) for OR pieces than for any of the other pieces, losses from OR pieces were lower ($P < 0.05$) than losses from any of the others. Losses from PB pieces differed ($P < 0.05$) from those for DF and OB pieces. However, there was no difference between losses from DF and OB pieces.

Hood (1960) found that cooking losses were less for roasted than for braised beef. Clark _et al_. (1955) reported cooking losses of 33.1% for round steaks cooked to 80°C (well-done) by both pressure braising at 10 p.s.i.g. (239°F) and oven braising at 300°F. They concluded that it was the end point temperature to which steaks were cooked rather than the method of cooking that affected most of the measurements made on the steaks they cooked. In the study reported here, total cooking losses were 33.2% for PB pieces and 27.9% for OB pieces cooked to 70°C (medium-done).

The correlation coefficient between total cooking losses and rate of heat penetration was high ($r = 0.91^{**}$) for PB pieces. Coefficients for those two factors were low for all other heat treatments (Table 3).

Total moisture, press fluid yield, and water-holding capacity

Total moisture, press fluid yield, and water-holding capacity all are measurements that have been used by researchers as objective measures of muscle juiciness. All three of those factors were affected ($P < 0.01$) by heat treatment. Total moisture was higher ($P < 0.05$) in OR pieces than in pieces given any of the other treatments. There were no significant differences in total moisture between treatment PB and OB or DF, nor between treatments DF and OB (Table 2).

The press fluid yield from OR pieces was greater ($P < 0.05$) than that from pieces given the other heat treatments. Moreover, press fluid yield differed ($P < 0.05$) between PB and both DF and OB, whereas there was no difference between treatments DF and OB (Table 2).

Similar to press fluid yield, values for water-holding capacity were higher ($P < 0.05$), i.e. more moisture was expressed under pressure, for OR pieces than for PB and DF pieces. However, there was no significant difference in water-holding capacity of OR and OB pieces. Values for PB pieces were not significantly different from values for DF pieces, but were lower ($P < 0.05$) than those for OB pieces.

Correlation coefficients for rate of heat penetration vs total moisture, press fluid yield, and water-holding capacity were moderately high for PB pieces only. Also, total moisture and press fluid yield were moderately related to cooking time and losses for PB pieces only. Total moisture was moderately related (Table 3) to press fluid yield in treatments DF (not significant), OR (not significant), and PB ($P < 0.01$).

Warner-Bratzler shear values, pH, and Gardner color-difference values

There were no significant differences attributable to heat treatment for shear values, pH, and color-difference of the muscle pieces (Table 2). In contrast, Harrison (1943) found that cooking medium (water, steam, oil, air) significantly affected shear values.

Several researchers have reported that beef was more tender when cooked for long periods of time, i.e. slow heat penetration (Morgan and Nelson, 1926; Cover, 1937; 1938, 1941a, b, 1943; Lowe, 1955; Bramblett _et_ _al_., 1959; Hood, 1960; Bramblett and Vail, 1964). Data in Table 3 indicate that, in this study, shear values were not related to rate of heat penetration. Also in this study, pH was not related to rate of heat penetration, or to total moisture except for the moderately high relationship ($r = 0.71^{**}$) between pH and total moisture for OR pieces of muscle. However, pH was related moderately to press fluid yield for treatments DF and OR. For all four heat treatments, pH was related moderately to shear value (Table 3). In contrast, Rogers et al. (1967) found no relationship between shear values and pH of turkey muscle.

Negative correlation coefficients for shear vs panel tenderness scores were moderately high for DF and OB pieces and high for treatments OR and PB (Table 3). As might be expected, as the shear values decreased, scores for tenderness increased. Harrison (1943) and Visser et al. (1960) found no significant relationship between panel tenderness scores and shear value.

Effect of Heat Treatment on Organoleptic Measurements

Apparent degree of doneness and juiciness were the only organoleptic factors affected ($P < 0.05$ and $P < 0.01$) by heat treatment (Table 2). All pieces were cooked to an end point temperature of $70^{\circ}C$, a temperature usually considered in the range for medium-done beef. Apparent degree of doneness scores for muscle given all treatments averaged between medium- and well-done, with the mean value for OR pieces being closest to the score for medium-done and the mean value for OB pieces closest to the score for well-done. Differences in mean scores for apparent degree of doneness were significant ($P < 0.05$) only between treatment OR and every other treatment.

Differences in juiciness scores were significant ($P < 0.05$) between treatment OR and both treatments DF and PB, and between treatments OB and PB (Table 2). Differences between OR and OB and between DF and PB approached significance. On the basis of adjusted means for treatments OR (5.93) and OB (5.25) the difference between the two treatments was significant.

There was a moderate negative correlation (r = -0.63*) between rate of heat penetration and apparent degree of doneness for OR pieces, and a positive correlation (r = 0.79**) for PB pieces. Although an inverse relationship existed between apparent degree of doneness and rate of heat penetration in OR pieces, the over-all rate of heat penetration for OR pieces was slower and the average score for apparent degree of doneness was lower than in any of the other heat treatments (Table 2). Apparent degree of doneness was not related to rate of heat penetration in DF and OB pieces (Table 3). No significant relationship between apparent degree of doneness scores and color-difference values was found (Table 3).

Reports in the literature indicate that the effect of rate of heat penetration on apparent degree of doneness may depend, in part, on the temperature of the cooking medium, which affects the rate of heat penetration. Cover (1943) roasted beef at two relatively low oven temperatures, both of which would cause relatively slow rates of heat penetration in the muscle. She obtained rare beef at 63°C when it was roasted at 125°C (257°F). However, when beef was roasted at 80°C (176°F), it was rare at 58-59°C. Thus, it appeared that the slower the rate of heat penetration the more well-done the meat at a given internal temperature. When Visser <u>et al</u>. (1960) cooked beef by dry heat (air) in an oven at 149°C (300°F) and in deep fat at 100°C (212°F) to 55°, 70°, and 85°C, the rate of heat penetration was much slower in the oven-roasted muscle than in muscle cooked in deep fat. That study seemed to indicate that the slower the rate of heat penetration the less well-done the meat at a given internal temperature. The slower rate of heat penetration in the study of Visser et al. (1960) probably was more rapid than the faster rate in Cover's (1943) study.

The correlation coefficients for juiciness and rate of heat penetration, cooking time (total min and min/lb), and apparent degree of doneness in PB pieces only were moderately high. Juiciness was related to percentage total cooking loss for PB and OR pieces only. No significant relationship was found between juiciness and press fluid yield for pieces given any of the four treatments. A moderate ($P < 0.05$) negative correlation between juiciness and total cooking losses also was found for OR pieces. Juiciness was not related to water-holding capacity except in OB pieces.

Although no significant relationship occurred between heat treatment and mean flavor scores (Table 2), a significant ($P < 0.01$) negative correlation occurred between flavor scores and apparent degree of doneness scores for treatment DF (Table 3). Also, in this study, desirability of flavor was not related significantly to rate of heat penetration. However, Hood (1960) found that beef cooked by dry heat for a long period of time at a slow rate of heat penetration had significantly higher flavor scores than that cooked by moist heat.

The mean over-all acceptability score for OR pieces was higher than for pieces given any of the other treatments (Table

2). The descending order of acceptability for other heat treatments was OB, DF, and PB. Flavor scores were related moderately to over-all acceptability in treatments OR (r = 0.73**) and OB (r = 0.72**), Table 3. A survey of the palatability panel indicated that flavor was one of the most important criteria on which the judges based their over-all acceptability scores, and that the flavor of medium-rare meat (pinkish-red interior) was more desirable to most of them than the flavor of well-done meat (brown-gray). The significantly lower apparent degree of doneness scores for OR pieces may explain, in part, the slightly higher over-all acceptability scores for OR pieces (Table 2).

The correlation coefficients for over-all acceptability vs tenderness were moderate but not significant for OB (r = 0.47), and significant for OR (r = 0.70*), DF (r = 0.94**), and PB (r = 0.86**). Correspondingly, as tenderness scores were correlated positively with over-all acceptability, there was a negative relationship of shear value to over-all acceptability for DF (r = -0.23), OB (r = -0.52), OR (r = -0.79**), and PB (r = -0.80**). For treatment PB, as juiciness increased and cooking losses decreased, over-all acceptability increased (Tables 8, 13, Appendix).

From the r-values stated above, it appears that, in general, of the three palatability factors studied, tenderness had the most influence on the over-all acceptability scores for all four heat treatments. Flavor had a moderate influence and juiciness the least influence on over-all acceptability scores, except for PB pieces, for which tenderness and juiciness were most important.

However, as stated previously, the survey of the palatability panel indicated that flavor seemed to be more important than tenderness in assignment of the over-all acceptability scores. Juiciness appeared to be an important factor to most judges only when extremely low levels were noted.

Differences Between Raw and Cooked Muscle

As expected, total moisture, shear value (tenderness), pH, and Gardner color-difference of raw beef changed when any one of the four heat treatments was applied. To further study the changes attributable to the specific heat treatments, the difference between values for selected characteristics of raw muscle and of muscle subjected to each treatment (cooking medium) was calculated. None of the calculated differences was significantly different from the others (Table 4).

SUMMARY

Pieces of SM muscle, relatively uniform in weight and shape, were cooked by four methods (OR, OB, DF, and PB) to an internal end point temperature of 70°C to investigate the effects of heat treatment on selected characteristics of beef. The results of this study indicate that it is important for meat researchers to consider the type of heat treatment (cooking medium) when planning experiments.

Warner-Bratzler shear values, pH, Gardner color-difference values, and panel scores for flavor, tenderness, and over-all acceptability were not affected significantly by type of heat

Table 4. Mean values for selected measurements on raw and cooked muscle according to heat treatment.

Measurement	Raw muscle	Cooked muscle[a]							
		OR	Diff	OB	Diff	DF	Diff	PB	Diff
Total moisture, %	72.8	64.0	8.8	61.1	11.7	60.9	11.9	59.6	13.2
Shear value, lb/$\frac{1}{2}$-in. core	7.4	8.8	1.4	9.7	2.3	9.9	2.5	8.8	1.4
pH	5.61	5.63	0.02	5.61	0.00	5.64	0.03	5.66	0.05
Gardner color difference									
Rd	8.76	22.00	13.24	21.08	12.32	21.03	12.27	20.26	11.50
a+	12.30	7.31	4.99	6.92	5.38	6.75	5.55	6.81	5.49

[a] Note: Diff - the difference between the value for raw and cooked muscle.
OR - Oven-roasted
OB - Braised, atmospheric pressure
DF - Deep-fat fried
PB - Braised, 10 p.s.i.g.

treatment. Rate of heat penetration, cooking time, cooking losses, total moisture, press fluid yield, and water-holding capacity were affected significantly ($P < 0.01$) by the different heat treatments. Likewise, panel scores for juiciness ($P < 0.01$) and apparent degree of doneness ($P < 0.05$) were different for the different heat treatments.

Of the four heat treatments, OR pieces had the slowest rate of heat penetration and the longest cooking time, as well as highest values for total moisture, press fluid yield, water-holding capacity, and panel scores for juiciness. For the same measurements, values for OB pieces always ranked next to the values for OR pieces, followed by DF and then PB pieces. Apparent degree of doneness scores indicated that OR pieces appeared less well-done than meat in the other treatments. The difference in apparent degree of doneness may be attributable to the influence of the cooking mediums on rate of heat penetration.

Rate of heat penetration was related to cooking time in all four heat treatments. In PB pieces, rate of heat penetration was related significantly to cooking losses ($P < 0.01$), total moisture ($P < 0.05$), press fluid yield ($P < 0.01$), and panel scores for juiciness ($P < 0.05$) and apparent degree of doneness ($P < 0.01$). Also in PB pieces, cooking time, cooking losses, press fluid yield, and juiciness scores appeared to be interrelated. In general, it appeared that, of the three palatability factors studied, tenderness had the most influence on the over-all acceptability scores. The calculated differences between values for selected characteristics of raw muscle and of muscle subjected to each treatment were not significantly different from each other.

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APPENDIX

Explanation of Terms and Abbreviations for Appendix Tables

OR(T_2) - Oven-roasted, 300°F.

OB(T_3) - Braised, atmospheric pressure, 300°F.

DF(T_1) - Deep-fat fried, 100°C.

PB(T_4) - Braised, 10 p.s.i.g., 115°C.

Form 1. Score Card For Cooked Beef Semimembranosus.

Judge__________ Code__________ Date__________

Sample No.	Desirability of Flavor	Juiciness	Tenderness		Over-all Accept-ability	Degree of Doneness (Check one)			Comments
			No. Chews	Score		R	M	W	
1									
2									

Descriptive terms for scoring:

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

Degree of Doneness

R = Rare
M = Medium-done
W = Well-done

Form 2. Instructions to Judges for Sensory Evaluation of Top Round.

You may use one cube of meat to score flavor and juiciness and another cube to score tenderness.

Scoring for flavor and juiciness

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

Scoring for tenderness

Count the number of times you chew the $\frac{1}{2}$-in. cube of meat before swallowing. Chew until the cube is masticated completely, then swallow. Record the number of chews required to masticate the cube. Record a score from 7 to 1 that describes your impression of the tenderness of the cube. See the score card for descriptive terms for specific scores within the range of 7 to 1.

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

Over-all acceptability

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

Degree of doneness

Evaluate the slice of meat provided for the purpose under the Macbeth Skylight. Use the foot pedals to change the color of the light. Check the appropriate column, indicating whether you believe the sample looks rare, medium, or well-done.

Form 2. (continued)

Comments

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

Take your time to score each sample. Water is provided for rinsing your mouth between samples. If you use two cubes of meat, it isn't necessary to swallow the cube used to score flavor and juiciness.

Table 5. Initial weight, initial temperature, and initial volume.

Measurement	Heat treatment			
	OR(T_2)	OB(T_3)	DF(T_1)	PB(T_4)
Initial weight, g	806	817	830	792
	837	855	772	835
	826	836	816	824
	812	823	827	823
	827	829	831	---
	815	830	829	---
	813	819	830	805
	813	816	815	818
	821	821	---	788
	817	822	824	806
	820	823	813	803
	820	822	812	803
Av.	818.9	826.1	818.1	809.7
Initial temperature, °C	2	2	3	7
	-1	2	5	10
	5	6	6	14
	6	9	7	7
	6	9	7	--
	4	4	10	--
	4	3	4	12
	2	2	4	3
	4	4	2	2
	3	4	4	5
	4	4	4	7
	0	3	2	4
Av.	3.2	4.3	4.8	7.1
Initial volume (cm^3)	924.0	675.8	595.1	793.5
	945.0	859.6	934.4	862.5
	859.6	793.5	792.0	793.5
	853.1	810.0	819.0	858.0
	750.8	793.5	828.0	---
	859.6	787.5	887.2	---
	822.2	910.0	858.0	825.0
	812.5	955.5	975.0	793.5
	887.2	887.2	822.2	862.5
	819.0	897.0	858.0	793.5
	891.0	822.2	929.5	825.0
	897.0	819.0	936.0	720.0
Av.	860.1	800.4	852.9	812.7

Table 6. Rate of heat penetration, minutes/5°C, according to heat treatment.

	Temperature (°C)													
	5	10	15	20	25	30	35	40	45	50	55	60	65	70
							OR(T_2)							
Min/5°C	5	6	6	6	5	5	6	6	6	7	9	9	14	17
	27	5	4	5	4	5	5	6	6	7	7	11	11	13
	0	17	8	6	6	6	5	6	5	7	6	9	10	11
	0	17	5	5	3	3	4	5	5	6	8	8	12	13
	0	16	7	5	5	5	5	5	5	5	6	7	9	10
	4	11	6	5	5	5	6	5	6	7	7	9	11	15
	6	11	6	5	5	5	5	6	5	6	7	8	8	9
	13	10	5	5	6	5	5	6	7	6	7	9	10	12
	2	12	6	5	5	5	6	5	6	7	8	10	12	15
	10	8	5	6	5	5	4	6	6	7	7	9	11	10
	5	11	7	4	4	5	5	5	7	6	7	8	12	12
	27	3	3	3	3	5	4	4	6	6	6	7	11	11
Av.	8.2	10.6	5.7	5.0	4.7	4.9	5.0	5.4	5.8	6.4	7.1	8.7	10.9	12.3
							OB(T_3)							
Min/5°C	7	10	9	6	6	6	6	7	6	6	6	5	6	6
	11	12	9	7	7	8	7	6	5	5	5	5	5	4
	0	16	13	8	8	6	6	6	6	6	5	6	6	5
	0	1	18	10	8	7	7	7	7	6	5	6	6	6
	0	1	18	11	8	7	7	6	5	6	5	5	5	6
	1	16	10	8	7	6	7	7	6	5	5	4	5	6
	4	18	9	8	6	7	5	5	5	5	6	5	5	6
	10	12	8	6	6	5	5	5	6	6	5	6	6	7
	2	17	9	7	7	7	7	6	7	6	5	6	5	6
	1	11	8	7	6	7	6	5	8	9	8	7	6	7
	3	17	11	7	8	6	7	6	6	5	5	6	5	8
	6	12	11	11	5	4	4	8	5	5	8	5	5	5
Av.	3.8	11.9	11.1	8.0	6.8	6.3	6.2	6.2	6.0	5.8	5.7	5.5	5.4	6.0

Table 6. (concluded)

	Temperature (°C)													
	5	10	15	20	25	30	35	40	45	50	55	60	65	70
	DF(T_1)													
Min/5°C	4	8	5	4	4	4	4	3	4	5	5	5	6	6
	0	12	6	5	4	4	4	4	4	5	5	5	5	5
	0	12	6	5	5	4	5	4	5	5	6	6	7	7
	0	12	6	5	4	5	5	5	4	5	5	5	5	7
	0	11	5	4	3	4	3	3	4	4	4	5	6	6
	0	0	12	6	5	4	3	4	4	4	4	5	5	6
	7	9	5	4	3	4	3	4	4	4	4	5	5	5
	7	9	5	5	3	4	3	4	3	4	4	5	5	5
	14	6	4	4	3	3	2	3	3	3	4	3	5	5
	3	9	5	5	3	4	4	3	4	4	4	4	5	5
	5	11	6	3	4	3	3	4	3	3	4	4	4	5
	5	8	4	5	3	4	3	4	3	4	4	4	4	5
Av.	3.7	7.9	5.8	4.6	3.7	3.9	3.5	3.8	3.8	4.2	4.4	4.7	5.2	5.6
	PB(T_4)													
Min/5°C	0	10	4	3	3	2	3	2	3	3	2	3	3	3
	0	0	6	2	2	1	2	1	2	2	2	2	4	4
	0	0	1	2	2	2	2	2	5	9	2	2	4	2
	0	11	5	3	3	2	3	4	2	5	1	2	4	4
	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0	0	7	6	5	2	4	2	3	3	3	3	3	3
	2	8	4	3	3	2	3	2	2	3	2	3	3	4
	3	6	4	2	1	3	3	1	2	2	2	2	2	3
	0	11	5	4	2	3	3	2	3	3	3	3	4	3
	0	8	6	4	3	2	3	2	3	1	4	4	3	3
	3	7	4	4	3	2	2	3	2	2	3	3	2	4
Av.	0.8	6.1	4.6	3.3	2.7	2.1	2.8	2.1	2.7	3.3	2.4	2.7	3.2	2.9

Table 7. Cooking time, in total minutes and minutes per pound, and pH.

Measurement	Heat treatment			
	OR(T_2)	OB(T_3	DF(T_1)	PB(T_4)
Total, min	107	92	67	44
	116	96	68	30
	102	97	77	35
	99	94	73	57
	90	90	62	--
	102	93	62	--
	92	94	66	44
	106	93	66	44
	104	97	62	36
	99	96	62	49
	98	100	62	46
	99	94	60	44
Av.	101.2	94.7	65.6	42.9
Min/lb	60.4	51.1	36.6	25.3
	63.0	51.1	40.0	16.3
	56.0	52.7	42.8	19.3
	55.3	51.9	40.1	31.5
	49.4	49.4	33.9	---
	56.7	50.8	34.0	---
	51.4	52.2	36.1	24.8
	59.2	51.7	36.7	24.4
	57.4	53.6	---	20.7
	55.0	53.0	34.2	27.5
	54.1	55.2	34.6	26.0
	54.7	51.9	33.5	24.8
Av.	56.0	52.0	36.6	24.1
pH	5.63	5.51	5.50	5.59
	5.62	5.60	5.60	5.66
	5.70	5.58	5.60	5.59
	5.62	5.61	5.62	5.62
	5.58	5.68	5.62	---
	5.71	5.82	5.98	---
	5.74	5.52	5.68	5.80
	5.62	5.64	5.58	5.82
	5.58	5.52	5.60	5.64
	5.54	5.67	5.59	5.62
	5.61	5.59	5.64	5.64
	5.61	5.62	5.61	5.59
Av.	5.63	5.61	5.64	5.66

Table 8. Cooking losses.

Measurement	Heat treatment			
	OR(T_2)	OB(T_3)	DF(T_1)	PB(T_4)
Total, %	23.6	27.9	28.2	34.1
	26.8	31.6	29.1	25.0
	24.2	29.4	30.6	30.0
	25.2	25.8	29.9	36.2
	22.5	30.2	26.3	----
	25.9	28.2	26.0	----
	23.7	26.9	28.7	35.0
	21.8	23.9	27.8	37.4
	22.4	26.8	----	31.2
	21.4	29.6	31.9	36.8
	22.2	28.6	28.8	35.2
	22.8	25.5	28.7	31.6
Av.	23.5	27.9	28.7	33.2
Volatile, %	20.3	----	----	----
	21.7	----	----	----
	18.8	----	----	----
	20.0	----	----	----
	17.6	----	----	----
	21.0	----	----	----
	18.9	----	----	----
	19.3	----	----	----
	17.7	----	----	----
	17.1	----	----	----
	19.5	----	----	----
	19.4	----	----	----
Av.	19.3			
Drip, %	2.4	----	----	----
	4.3	----	----	----
	4.6	----	----	----
	4.1	----	----	----
	3.9	----	----	----
	2.6	----	----	----
	2.5	----	----	----
	1.8	----	----	----
	1.6	----	----	----
	3.7	----	----	----
	2.2	----	----	----
	3.7	----	----	----
Av.	3.1			

Table 9. Total moisture, WHC, and shear values.

Measurement	Heat treatment			
	OR(T_2)	OB(T_3)	DF(T_1)	PB(T_4)
Total moisture, %	65.3	62.8	62.8	59.8
	64.6	60.8	61.0	61.0
	64.7	60.2	58.6	61.9
	62.6	60.6	61.7	57.8
	63.6	60.0	60.8	----
	64.7	62.3	60.2	----
	66.0	58.6	60.0	59.4
	63.2	61.6	60.0	57.8
	64.3	61.0	61.3	64.6
	62.5	62.5	62.0	59.8
	62.7	60.0	61.2	57.6
	63.4	63.0	61.1	56.1
Av.	64.0	61.1	60.9	59.6
WHC[a]	0.62	0.60	0.61	0.53
	0.62	0.56	0.58	0.55
	0.66	0.67	0.51	0.66
	0.63	0.67	0.59	0.59
	0.65	0.62	0.59	----
	0.59	0.58	0.63	----
	0.66	0.56	0.58	0.62
	0.68	0.63	0.44	0.56
	0.60	0.53	0.62	0.63
	0.64	0.68	0.57	0.41
	0.67	0.60	0.53	0.45
	0.64	0.63	0.64	0.46
Av.	0.64	0.61	0.57	0.55
Shear value, lb/½-in. core	9.0	10.3	12.8	6.9
	7.2	10.7	10.0	9.6
	8.1	6.9	8.3	7.4
	9.7	8.1	8.0	8.5
	7.5	9.4	9.6	---
	16.0	15.4	15.9	---
	10.5	11.1	15.4	8.5
	7.5	11.9	8.6	15.9
	6.6	6.8	9.7	7.8
	6.4	8.8	7.0	10.8
	10.8	10.4	8.2	8.0
	6.8	6.3	5.8	4.8
Av.	8.8	9.7	9.9	8.8

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

Table 10. Press fluid yield.

Measurement	Heat treatment			
	OR(T_2)	OB(T_3)	DF(T_1)	PB(T_4)
Total, ml/25 g	7.8	6.8	7.9	6.0
	8.2	6.6	7.9	7.2
	8.6	7.6	6.6	7.6
	7.1	7.9	7.7	5.5
	8.5	7.8	8.3	---
	9.3	7.5	6.6	---
	9.8	7.4	6.8	6.0
	8.4	7.6	7.8	5.8
	8.4	7.0	7.4	8.5
	7.7	7.6	7.4	6.1
	8.6	7.4	7.3	6.0
	9.3	8.8	8.0	7.0
Av.	8.5	7.5	7.5	6.6
Serum, ml/25 g	7.0	5.9	7.4	5.5
	7.4	5.2	6.4	6.0
	7.6	6.4	5.6	6.6
	6.4	7.0	6.4	4.8
	7.4	7.2	7.2	---
	8.2	7.0	6.0	---
	9.4	6.3	6.0	5.2
	7.8	7.3	6.8	5.1
	7.4	6.4	6.7	8.1
	7.0	7.2	6.6	5.6
	8.2	6.8	6.8	5.2
	8.2	8.2	7.4	5.7
Av.	7.7	6.7	6.6	5.8
Fat, ml/25 g	0.7	0.8	0.5	0.6
	0.8	1.3	2.0	1.2
	0.9	1.1	1.0	1.0
	0.8	1.0	1.4	0.8
	1.0	0.6	1.1	---
	1.2	0.5	0.6	---
	0.4	1.1	0.8	0.8
	0.7	0.4	1.0	0.8
	1.0	0.7	0.6	0.4
	0.8	0.4	0.7	0.5
	0.5	0.6	0.4	0.8
	1.0	0.6	0.6	1.2
Av.	0.8	0.8	0.9	0.8

Table 11. Gardner color-difference values on ground meat.[a]

Measurement	Heat treatment			
	OR(T_2)	OB(T_3)	DF(T_1)	PB(T_4)
Rd	21.52	20.97	19.85	19.96
	18.86	18.78	15.32	18.51
	19.86	19.76	21.74	20.74
	22.28	20.29	20.62	19.86
	21.92	22.01	22.90	-----
	22.14	17.10	17.37	-----
	19.23	20.78	22.15	17.54
	22.26	22.45	20.08	18.82
	24.51	20.96	22.76	20.20
	23.74	23.72	22.96	21.81
	22.78	22.34	21.32	20.75
	24.84	23.82	25.32	24.37
Av.	22.00	21.08	21.03	20.26
a+	9.40	5.50	5.23	6.51
	9.12	6.47	6.30	6.44
	9.18	9.08	9.24	7.81
	9.48	8.61	8.40	9.48
	9.47	8.60	9.24	----
	----	9.47	8.76	----
	0.60	4.64	----	8.50
	6.00	5.42	4.76	----
	5.75	6.90	5.63	5.87
	5.82	7.48	6.86	7.06
	8.72	6.74	6.04	5.50
	6.85	4.08	3.84	4.14
Av.	7.31	6.92	6.75	6.81
b+	10.54	10.69	10.50	11.06
	10.51	11.34	10.25	10.57
	13.02	12.96	12.30	12.86
	13.25	12.98	14.07	13.48
	12.38	13.97	12.76	-----
	12.70	11.77	12.57	-----
	18.58	11.26	12.34	12.02
	11.09	11.65	11.14	17.80
	11.19	10.79	11.45	10.46
	10.15	11.56	11.12	11.48
	12.60	12.03	11.28	10.95
	17.27	10.52	17.24	10.65
Av.	12.77	11.79	12.25	12.13

[a] Calculated values for standard tile: 15.53 (Rd), +9.33 (a+), +13.10 (b+).

Table 12. Tenderness and apparent degree of doneness.

Measurement	Heat treatment			
	OR(T_2)	OB(T_3)	DF(T_1)	PB(T_4)
Tenderness[a]	5.6	4.4	6.0	5.9
	6.0	4.5	4.9	6.1
	4.8	5.6	6.0	6.3
	5.2	5.0	5.6	5.8
	5.0	5.5	4.4	---
	3.8	4.7	3.8	---
	5.4	5.6	4.4	4.8
	5.7	5.1	4.5	3.6
	5.7	6.1	4.7	5.3
	6.0	5.0	6.4	5.1
	4.1	5.4	3.4	5.6
	5.6	5.3	5.6	6.0
Av.	5.2	5.2	5.0	5.4
Apparent degree[b] of doneness	2.0	2.9	2.5	3.0
	2.1	2.8	2.9	1.4
	2.0	3.0	2.3	3.0
	2.7	2.9	2.9	3.0
	2.8	3.0	2.0	---
	2.2	3.0	3.0	---
	2.2	3.0	2.8	3.0
	2.0	3.0	3.0	3.0
	1.7	3.0	3.0	2.2
	2.7	3.0	3.0	3.0
	2.2	2.9	3.0	3.0
	2.3	2.8	2.8	2.8
Av.	2.2	2.9	2.8	2.7

[a] Range, 7 (extremely tender) to 1 (extremely tough).

[b] Apparent degree of doneness, assigned numerical values; rare, 1; medium-done, 2; well-done, 3.

Table 13. Flavor, juiciness, and over-all acceptability scores.

Measurement	Heat treatment			
	OR(T_2)	OB(T_3)	DF(T_1)	PB(T_4)
Flavor[a]	6.4	6.1	6.1	5.1
	5.9	5.4	5.9	5.4
	6.0	6.0	6.1	5.4
	5.4	5.7	5.5	5.3
	5.9	6.4	6.0	---
	5.5	5.4	5.6	---
	5.8	5.6	5.6	5.9
	5.3	5.4	5.4	5.4
	5.4	5.4	5.5	5.9
	5.7	5.5	5.8	5.6
	5.5	5.5	5.7	5.7
	6.3	5.4	5.6	6.0
Av.	5.8	5.6	5.7	5.6
Juiciness[b]	5.5	6.0	4.5	5.6
	5.5	4.9	5.5	6.2
	5.6	5.4	4.7	4.9
	5.6	5.7	3.5	3.1
	6.0	5.1	5.2	---
	5.6	4.8	5.2	---
	5.5	5.0	5.8	3.8
	6.1	5.2	5.9	3.0
	6.0	4.5	4.8	4.8
	5.9	5.6	6.1	3.5
	6.6	5.9	4.8	4.8
	6.0	5.6	4.6	5.7
Av.	5.8	5.3	5.0	4.5
Over-all acceptability[a]	6.0	5.4	5.8	5.2
	5.8	5.0	5.2	5.8
	5.7	6.0	6.0	5.2
	5.3	5.4	5.2	4.8
	5.8	5.8	5.1	---
	4.9	4.8	4.6	---
	5.5	5.4	5.0	4.8
	5.4	5.2	4.9	3.8
	5.6	5.2	5.1	5.3
	5.8	5.2	5.9	4.9
	5.3	5.6	4.1	5.3
	5.8	5.3	5.3	5.7
Av.	5.6	5.4	5.2	5.1

[a] Range, 7 (extremely desirable) to 1 (extremely undesirable).

[b] Range, 7 (extremely juicy) to 1 (extremely dry).

Table 14. Values for selected measurements on raw muscle.

Shear value, lb/$\frac{1}{2}$-in. core	Total moisture, %	pH	Gardner color-difference[a]	
			Rd	a+
5.2	72.4	5.62	10.84	11.66
6.8	71.4	5.59	5.94	11.08
9.1	72.6	5.70	8.87	10.57
5.8	73.0	5.65	8.86	10.82
8.6	73.2	5.61	9.88	11.00
6.3	73.2	5.82	6.56	16.98
8.5	73.6	5.68	9.53	17.06
12.0	72.8	5.46	8.97	8.04
6.7	72.8	5.62	8.62	9.55
7.6	72.9	5.50	8.12	9.64
6.6	72.2	5.52	10.56	14.64
6.0	73.2	5.56	8.42	16.54
Av. 7.4	72.8	5.61	8.76	12.30

[a] Calculated values for standard tile: 5.50 (Rd), +26.80 (a+).

EFFECT OF DRY AND MOIST HEAT TREATMENTS ON SELECTED MEASUREMENTS FOR EVALUATING THE QUALITY OF BEEF

by

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AN ABSTRACT OF A MASTER'S THESIS

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Differences among data from two or more laboratories studying similar problems related to the production and/or processing of beef often are reported in the literature. It is important to know whether there are significant effects attributable to type of heat treatment (cooking medium) on the characteristics of cooked beef to provide a guide for selecting the method of cooking for laboratory experiments with meat.

Pieces of SM muscle, relatively uniform in weight and shape, were cooked by four methods (oven-roasting, OR; oven-braising, OB; deep-fat frying, DF; and pressure-braising, PB) to an end point temperature of $70^{\circ}C$ to investigate the effects of heat treatment on selected characteristics of beef. The results of this study indicate that it is important for meat researchers to consider the type of heat treatment (cooking medium) when planning experiments.

Warner-Bratzler shear values, pH, Gardner color-difference values, and panel scores for flavor, tenderness, and over-all acceptability were not affected significantly by type of heat treatment. Rate of heat penetration, cooking time, cooking losses, total moisture, press fluid yield, and water-holding capacity were affected significantly ($P < 0.01$) by the different heat treatments. Likewise, panel scores for juiciness ($P < 0.01$) and apparent degree of doneness ($P < 0.05$) were different for the different heat treatments.

Of the four heat treatments, OR pieces had the slowest rate of heat penetration and the longest cooking time, as well as

highest values for total moisture, press fluid yield, water-holding capacity, and panel scores for juiciness. For the same measurements, values for OB pieces always ranked next to the values for OR pieces, followed by DF and then PB pieces. Apparent degree of doneness scores indicated that OR pieces appeared less well-done than meat in the other treatments. The difference in apparent degree of doneness may be attributable to the influence of the cooking mediums on rate of heat penetration.

Rate of heat penetration was related to cooking time in all four heat treatments. In PB pieces, rate of heat penetration was related significantly to cooking losses ($P < 0.01$), total moisture ($P < 0.05$), press fluid yield ($P < 0.01$), and panel scores for juiciness ($P < 0.05$) and apparent degree of doneness ($P < 0.01$). Also in PB pieces, cooking time, cooking losses, press fluid yield, and juiciness scores appeared to be interrelated. In general, it appeared that, of the three palatability factors studied, tenderness had the most influence on the over-all acceptability scores. The calculated differences between values for selected characteristics of raw muscle and of muscle subjected to each treatment were not significantly different from each other.