EFFECTS ON BOVINE MUSCLE OF LOW-TEMPERATURE
COOKING FROM THE FROZEN STATE

by

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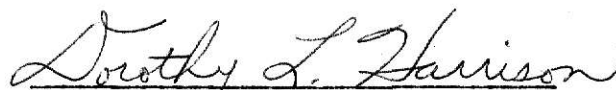submitted in partial fulfillment of the

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INTRODUCTION

The selection of a cooking method for meat is based on the convenience of
the method and the effect on end product quality. The consumer considers
tenderness one of the most important attributes of meat quality. Tenderness
in cooked meat is the total effect of muscle composition, aging before cooking,
heat coagulation of muscle fiber proteins and changes that occur in the con-
nective tissues (Harrison et al., 1959).

It has been recognized for some time that the method and length of cook-
ing time influence the tenderness and juiciness of meat. Cover (1943) stated
that the cooking time, indicative of rate of heat penetration, had more
influence on tenderness than did oven temperatures. Cline et al. (1930)
indicated that beef roasts were more tender and juicy when cooked at low
temperatures (125°C or 257°F) than when cooked at higher temperatures (165°C
or 331°F). Several workers (Clark et al., 1955; Cline et al., 1930; Latzke,
1930) indicated that the internal temperature to which the meat is cooked
influences tenderness and juiciness. Lawrie (1968) stated that a variety of
factors, including cooking temperature, internal end point temperature and the
particular muscle being considered, would determine whether cooking will
increase or decrease tenderness.

A major factor involved in the tenderness of a piece of cooked meat is
the amount of residual collagenous connective tissue or collagen it contains.
Cover and Smith (1956) and Irwin and Cover (1959) indicated that the amount of
residual collagen is dependent on methods of cooking and the particular muscle
or cut of meat. In general, tenderness results when collagenous connective
tissue is softened and partially hydrolyzed to gelatin during the cooking
process (Harrison et al., 1959). Cover and Smith (1956) noted that the amount

of collagen conversion was associated with tenderness when biceps femoris was cooked by either moist or dry heat. They reported that moist heat was more effective than dry heat in conversion of collagen to increase tenderness. Weir (1960) stated that the cooking time is important for collagen conversion, and temperature is critical for toughening of the myofibril. Bramblett et al. (1959) stated that the length of time beef is in the region of 57-60°C (135-140°F) may be an important factor in softening connective tissue while retarding toughening of the myofibrillar proteins.

Oven film cooking bags and slow-cooking appliances now are offered to the consumer as convenient methods of moist heat cookery. Advertising for both products implies that those methods result in a juicier, more flavorful roast than one cooked by "traditional" methods. The idea that less tender cuts of meat are suited to cooking in oven film bags or in slow cooking appliances agrees with the usual recommendation that moist heat be used to soften collagenous connective tissue. Manufacturers of slow cooking appliances advocate cooking food for several hours to enhance flavor and aroma. No studies were found comparing the effects of low-temperature cooking by dry and moist heat on beef cooked from the frozen state. This experiment was designed to study the effects of: (1) low temperature roasting (dry heat), (2) cooking in oven film bags (moist heat) and (3) cooking in a slow-cooking appliance (moist heat) on beef top round cooked from the frozen state.

REVIEW OF LITERATURE

Effect of cooking method on tenderness of muscle

Traditionally, methods of meat cookery have been designated as either "dry" or "moist," with that terminology referring to the atmosphere

surrounding the meat. Dry heat involves the transfer of heat from the source, via the surrounding air, to the meat. Moist heat involves heat transfer to the meat via steam, which results when the heat supplied causes moisture to vaporize in an enclosed environment. In both methods, convection is the principle form of energy transfer. Steam conveys heat energy more rapidly than air; therefore, the meat is heated throughout at a faster rate by moist heat than by dry heat (Paul, 1972). Examples of dry heat methods, or cooking in an open container, include roasting, baking, broiling and pan-broiling. Examples of moist heat methods, or cooking in a closed container, include braising, steaming, stewing, pressure cooking, and wrapping in aluminum foil.

Few adaptations of traditional dry heat cookery methods have been developed. However, several relatively new modifications of moist heat cooking methods have been developed. Two such modifications are oven film cooking bags and slow cooking appliances, or "crock pots."

By custom, dry heat has been recommended for those cuts expected to be "tender" because they contain relatively little collagenous tissue, and moist heat for those expected to be "tough," because they contain more connective tissue than "tender" cuts. This practice was associated with the idea that the environment provided by moist heat facilitates the partial hydrolysis of collagen, and it appears to enhance tenderness. Inherent differences in the cut of meat as well as the effect of time and temperature interact to alter the characteristics of the end product. The time-temperature factors are discussed in more detail later.

Several statements can be made concerning the effects of dry and moist heat cookery. In general, cooking time increases, but losses decrease with dry heat (Cover, 1941; Cover and Smith, 1956; Cover et al., 1957; Hood, 1960).

Moist heat treatment results in a product that appears more well-done than a product subjected to dry heat treatment and cooked to the same end point (Schock et al., 1970; Ferger et al., 1972; Shaffer et al., 1973). Palatability factors such as juiciness and flavor have scored consistently higher when the muscle was cooked by dry heat (Cover and Shrode, 1955; Cover and Smith, 1956; Paul et al., 1956). Tenderness, as indicated by palatability scores and shear values, appears to be greater for meat cooked by dry heat than for meat cooked by moist heat (Cover, 1938; Cover, 1941), although there are some studies that refute this (Cover and Smith, 1956; Cover et al., 1962a).

Vail (1948) stated that methods recommended for cooking fresh cuts are suitable for cooking frozen meat. The early studies on frozen meat included the effects of different thawing methods on cooking time, thawing and cooking losses and palatability of the cooked product. Cooking meat from the frozen state requires approximately 1/3 to 1/2 longer to cook than fresh or thawed meat (Vail et al., 1943; Kalen et al., 1948; Lowe et al., 1952). This finding was confirmed by Lind et al. (1971). Vail et al. (1943) found that roasts cooked from the frozen state had the greatest cooking losses, but that when thawing losses were added to cooking losses for thawed meat, losses were approximately the same. Weir (1960) pointed out that frozen meats that have more drip during thawing lose less moisture during cooking. Therefore, total losses would be expected to be similar for thawed meat and meat cooked from the frozen state. No differences in palatability between thawing meat before or during cooking were reported by any of the studies reviewed (Paul and Child, 1937; Vail et al., 1943; Kalen et al., 1948; Causey et al., 1950; Lowe et al., 1952; Fenton et al., 1956; Lind et al., 1971).

Recent work compared methods of cooking meat from the frozen state. Ferger et al. (1972) studied leg of lamb roasts and beef rib roasts cooked from the frozen state by dry and moist heat. They found little difference in cooking time, percentage total cooking losses and palatability characteristics of the roasts attributable to type of heat. Shaffer et al. (1973) studied beef top round cooked from the frozen state, and found that the use of dry heat required longer cooking time, but weight losses were less than with moist heat. They also found that differences in flavor, juiciness and overall acceptability scores were not affected significantly by type of heat.

Changes in muscle fiber. Muscle has a definite physical structure that influences its characteristics, and that is altered by heat. The major structural components include muscle fibers, connective tissue and fat. Laakonen (1973) stated that there are three major changes that occur in muscle tissue with the application of heat. Those changes are: (1) collagen shrinkage; (2) a hardening reaction attributable to muscle fiber changes; and (3) a softening reaction attributable to solubilization of collagen. He also pointed out that the most obvious basic change is shrinkage of both muscle and collagen fibers.

Muscle fiber shrinkage occurs in two phases. There is a decrease in width followed by a subsequent decrease in the length of the fibers. Soon after heating begins, fiber width begins to decrease and continues up to 62° – 67°C. Decrease in length of the muscle fibers appears to begin at 50°C, becomes rapid from 55° – 60°C and continues at a slower rate until ceasing at 70° – 80°C. Shrinkage causes closer packing of muscle fibers resulting in decreased volume of the sample. Differences associated with volume changes vary with inherent differences between muscle fibers (Cover et al., 1957; Paul, 1963).

The shrinkage of the fibers seems to result in the hardness of the muscle, and according to Cover et al. (1962c) and Tuomy et al. (1963), this hardening results from denaturation and coagulation of fiber proteins. Coagulation has been observed to occur at different temperatures, depending largely on the sample. A range of 47° - 55°C has been reported as the temperature at which coagulation of the fibers begins (Howe, 1927; Visser et al., 1960; Hostetler and Landmann, 1968). As coagulation continues, the hardening process begins. Schmidt et al. (1970) stated that hardening becomes apparent at 50°C, whereas Machlik and Draudt (1963) indicated 67°C as the temperature at which hardening appeared. In a study in which shear values were used as an indication of change in muscle structure, Satorius and Child (1938) found that coagulation was complete at 67°C, but that hardening continued up to 75°C. Howe (1927) found that coagulation ceased at 74°C. Findings of those authors suggest that coagulation may continue at higher temperatures at a decreased rate, thereby contributing to continued hardening of the fibers. Machlik and Draudt (1963) reported that there may be an increase in the rate of hardening at higher temperatures.

Changes in connective tissue. With the application of heat, changes occur in both collagenous and elastic connective tissue. However, in general, it is agreed that the changes related to tenderness that occur in collagenous tissue are of more importance than those that occur in elastic connective tissue. Most workers agree that collagen is partially or completely solubilized during cooking, with the extent of solubility depending on duration of heating and availability of moisture. Cover (1943) and Paul (1972) stated that the moisture may come from either added water or water of hydration that is released from the muscle during heating.

Reports in the literature suggest that changes that occur in collagenous connective tissue become apparent at different temperatures. Machlik and Draudt (1963) reported little change in collagenous connective tissue during heating to 50°C. Collagen shrinkage became apparent above 55°C, as shown by changes in shear values. The rate of shrinkage increased up to 65°C, with maximum tenderness occurring within the range of 60° - 65°C. Weirbicki et al. (1957) pointed out that above 60°C, a gradual hardening process occurs; whereas, Machlik and Draudt (1963) noted similar apparent changes beginning at 66°C. These latter workers stated that the rate of hardening increased with increased temperatures and concluded that it continued up to 90°C. Weirbicki et al. (1957) found a softening action above 76°C, which he attributed to hydrolysis of collagen to gelatin. Winegarden et al. (1952) reported that a similar process occurred above 80°C.

Changes in collagenous connective tissue are partially dependent on the inherent differences between muscles and the age of the animal (Irvin and Cover, 1959). An increase in the age of the animal is associated with an increased number of collagen cross-linkages (Verzar, 1963). Those alterations in character make the collagenous tissue less resistant to heat-induced changes.

Comparatively speaking, elastin is reported less extensively in the literature than collagen, mainly because of the inherent difficulty in studying a protein that is characteristically insoluble during heating (Cross et al., 1973). Lowe and Kastelic (1961) reported some variation in elastin content between some muscles on heating; the longissimus dorsi and the psoas major decreased in elastin content; whereas, the biceps femoris, semitendinosus and semimembranosus increased in elastin content. Paul (1962) found an increase in elastin content in the semitendinosus muscle on heating. Variable

results were attributed to different methods of measurement. Winegarden et al. (1952) compared the microscopic appearance of both raw and heated connective tissue, and found no apparent change in elastic fibers after heating. They noted that collagenous fibers appeared merged or fused in some areas and were straighter and less distinct after heating. However, they stated that both elastic and collagenous tissues would soften if heated in water at a sufficiently high temperature. Henrichs and Whitaker (1962) measured the extent of solubilization of connective tissue by enzymatic action, and reported that the rigidity of elastin increased on heating. However, Szczesniak and Torgeson (1965) were of the opinion that the elastin portion of the connective tissue is not changed by heat.

Lowe (1955) stated that the effect of heat on tendering meat depends on a balance between the extent of softening of the collagenous connective tissue and hardening of muscle fibers.

Changes in fat. Ritchey and Hostetler (1965) stated that in relation to total muscle changes induced by heat, fat content is an important factor. Ramsbottom et al. (1945) indicated there is an increase in tenderness of adipose tissue during heating. This may be attributed to the effect of heat on the collagenous connective tissue membrane, thereby causing the membrane to burst or be converted to gelatin. Destruction of the membrane allows the melted fat to escape, and according to Thille et al. (1932) and Wang et al. (1954), it will flow in droplets along the path of the heat degraded collagen fibers. However, Lowe (1955) found that the fat content of beef muscle was the same both before and after heating.

Effect of low-temperature, long-time cooking

Palatability characteristics. The tenderizing effects of long-time, low-temperature cooking have been reported since 1937. Cover (1937) used oven temperatures of 125° and 225°C for dry heat roasting, and found that well-done round-bone chuck and rump roasts were more tender when cooked at the lower oven temperature. She related this to low rate of heat penetration and the amount of time that it took for the internal temperature of the meat to go from 65° - 75°C. Later, she (1938) attempted to establish relationships among cooking method, cooking time and tenderness. An oven was specially constructed to maintain high humidity and low air flow conditions similar to those occurring when roast is cooked on top of the stove in a heavy covered pot without added water. Roasts were cooked under those conditions and compared to roasts cooked by dry heat in a traditional gas oven. Both cooking media were maintained at 125°C. Cooking time was less for the roasts cooked in the specially built oven, but a less tender product resulted from the faster cooking rate.

Cover (1943) found that well-done chuck and round roasts were more tender when roasted at an oven temperature of 80°C than at 125°C. Tenderness appeared to be related to low cooking temperature. She noted that if 30 hours or more were required for meat to lose its pink color, the roasts were always tender. She noted that the improved tenderness was related to the slow release of the water of hydration allowing for the effective conversion of collagen to gelatin. Cline et al. (1930) compared broiling and roasting meat at 125° and 165°C, and found that the meat cooked at the lower temperature was uniformly done and was more tender than meat cooked at the higher temperature. Hood (1960) cooked beef shoulder roasts to an internal end point temperature

of 77°C in open pans and aluminum foil at 149°C, and found that roasts wrapped in foil were less tender as a result of fast heat penetration. Bramblett et al. (1959) cooked beef rounds wrapped in heavy duty aluminum foil at 63°C and 68°C for more than 30 hours. They pointed out that the amount of time the roast was between 57° - 60°C was closely related to increased tenderness and attributed this to the softening of collagenous connective tissue while retarding the toughening of the myofibrillar proteins.

Laakonen et al. (1970) devised a model system to control the rate of heat penetration in small samples (100 - 130 g) to approximately 0.1°C per minute, thus simulating the conditions for a 15.7 kg (34.6 lb) roast cooked at 121°C in an institutional gas heated oven. Samples were heated for six hours (rare) or for 10 hours (well-done) under those conditions. Those samples were compared to quickly heated control samples that were tempered for 60 min at 30°C in a water bath, then heated to 80°C in 60 min and held at that temperature for an additional 60 min. Slower rates of heat penetration produced more tender meat. It was pointed out that total heating time was an important factor. Meat cooked 6 hours (rare) had shear values ranging from 10.83 - 19.53, and was only slightly more tender than the control that had shear values ranging from 14.55 - 20.55. However, meat cooked for 10 hours (well-done) was noticeably more tender than the control, as shown by decreased shear values ranging from 11.49 - 15.44 (Laakonen, 1973).

Bramblett et al. (1959) found that juiciness scores were higher for meat cooked at low oven temperatures with a slow rate of heat penetration. However, Bramblett and Vail (1964) noted the opposite effect on juiciness. Cover (1943) stated that flavor does not seem to be affected by rate of heat penetration.

Cooking losses. Visser et al. (1960) noted that a slow rate of heat penetration was associated with lower cooking losses than meat cooked at a faster rate. Bramblett et al. (1959) found that percentage total cooking losses were less for beef round roasts cooked at 63°C (a slow rate of heat penetration) than for roasts cooked at 68°C (faster rate of heat penetration). Weir et al. (1963) cooked pork loin roasts in open pans at oven temperatures ranging from 149°C - 205°C. Percentage drip loss were higher for roasts cooked at higher temperatures. Cover (1943) found little difference in cooking losses from beef roasted in open pans at 80°C and 125°C.

Effect of end point temperature on muscle characteristics

Degree of doneness. Visible color changes that occur during cooking are related to internal temperature, and were described by Bratzler (1971) as follows: "below 60°C, little or no color change (rare); 65° - 75°C, decreasing pinkness to 70°C (medium); at 75°C, complete loss of pinkness (well-done)."

Apparent degree of doneness as indicated by color change varies with cooking method. Shaffer et al. (1973) found that apparent degree of doneness scores were higher (1=rare, 3=well-done) for roasts cooked by moist heat than for those cooked by dry heat. She noted the appearance of roasts cooked by dry heat to an internal temperature of 60°C as bright red in the center fading to grey brown around the edges. An internal temperature of 70°C resulted in the center of the roast being pink in color with rapid fading to grey brown at the edges. An internal temperature of 80°C resulted in a roast slightly pink in the center with fading to grey brown throughout the remainder of the meat. When moist heat was used, an internal end point temperature of 60°C produced a roast that was slightly pink in the center, and faded quickly

to a grey brown on the edges. Roasts were uniformly grey throughout when cooked by moist heat to end point temperatures of 70° and 80°C. Those findings were in agreement with the results of Schock et al. (1970) and Ferger et al. (1972).

Visser et al. (1960) reported that method of heating affects end point temperatures that correspond to color changes indicative of degree of doneness. When frying in deep fat at 100°C, end point temperatures of 45°C and 65°C gave the appearance of rare and medium-done, respectively; whereas, for other dry heat methods, temperatures of 55°C and 70°C usually give the appearance of rare and medium-done meat.

Differences in apparent degree of doneness may be attributable to the influence of the cooking medium on the rate of heat penetration. The faster rate of heat penetration produces a product that appears more well-done at lower end point temperatures; whereas, a slower rate of heat penetration requires higher end point temperatures to appear well-done.

Cooking time and cooking losses. In general, as the internal end point temperature increases, cooking time and losses increase (Cover, 1943; Cover et al., 1962b; Visser et al., 1960; Hunt et al., 1963). When cooking beef rib roasts at oven temperatures of 107° and 163°C to end point temperatures of 60°, 70° and 77°C, Bayne et al. (1973) found that cooking time increased as the internal end point temperature increased, regardless of cooking temperature-end point temperature treatment combination. They also noted that cooking losses increased and juiciness decreased as the internal end point temperature increased, regardless of cooking temperature. Shaffer et al. (1973) roasted beef top round at 177° and 205°C to internal end points of 60°, 70° and 80°C, and found that total and volatile losses increased with increasing end point temperatures. However, drip losses increased slightly

between 60° and 70°C, but decreased between 70° and 80°C. They also reported that the volume of drippings and percentage fat in the drippings were unaffected by internal end point temperature when beef top round was cooked in oven film bags. Both Marshall et al. (1959) and Webb et al. (1961) pointed out that as internal end point temperature increased, total, drip and evaporative losses increased.

Palatability characteristics. Visser et al. (1960), Marshall et al. (1959) and Bayne et al. (1973) reported that tenderness scores were approximately the same when different beef muscles were oven roasted to internal end point temperatures corresponding to rare, medium and well-done. Data of Shaffer et al. (1973) supported those findings when they found that tenderness scores, as indicated by Warner Bratzler shear values, were not affected significantly by internal end point temperature. Harrison et al. (1953) found that U.S. Commercial rib roasts (P<0.05) and loin steaks (P<0.01) were more tender, as indicated by shear values and tenderness scores, when cooked to 70°C than when cooked to 80°C. Satorius and Child (1938) found that a major increase in tenderness occurred between 67° and 75°C when cooking the semimembranosus muscle to end points of 58°, 67° and 75°C.

Cover (1959) pointed out the effects of different cooking methods in relation to end point temperatures when she reported that tenderness scores were low when bottom round was broiled to the rare stage of doneness but high when it was braised to well-done. Sanderson and Vail (1963) observed a relationship between internal end point temperature and tenderness with respect to different muscles. Tenderness scores for the longissimus dorsi muscle differed little when heated to different end points, but tenderness scores for beef round muscles increased as the internal end point increased.

Cover et al. (1962b) stated that increasing the internal end point temperatures of longissimus dorsi (LD) and biceps femoris (BF) muscles resulted in a drier, less juicy piece of meat. Several other workers substantiated that juiciness decreased as end point increased (Bunyan, 1958; Marshall et al., 1959; Visser et al., 1960).

Marshall et al. (1959) found that flavor scores were similar for all degrees of doneness; whereas, Bunyan (1958) and Bayne et al. (1973) indicated that flavor and aroma scores increased with increased degree of doneness. Several workers reported that end point temperatures had no significant effects on flavor and aroma scores (Cover et al., 1957; Visser et al., 1960; Sanderson and Vail, 1963; Shaffer et al., 1973).

Factors affecting rate of heat penetration

Muscle composition. The conductivity of heat through meat is not dependent on a single component, but rather on the complex effects of its constituents (Lentz, 1961; Hill et al., 1967). Thille et al. (1932) suggested that the size and arrangement of muscle fibers may affect the rate of heat penetration. They also stated that, during the initial heating period, the muscle fiber portion conducted heat faster than any other muscle constituent. Lentz (1961) and Hill et al. (1967) reported that thermal conductivity of muscle was greater along the fibers than it was perpendicular to them.

Thille et al. (1932) stated that fat is a good conductor of heat when melted, but a poor conductor when solid. They found that at approximately 50°C, the rate of heat conduction in the muscle portion of a beef rib roast slowed down, and conduction in the fat portion of the roast increased. This

indicates that the distribution of the fat in meat is important to the rate of heat penetration.

Irmiter et al. (1967) studied the rate of temperature rise in ground beef cylinders fabricated from selected muscles of the round. They stated that temperature rise is affected by fat content throughout cooking. This was illustrated by a rapid rise in temperature during the early stages of heating in meat with little fat as compared to meat with high fat content. Conversely, a rapid rise in temperature was noted in the final stages of heating in meat with high fat content as compared to that with a low fat content.

Lentz (1961) and Qashou et al. (1970) found a positive relationship between moisture and fat components in relation to thermal conductivity. Miller and Sunderland (1963) and Hill et al. (1967) found that thermal conductivity increased with increased moisture content.

Hill et al. (1967) stated that below freezing, heat conductivity is inversely related to the internal temperature of the meat, and above freezing, conductivity increases slightly with increased temperatures. During heating, some denaturation of fiber protein begins at temperatures of 55° - 60°C. Since denaturation is an endothermic reaction, the abrupt slowing of conductivity and the resultant flattening of the rate of heat penetration curve can be attributed to the absorption of heat (Lowe, 1955; Visser et al., 1960; Hamm, 1966). Cover et al. (1957) attributed the slower conductivity to the release of water of hydration. Funk et al. (1966) noted that the rate of temperature rise differed at different depths in the roast. Therefore, it is possible to obtain a roast with layers of different degrees of doneness when cooking to a specific end point temperature.

Size and shape of meat. In general, cooking time per pound is longer for smaller cuts of meat, but total cooking time increases as size and weight of

the meat increases. Jacobson and Fenton (1956) reported that variations in cooking times decreased markedly with roasts of uniform size and shape. Cooking time is associated with the weight, surface area and distance that heat must travel to get to the thickest part of the meat. Lowe (1955) stated that with those factors standardized, large cuts of meat required less cooking time per pound than similar small cuts, because as the size of a piece of meat is increased, its weight is increased in greater ratio than its dimensions. That agrees with the work done by Harrison et al. (1953) who found that rib roasts had less surface area per unit weight than steaks and required less time per pound to cook. Bramblett and Vail (1964) stated that cooking time varied with the size of the muscle as well as with the temperature of cooking. They also reported that smaller cuts required longer cooking time per pound than did larger cuts.

Cooking medium and temperature. As previously stated, the cooking medium influences the rate at which heat is transferred into the meat, with moist heat methods facilitating a faster rate of heat penetration (Morgan and Nelson, 1926; Harrison et al., 1953; Visser et al., 1960). Cover (1941) cooked beef roasts in an open pan in an oven at 90°C and by submerging them in a water bath at 90°C. One-third to one-half less cooking time for water-cooked roasts indicated faster heat penetration with moist heat than with dry heat.

Lowe (1955) stated that the higher the temperature of the medium surrounding the meat, the faster the heat will penetrate into the interior. Beef cooked at high temperatures takes less total cooking time and less time per pound than that cooked at lower temperatures (Cover, 1943; Hunt et al., 1963; Weir et al., 1963). Cover (1943) cooked beef roasts at oven temperatures of 80° and 125°C, and found that the use of 80°C took three to five times longer

to reach a particular end point temperature in the center of the roast than roasting at 125°C. Thus, there was slower heat penetration at the lower temperature. Bramblett and Vail (1964) reported similar findings.

MATERIALS AND METHODS

Twelve USDA Choice Grade top rounds (2.7-3.1 kg) were purchased from a local wholesale company. The outside fat covering was removed, and the semi-membranosus (SM) and adductor (AD) muscle were squared off and divided into four roasts (Fig. 1), ranging from 1232 to 1400 g. Dimensions of roasts, in cm, were: length, 10-17; width, 10-15.5; and depth, 6.5-10. At the time of cutting, all roasts were wrapped in 0.0015 gauge aluminum foil, frozen in an upright household freezer at -19°C (-2°F), and stored in that freezer for 3-9 weeks.

At each evaluation period three roasts were cooked from the frozen state by one of the following treatments: (1) dry heat roasting (OR); (2) moist heat cooking in oven film bags (OFB);[a] or (3) moist heat cooking in a slow cooker (SC)[b] (Table 1). A rotary hearth gas oven maintained at 94°C (200°F) was used for the dry heat roasting and for cooking in oven film bags. The slow cooker was maintained at setting No. 3. Under preliminary test conditions, the temperature of 1890 ml tap water in the slow cooker rose from 26° to 87°C after 190 minutes, and remained at 87°C for an additional 30 min. After 60 min, the temperature of the empty pot did not change when the cooker was heated for a total of 120 min (Table 7, Appendix p. 65). The roasts were cooked to an internal end point temperature of 60°C (140°F) or 70°C (158°F) as specified by the experimental design (Table 1).

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[a] Reynold's Brown-In-Bag (nylon 66 with a heat stabilizer).

[b] West Bend 'Lazy Day' Slo-Cooker.

Table 1-Experimental design for cooking and raw sample position

Evaluation period	Replication	Animal number	Roast code	Treatment[a]	Raw sample position
1	1	1	C	I	Distal
		1	A	III	Proximal
		1	B	V	Proximal
2	1	2	B	II	Proximal
		2	A	IV	Proximal
		2	D	VI	Distal
3	2	3	D	II	Distal
		3	B	IV	Proximal
		3	A	VI	Proximal
4	2	4	B	I	Proximal
		4	C	III	Distal
		4	D	V	Distal
5	3	5	D	I	Distal
		5	B	III	Proximal
		5	A	V	Proximal
6	3	6	B	II	Proximal
		6	C	IV	Distal
		6	A	VI	Proximal
7	4	7	A	II	Proximal
		7	C	IV	Distal
		7	D	VI	Distal
8	4	8	A	I	Proximal
		8	D	III	Distal
		8	C	V	Distal
9	5	9	C	I	Distal
		9	A	III	Proximal
		9	B	V	Proximal
10	5	10	A	II	Proximal
		10	B	IV	Proximal
		10	C	VI	Distal
11	6	11	D	I	Distal
		11	C	III	Distal
		11	A	V	Proximal

Table 1-(Concluded)

Evaluation period	Replication	Animal number	Roast code	Treatment[a]	Raw sample position
12	6	12	D	II	Distal
		12	B	IV	Proximal
		12	A	VI	Proximal

[a] Treatments:
    I 60°C, Oven roasted
   II 70°C, Oven roasted
 III 60°C, Oven film bag
  IV 70°C, Oven film bag
   V 60°C, Slow cooker
  VI 70°C, Slow cooker

A hole was bored into the center of each roast for a centigrade thermometer. Roasts cooked by dry heat were removed from the foil, and placed on a low rack in a shallow roasting pan. Roasts cooked in the oven film bags were removed from the foil, placed in the bag, and the bag was closed with a twister tie. Six slits (approximately 5.0 cm long) were made in the bag to allow escape of steam to help prevent the bag from breaking. Roasts cooked in the low cooker were removed from the foil, placed on a rack in the porcelain cooking pot, and the pot placed on the electric base.

Analysis of data

The experimental design was a split plot for six treatment combinations with six replications. The end point temperatures were the main plots, and the types of cooking were the subplots. Data for each measurement used to evaluate the effects of internal end point temperature and type of cooking were analyzed by the following analysis of variance:

Source of variation	D/F
End point	1
Error (a)	2(r − 1)
Type of cooking	2
End point x type of cooking	2
Error (b)	4(r − 1)
Total	6r − 1, where r is the number of replications.

Data were analyzed by analysis of variance; when F-values were significant least significant differences at the 5% level were calculated. Correlation coefficients for selected paired variates were calculated on the basis of end point temperature.

Rate of heat penetration, cooking time, post-heating
temperature rise and cooking losses

The rate that heat penetrated the muscle was observed by recording the

time, in minutes, required for the internal temperature of each roast to reach

0°C, and for each 10°C increase between 0° and 40°C, and for every 5°C increase

between 40°C and the internal end point temperature. Total cooking time in

minutes was recorded, and cooking time in min/kg was calculated.

The maximum internal temperature (°C) reached after removal from heat,

and the time required to reach that temperature was recorded as post-heating

temperature rise.

Percentage total and dripping losses were calculated on the basis of the

weight of the frozen roast for all methods; also, volatile losses were cal-

culated on the same basis for the roast cooked by dry heat roasting. Drippings

from all roasts were collected in 250-ml graduated cylinders and the total

volume of drippings were recorded after standing 30 min.

pH, shear values and Gardner color-difference

Duplicate pH measurements were made on slurries of ground raw and cooked

muscle using a Beckman Expanded Scale pH Meter. For each slurry, 10 g ground

muscle (Fig. 1) was blended with 100 ml distilled, deionized water for 2 min

at high speed in a Waring Blendor. The slurry was stirred 30 sec with a

magnetic stirrer and the pH reading taken. The beaker was turned 180°, the

slurry stirred an additional 15 sec, and a second pH reading taken. The pH

meter was standardized against a buffer of pH 6.86.

Tenderness was measured by shearing 1.3-cm cores from raw and cooked

samples (Fig. 1) on the Warner-Bratzler shearing apparatus with a 11.4-kg

dynanometer. Triplicate measurements were made on each core, and the average shear value was calculated.

Color-difference factors were measured with a Gardner Color Difference Meter standardized against ceramic tiles similar in color to the samples measured. Calculated values of the ceramic tile used to standardize the instrument for raw samples are: Rd (reflectance), 5.5; a+ (redness), 26.8; and b+ (yellowness), 13.0. Calculated values of the ceramic tile used to standardize the instrument for measurements on cooked samples are: Rd (reflectance), 38.0; a+ (redness), 6.6; and b+ (yellowness), 14.7. A center of a slice of meat (Fig. 1) was cut with a round cookie cutter 5.5 cm diam; the sample was allowed to bloom for 5 min, then inserted in the Gardner plexiglass cell so that light could not filter through the sample. Duplicate measurements were made for each color-difference factor. After the first measurement, the cell was rotated 90° for the second measurement.

Water-holding capacity and total moisture

Triplicate measurements for water-holding capacity (WHC) were made by the method of Miller and Harrison (1965) on samples from the center of cores from cooked samples used for Warner-Bratzler shear values (Fig. 1). The ratio of the area of pressed muscle to the area expressed liquid on filter paper on which the sample was pressed was designated as the expressible-liquid index. Values for WHC were obtained by subtracting the expressible-liquid index from 1.0, arbitrarily chosen as the maximum expressible-liquid index. The expressible-liquid index is inversely related to the amount of liquid expressed from the sample. Therefore, the larger the WHC value, the more liquid expressed.

Fig. 1-Sampling plan for beef top round (semimembranosus and adductor muscles).

A, B, C, D -- Roasts cut from the muscles into portions of similar size and shape. Each roast was sampled as indicated in B.

1 - Shear cores and water-holding capacity.

2 - Total moisture and pH.

3 - Thermometer.

4 - Slice for panel evaluation of degree of doneness.

5 - Slice for color-difference.

6 - Palatability samples.

7 - Raw samples were cut from the proximal (Roasts A and B) or distal (Roasts C and D) end, as indicated by position of samples (Table 1). Sample was taken for color-difference, and the rest was ground for total moisture and pH measurements.

E -- Portion of muscle that was discarded.

THIS BOOK
CONTAINS
NUMEROUS PAGES
WITH DIAGRAMS
THAT ARE CROOKED
COMPARED TO THE
REST OF THE
INFORMATION ON
THE PAGE.

THIS IS AS
RECEIVED FROM
CUSTOMER.
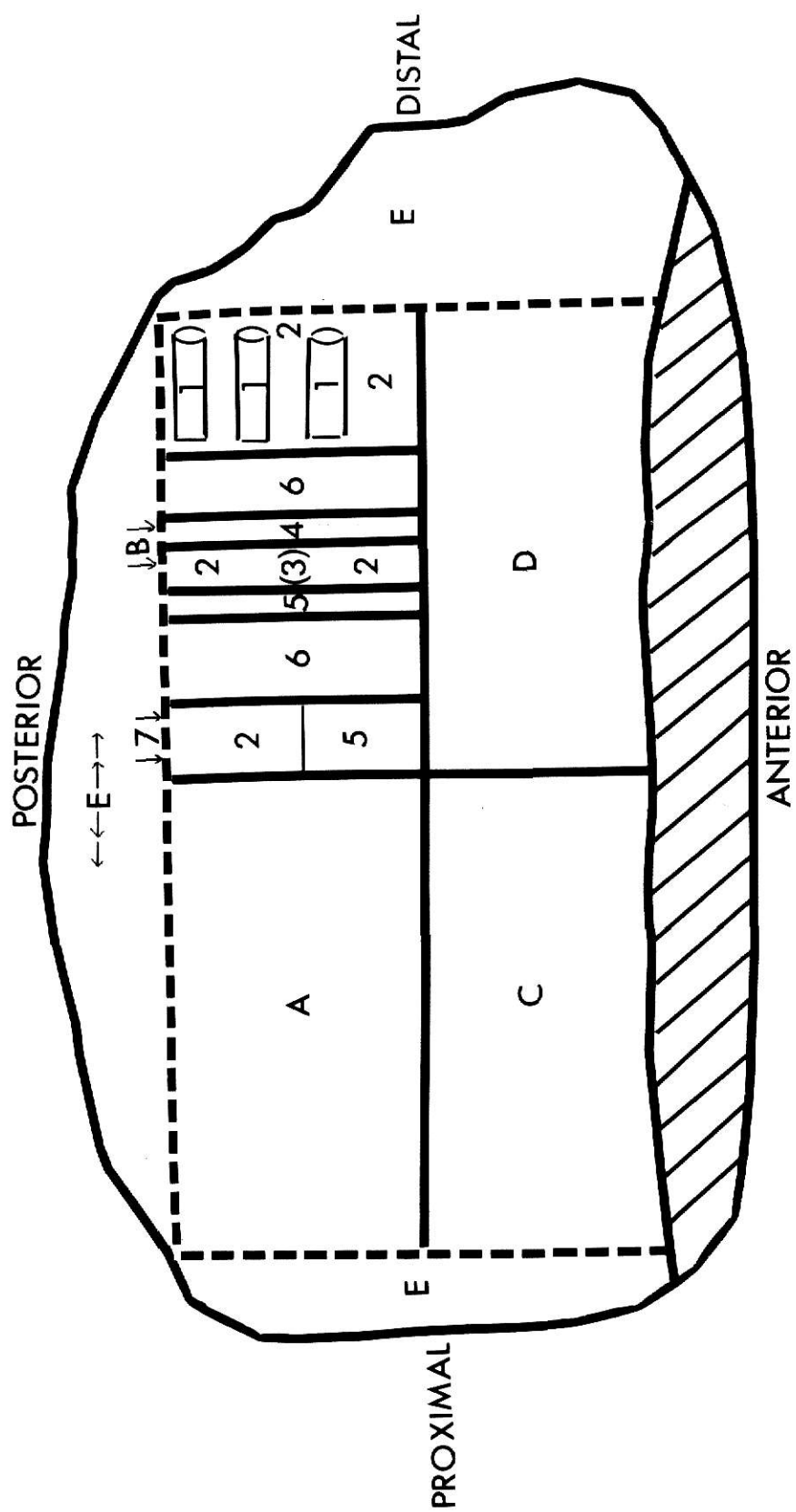
Percentage total moisture was determined by drying duplicate 10-g samples of ground muscle (Fig. 1) in a C.W. Brabender Semi-Automatic Rapid Moisture Tester regulated at 121°C. Raw and cooked samples were dried 90 and 60 min, respectively.

Sensory evaluation

Tenderness, texture, juiciness, flavor and apparent degree of doneness of each sample were scored by a laboratory panel of eight members (Form I, Appendix p. 62). A slice of muscle (Fig. 1) was covered with a transparent household plastic wrap and was placed under a MacBeth Skylight and evaluated as rare, medium-, or well-done. Instructions for evaluation were given to each judge during preliminary work (Form II, Appendix p. 63). Judges selected at random two samples (1.3-cm cubes) of muscle from small ceramic casseroles set on an electric hot tray maintained at 35°C ± 1°C. The samples were scored within 30 min after the meat was prepared for evaluation.

RESULTS AND DISCUSSION

Initial weight of roasts, rate of heat penetration

Analysis of variance indicated no significant differences among weights of the roasts assigned to the three methods of cooking (Table 2). However, there were differences (P<0.01) among weights of the roasts assigned to the two end point temperatures (Table 3). Roasts cooked to 60°C weighed approximately 43 g or 3% more than those cooked to 70°C.

Data for the rate heat penetrated the muscle by each cooking method are presented in Table 2. The time required to raise the internal temperature to 0°C and from 0° to 10°C was less for OR than for either OFB or SC. This

Table 2—Means, F-values and LSDs for effects of method of cooking[a]

| Measurement | Method of cooking[b] | | | F-value | LSD* |
	OR	OFB	SC		
Initial weight, g	1345.25	1338.17	1354.92	0.24 ns	----
Rate of heat penetration					
Initial temp to 0°C, min	150.17	168.33	176.17	5.12**	----
0° to 10°C, min	35.38	49.91	42.18	4.44*	----
min/10°C, 10° to 40°C	21.45	17.15	17.29	----	----
min/5°C, 40° to 60°C	34.79	19.31	19.21	----	----
min/5°C, 60° to 70°C[c]	101.25	37.42	31.67	----	----
Cooking time					
Total, min	497.50	379.17[d]	376.92[d]	63.30**	25.58
Min/kg	372.69	283.41[d]	278.96[d]	54.46**	21.14
Cooking losses, %					
Total	24.84	25.00	24.08	0.40 ns	----
Drip	2.11	20.28[d]	19.85[d]	124.42**	2.74
Volume of drip, ml	----	227.50	245.75	0.77 ns	----
Total moisture, %	64.57	64.09	65.17	0.78 ns	----
Water holding capacity[e]	0.68	0.68	0.69	0.20 ns	----
pH	5.67	5.65	5.64	0.28 ns	----
Shear value, kg/1.3 cm core	4.16	4.70	4.85	0.95 ns	----

Table 2-(Concluded)

Measurement	Method of cooking[b]			F-value	LSD*
	OR	OFB	SC		
Color-difference, Gardner					
Rd (reflectance)	16.27	17.49	15.92	2.05 ns	----
a+ (redness)	9.04	6.48	8.07	3.12 ns	----
b+ (yellowness)	10.77	11.42	11.69	0.68 ns	----
Sensory scores					
Tenderness[f]	5.41	4.68	5.51	3.28 ns	----
Softness[f]	5.02	4.32	4.86	2.06 ns	----
Mealiness[f]	4.65	4.42	4.55	0.46 ns	----
Juiciness[f]	4.66	4.02	4.50	3.01 ns	----
Flavor[f]	4.73	4.64	4.85	0.95 ns	----
Apparent degree of doneness[g]	1.93	2.22[d]	2.15[d]	4.42*	0.21

[a] Data irrespective of end point temperature

[b] OR--oven roasted; OFB--oven film bag; SC--slow cooker

[c] Data for roasts cooked to 70°C

[d] Means sharing a common superscript are not significantly different at the 5% level

[e] 1.0 minus (expressible liquid index); the larger the value, the greater the amount of liquid expressed

[f] 7--(extremely tender, soft, mealy, juicy or desirable flavor); 1--(extremely tough, hard, chewy, dry or undesirable flavor)

[g] 3 = well-done; 2 = medium-done; 1 = rare

* $P<0.05$; ** $P<0.01$

Table 3—Means and F-values for effects of end point temperature[a]

| Measurement | End point temperature, °C | | Difference | F-value |
	60	70		
Initial weight, g	1367.55	1324.67	42.88	15.74**
Cooking time				
Total, min	359.50	476.22	116.72	120.53**
Min/kg	262.77	360.60	97.83	189.87**
Cooking losses, %				
Total	19.64	29.65	10.01	66.25**
Drip	12.05	16.11	4.06	8.35*
Volatile	16.09	29.38	13.29	149.71**
Volume of drip, ml	195.25	278.00	82.75	14.70**
Total moisture, %	66.09	63.13	2.96	11.29**
Water-holding capacity[b]	0.69	0.66	0.03	6.82*
pH	5.64	5.66	0.02	0.10 ns
Shear value, kg/ 1.3-cm core	4.30	4.66	0.36	1.54 ns
Color-difference, Gardner				
Rd (reflectance)	14.58	18.54	3.96	6.40**
a+ (redness)	12.42	3.31	9.11	51.00**
b+ (yellowness)	9.78	12.80	3.02	2.82*
Sensory scores				
Tenderness[c]	5.20	5.20	0.00	ns
Softness[c]	4.85	4.61	0.24	0.81 ns
Mealiness[c]	4.23	4.84	0.61	7.81*
Juiciness[c]	5.14	3.65	1.49	41.56**
Flavor[c]	4.78	4.70	0.08	0.33 ns

Table 3-(Concluded)

| Measurement | End point temperature, °C | | Difference | F-value |
	60	70		
Apparent degree of doneness[d]	1.54	2.66	1.12	187.00**

[a] Irrespective of cooking method

[b] 1.0 minus (expressible liquid index); the larger the value, the greater the amount of liquid expressed

[c] 7--(extremely tender, soft, mealy, juicy or desirable flavor); 1--(extremely tough, hard, chewy, dry or undesirable flavor)

[d] 3 = well-done; 2 = medium-done; 1 = rare

* $P < 0.05$; ** $P < 0.01$

supports the findings of Ferger et al. (1972) who reported that it took less time for beef roasts cooked from the frozen state by dry heat at 149°, 163° or 177°C to reach 0°C than for beef roasts cooked by moist heat at the same temperatures. The rate of temperature rise in OR begain to slow down after reaching an internal temperature of 10°C, with the time lapse increasing with each temperature interval nearing the end point. There was little difference in the rate of temperature rise from 10°C to the end point between OFB and SC, indicating that the two moist heat treatments had similar effects on rate of heat penetration.

Additional details of mean heat penetration data in Table 2 can be observed in heat penetration curves in Fig. 2. For all three methods of cooking to both end point temperatures, heat penetrated the muscle at a fairly constant rate from the initial temperature to 0°C and from 0° to 10°C. In roasts cooked to 60°C, rate of penetration from 0° to 30°C for SC was faster than for OR or OFB. From 30° to 60°C, the temperature rise in OR slowed down; whereas, the rate remained fairly constant for OFB and SC. In roasts cooked to 70°C, rate of penetration from 0° to 40°C for OR was faster than for SC or OFB. From 40° to 70°C, the temperature rise in OR slowed down; whereas, the penetration rate remained fairly constant for OFB and SC. Rate of heat penetration data reported in this study are consistent with the findings of Visser et al. (1960), who found the rate of penetration slowed down after the internal temperature reached 40°C in beef roasts cooked by dry heat at 149°C. After that, the curves gradually flattened until the end point temperature was reached.

Fig. 2-Rate of heat penetration from initial temperature to 0°C, and from 0° to 60° or 70°C for beef top round cooked at low temperatures.

32

END POINT TEMP. – 60°C

OR
OFB
SC

MINUTES

END POINT TEMP. – 70°C

OR
OFB
SC

MINUTES

MINUTES

MINUTES
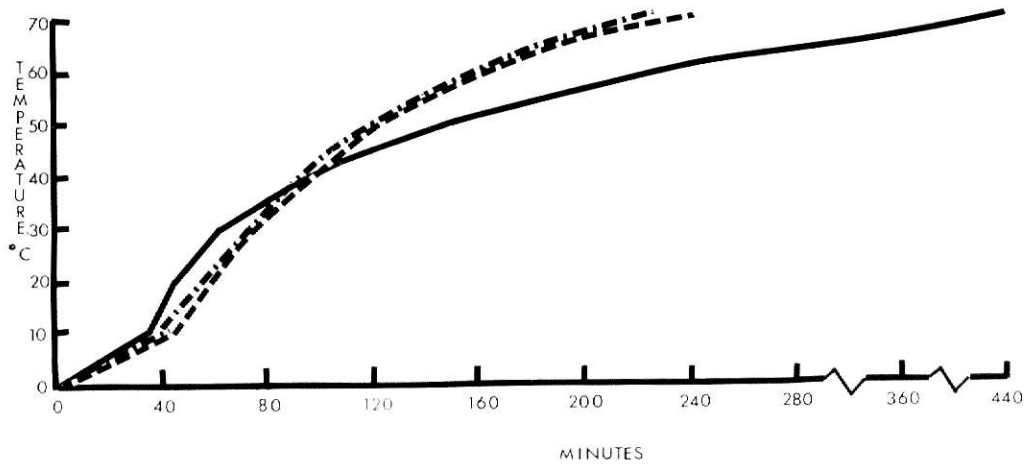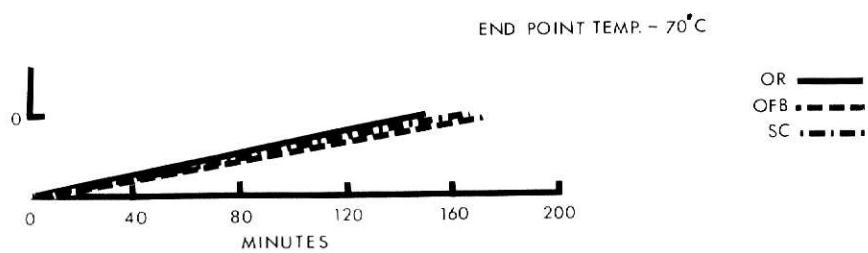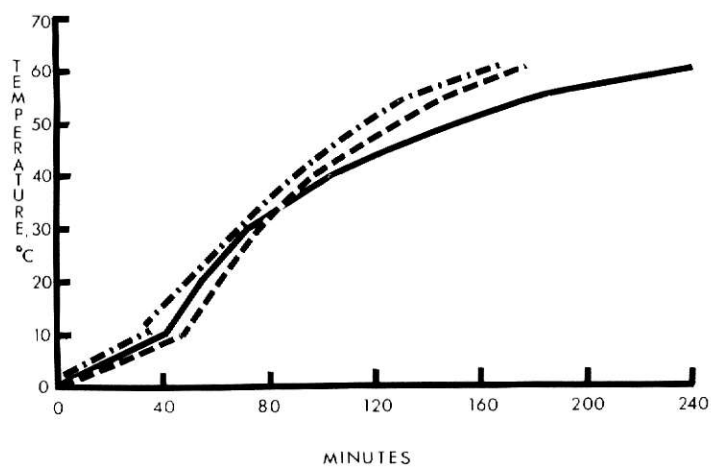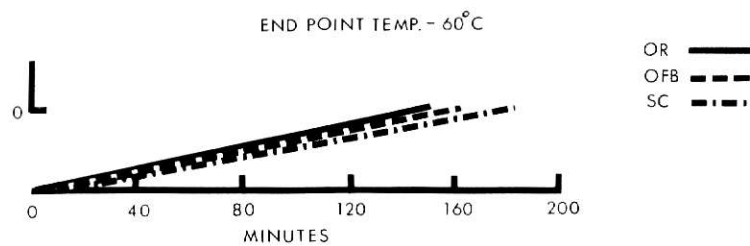
Method of cooking

Measurements affected (P<0.01) by method of cooking were: cooking time
in min and min/kg and drip cooking losses (Table 2). Total cooking time and
cooking time in min/kg for OR were greater (P<0.05) than for both OFB and SC;
whereas, drip cooking losses for OR were less (P<0.05) than for OFB and SC.
Hood (1960) cooked shoulder roasts by dry and moist heat at 149°C to an end
point temperature of 77°C. Roasts cooked by dry heat took longer to reach the
end point temperature, but had less drip loss than did the roasts cooked by
moist heat. Shaffer et al. (1973) cooked beef top round roasts in open pans
and in oven film bags at 177°C or 205°C to end point temperatures of 60°, 70°
or 80°C. They reported that cooking time in min/kg was greater (P<0.01) and
drip cooking losses were less (P<0.01) for roasts cooked by dry heat than for
roasts cooked by moist heat. Schock et al. (1970) reported similar findings.

Methods of cooking also affected (P<0.05) the apparent degree of doneness
scores (1 = rare; 3 = well-done). Scores were lower (P<0.05) for OR than for
either of the two moist heat methods, which were not significantly different
from each other. Schock et al. (1970) cooked beef top round roasts by deep
fat frying, oven-roasting, oven-braising and in a pressure saucepan to an end
point temperature of 70°C. They also found that apparent degree of doneness
scores were lower (P<0.05) for OR than for each of the other treatments.
Shaffer et al. (1973) reported similar findings for apparent degree of done-
ness scores as affected by dry and moist heat.

Measurements on which method of cooking had no significant effect were:
total cooking losses, volume of drip for the two moist heat methods of cook-
ing, total moisture, WHC, pH, Warner-Bratzler shear values, Gardner Rd

(reflectance), a+ (redness) and b+ (yellowness) values and tenderness, soft-

ness, mealiness, juiciness and flavor scores.

It was not possible to measure the volume of drip for OR. The "drip" for

the roasts cooked in open pans formed a sticky mass. With increased exposure

to heat, this formed a charred residue (Fig. 3). Those results can be

attributed to the low oven temperature (95°C) and the long cooking time

required for dry heat roasting. Marshall et al. (1960) obtained similar

results when they cooked beef top round roasts at three oven temperatures

(95°, 107° or 121°C) to three end point temperatures (60°, 70° and 80°C).

They reported that meat cooked to well-done (80°C) at a low oven temperature

resulted in the evaporation of drip to form a hard, almost charred residue.

The conditions of the two moist heat methods used in this study did not have

the same effect on the drip at the low cooking temperatures. Slightly more

drip was collected for SC than for OFB, but the difference was not significant

(Table 2, Fig. 3).

End point temperature

Data for effects of end point temperature are in Table 3 (p. 28).

Measurements affected at the P<0.01 level are: total cooking time in

minutes and min/kg, total and volatile cooking losses, total moisture, volume

of drip, Gardner Rd (reflectance) and a+ (redness) values and juiciness and

apparent degree of doneness scores. Measurements affected at the P<0.05 level

are: drip cooking losses, WHC, Gardner b+ (yellowness) values and mealiness

scores.

All differences between end points of 60° and 70°C were as would be

expected. Although initial weights of the roasts cooked to 60°C were greater

(P<0.01) than for those cooked to 70°C, total cooking time in min and min/kg

Fig. 3-Drip remaining in pan after dry heat roasting (OR), and volume of drippings, in ml, after moist heat cooking (OFB and SC).

OR -70°C.   OR-60°C.
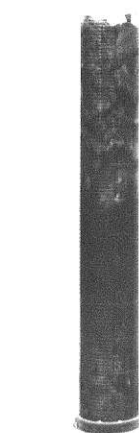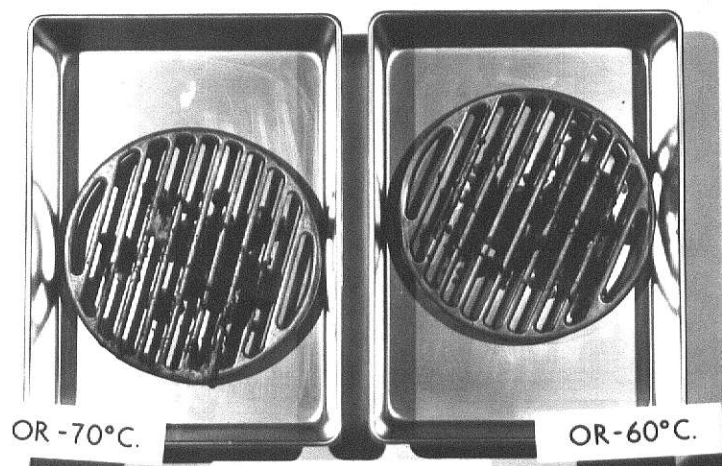
OFB -60°C.   OFB -70°C.   SC - 60°C.   SC - 70° C.

were 117 min and 98 min/kg less for the lower end point temperature. Total and volatile cooking losses (P<0.01), volume of drip (P<0.01) and drip cooking losses (P<0.05) were greater for roasts cooked to 70° than for those cooked to 60°C. Correlation coefficients calculated for total cooking time in min vs total cooking losses indicated a moderate positive relationship (r=0.50) between the variates at 70°C (Table 4).

As cooking losses and volume of drip increased with an increased end point temperature, WHC, total moisture and juiciness scores decreased. At 70°C, a moderate negative relationship existed for juiciness scores vs total cooking losses and juiciness scores vs volume of drip (r=-0.62 and r=-0.42, respectively). This supports the findings of Shaffer et al. (1973), who found that moisture was greatest in roasts cooked to 60°C, and decreased (P<0.05) with each succeeding increase in end point temperature.

With increased end point temperature, meat became lighter in color as indicated by Gardner Rd, reflectance, (P<0.01) and b+, yellowness, (P<0.05) values. Both Gardner a+ (redness) values and apparent degree of doneness scores indicated that roasts cooked to 60° were redder (P<0.01) or less well-done, than roasts cooked to 70°C. Correlation coefficients indicated moderate positive relationships between total cooking time in min vs Gardner Rd (r=0.40) and apparent degree of doneness (r=0.49), and a moderate negative relationship between total cooking time in min vs Gardner a+ values (r=-0.46). A moderate positive relationship existed for apparent degree of doneness vs Gardner Rd (r=0.51), and a moderate negative relationship was shown for apparent degree of doneness vs Gardner a+ values (r=-0.48). This is in agreement with Shaffer et al. (1973), who stated that meat became lighter (Rd values) and lost redness (a+ values) with an increase in end point temperature between 60° and 80°C.

Table 4—Correlation coefficients for selected paired variates on the basis of end point temperature

Paired variates d/f=16	r-Values[a] End point temperature, °C	
	60	70
Total cooking time, min, vs:		
Total cooking losses (%)	−0.38	0.50*
Post oven temperature rise	−0.36	−0.33
Color-difference, Gardner		
Rd	−0.26	0.40
a+	0.10	−0.46
b+	−0.58*	−0.12
Shear value (kg/1.3 cm core)	−0.20	0.48*
Tenderness score	0.32	0.02
Mealiness score	0.24	0.28
Juiciness score	0.42	−0.32
Apparent degree of doneness	0.37	0.49*
WHC[b] vs:		
Total moisture	0.22	0.54*
Volume of drip, ml	−0.37	0.43
Total moisture vs:		
Total cooking losses (%)	−0.25	−0.08
pH	0.63**	0.17
Apparent degree of doneness vs:		
Shear value (kg/1.3 cm core)	0.17	−0.61**
Color-difference, Gardner		
Rd	0.42	0.51*
a+	−0.67	−0.48*
b+	0.71**	0.07

Table 4-(Concluded)

Paired variates d/f=16	r-Values[a] End point temperature, °C	
	60	70
Tenderness score	-0.37	-0.45
Softness score	-0.51*	-0.38
Juiciness score	-0.66**	-0.73**
Shear value (kg/1.3-cm core) vs:		
Rate of heat penetration, min at 55-60°C	-0.04	0.05
Rate of heat penetration, min at 65-70°C	----	-0.54*
Tenderness score	-0.23	0.39
Softness score	-0.24	0.41
Juiciness score	-0.20	0.50*
Tenderness score vs:		
Rate of heat penetration, min at 55-60°C	0.36	0.37
Rate of heat penetration, min at 65-70°C	----	-0.20
Softness score	0.91**	0.94**
Mealiness score	0.69**	0.56*
Juiciness score	0.53*	0.58*
Juiciness score vs:		
Total cooking losses (%)	-0.31	-0.62*
Total moisture	0.08	-0.32
Volume of drip, ml	0.01	-0.42

[a] Levels of significance: *P<0.05, r=0.468; **P<0.01, r=0.590

[b] WHC, 1.0--(expressible moisture index)

Mealiness scores were higher (P<0.01) for roasts cooked to 70° than for those cooked to 60°C. Ritchey and Hostetler (1965) found that in biceps femoris muscle cooked to 61°, 68°, 74° and 80°C, there was a slight sensation of mealiness at 61°C, and that this sensation became more apparent as the end point temperature increased. In the present study, tenderness, softness and flavor scores, pH and Warner-Bratzler shear values were not affected significantly by end point temperature.

Effects of end point temperature, as reported in this study, for some measurements agree with results of Hood et al. (1955) and Visser et al. (1960). When Hood et al. (1955) broiled biceps femoris steaks to 71.5° and 80°C, those cooked to the lower end point temperature were the juicier. They reported no significant differences in tenderness or flavor of the steaks attributable to end point temperature. Visser et al. (1960) cooked beef roasts from seven muscles in the oven (149°C, 300°F) and in deep fat (100°C, 212°F) to rare, medium and well-done. They reported that average cooking time and average total cooking losses increased and juiciness decreased as degree of doneness increased. Average tenderness scores and shear values did not differ significantly among degrees of doneness.

Apparent degree of doneness, post-heating temperature rise

Apparent degree of doneness scores were lower (P<0.05) for roasts cooked by dry heat roasting than for either of the moist heat methods (Table 2), and as expected, were higher for roasts cooked to 70°C than for those cooked to 60°C (Table 3). Roasts cooked by dry heat to an internal temperature of 60°C appeared bright red throughout, and exuded juice on standing. Those cooked to 70°C appeared pink throughout and did not exude juice on standing. Roasts cooked in the OFB to 60°C appeared pink throughout, and those cooked to 70°C

appeared pinkish brown throughout. Roasts cooked to 60°C in the SC appeared pinkish red throughout most of the roast; whereas, the roasts cooked to 70°C appeared pinkish brown. However, in both roasts, a layer at the bottom of the roast (approximately 1-in thick) had faded to grey brown. This might be attributable to the heating element being located in the bottom of the slow cooker; thus, there was faster transfer of heat to the bottom of the roast via the metal rack.

The surface of the roasts cooked by dry heat was crusty and rich, dark brown. The surface color of roasts cooked by either moist heat method was grey brown. The drip collected from roasts cooked in the OFB was dark brown; whereas that from roasts cooked in the SC was reddish-orange. Coagulum could be seen in drip collected from roasts cooked by either moist heat method (Fig. 3).

Data for post-heating temperature rise were not analyzed statistically, because there was little rise in temperature after the roasts were removed from the source of heat. Post-heating temperature rise was observed most frequently when roasts were cooked by either moist heat method to 60°C. Those roasts remained in the oven film bag or in the porcelain cooking pot of the slow cooker during observation of post-heating temperature rise. Roasts cooked in the SC to 70°C averaged less than 1°C increase. However, time required to reach the maximum temperature rise ranged from 1.3 to 12.5 min (Table 14, Appendix p. 75). No post-heating temperature rise was exhibited by roasts cooked by dry heat to either 60° or 70°C and by roasts cooked in OFB to 70°C.

Slight post-heating temperature rise is not unusual when cooking at a low temperature for a long time. The findings of this study are consistent with those of Latzke (1930), who stated that the rise in temperature that occurs

after removal of beef roasts from heat varies directly with the cooking temperature, the higher the temperature the greater the post-heating temperature rise. She also pointed out that this rise varies inversely with the internal temperature of the roast at the time of removal from heat; thus explaining why roasts cooked to 70°C exhibited little or no post-heating temperature rise in this study.

Relationships between selected measurements on the
basis of end point temperature

Significant differences were found with end point temperature more often than with method of cooking for certain objective and subjective measurements. Therefore, correlation coefficients were computed pooling the data from the three cooking methods to establish relationships between selected measurements with respect to end point temperature (Table 4). In this discussion, relationships will be discussed in terms of Shindell (1964), who considered a coefficient between 0.00 and 0.39, irrespective of sign, low and a poor relationship between variates; a coefficient between 0.40 and 0.79 was designated as a moderate relationship; and one of 0.80 or above was considered a good relationship.

The positive correlation coefficients for tenderness score vs softness score at both 60° and 70°C were high and significant at the 5% level. Moderate correlations within each end point temperature occurred for the following paired variates: apparent degree of doneness vs Gardner Rd values (P<0.05 at 70°C), Gardner a+ values (P<0.05 at 70°C) and juiciness scores (P<0.05 at 60°C; P<0.01 at 70°C). As apparent degree of doneness scores increased (1 = rare; 3 = well done), Gardner Rd values increased; whereas, Gardner a+ values and juiciness scores decreased.

Moderate correlations for an end point of 60°C occurred for: total cooking time in min vs Gardner b+ value (P<0.05) and juiciness scores; total moisture vs pH; apparent degree of doneness vs Gardner b+ values (P<0.01) and softness scores (P<0.05). As total cooking time in min increased, juiciness scores increased and b+ values decreased. Total moisture was positively correlated with pH values. As apparent degree of doneness increased, b+ values increased and softness scores decreased.

Moderate correlations for an end point of 70°C occurred for: total cooking time in min vs total cooking losses (P<0.05), Gardner Rd and a+ values, shear values (P<0.05) and apparent degree of doneness scores (P<0.05); WHC vs total moisture (P<0.05) and volume of drip; apparent degree of doneness vs shear value (P<0.01) and tenderness scores; shear value vs rate of heat penetration from 65° - 70°C (P<0.05), softness score and juiciness score (P<0.05); juiciness score vs total cooking losses (P<0.05) and volume of drip. Total cooking losses, Rd values, shear values and apparent degree of doneness scores increased and a+ values decreased as total cooking time in min increased. There was a positive relationship between WHC and both total moisture and volume of drip. As apparent degree of doneness scores increased, shear values and tenderness scores decreased. There was a positive relationship between shear value and both softness and juiciness scores. Also, the longer the time that the internal temperature of the roasts was between 65° - 70°C, the lower the shear values. A decrease in total cooking losses and volume of drip resulted in a higher juiciness score.

End point temperature x method of cooking

Data in Table 5 for significant end point temperature x method of cooking interactions help explain some of the data in Tables 2 and 3. The interaction

Table 5-Means, F-values and LSDs for significant end point temperature x method of cooking interactions

Measurement	End point temperature, °C	Method of cooking			F-value	LSD*
		OR	OFB	SC		
Cooking time						
Total, min	60	383.17^{ab}	348.83^{bc}	346.50^{c}	31.26**	36.17
	70	611.83	409.50^{a}	407.33^{a}		
Min/kg	60	277.86^{bc}	258.80^{c}	251.66^{c}	30.83**	29.89
	70	467.52	308.02^{a}	306.25^{ab}		
Cooking losses, %						
Total	60	18.00^{c}	20.83^{c}	20.08^{c}	4.12*	3.28
	70	31.69^{a}	29.17^{ab}	28.08^{b}		
Color-difference Gardner						
Rd (reflectance)	60	12.85^{d}	16.53^{bc}	14.35^{cd}	4.92*	2.41
	70	19.68^{a}	18.45^{ab}	17.48^{ab}		
a+ (redness)	60	15.57	9.82^{a}	11.87^{a}	5.55*	3.05
	70	2.52^{b}	3.15^{b}	4.27^{b}		
Post-heating temperature						
Rise, °C	60	0.0	1.67	1.92	----	----
	70	0.0	0.0	0.33		
Sensory scores						
Juiciness^{e}	60	5.9	4.4^{ab}	5.1^{a}	6.36**	0.79
	70	3.4^{c}	3.7^{bc}	3.9^{b}		

Table 5-(Concluded)

| Measurement | End point temperature, °C | Method of cooking | | | F-value | LSD* |
		OR	OFB	SC		
Apparent degree of doneness[f]	60	1.08	1.82[b]	1.73[b]	12.31**	0.30
	70	2.78[a]	2.63[a]	2.57[a]		

[a,b,c,d] Means sharing a common superscript are <u>not</u> significantly different at the 5% level

[e] 7 = extremely juicy; 1 = extremely dry

[f] 3 = well-done; 2 = medium-done; 1 = rare

* $P<0.05$; ** $P<0.01$

between those two parameters was significant (P<0.01) for total cooking time in min and in min/kg, and for juiciness and apparent degree of doneness scores. End point temperature x method of cooking affected (P<0.05) total cooking losses and both Gardner Rd (reflectance) and a+ (redness) values (Table 5).

By each of the three methods of cooking, total cooking time and cooking time in min/kg was greater (P<0.05) for roasts cooked to 70°C than for those cooked to 60°C. Differences (P<0.01) for those factors as affected by end point temperature (Table 3) can be attributed to all methods of cooking (Table 5), but the magnitude of difference between means was greatest for OR. The only difference (P<0.05) for roasts cooked to 60°C was in total cooking time between OR and SC. When cooking to an internal end point temperature of 70°C, cooking time in min and min/kg was greater (P<0.05) for OR than for either OFB or SC, which were not significantly different. Therefore, the differences (P<0.05) for cooking time in min and min/kg between OR and each of the moist heat treatments in Table 2 can be attributed to the large mean value for OR cooked to 70°C for both of those factors (Table 5).

Total cooking time and cooking time in min/kg were not significantly different for OFB and SC at either end point, indicating that the two moist heat treatments had similar effect on cooking time. This suggests that cooking roasts to 70°C by approximately 163 - 165 min and 159 - 161 min/kg. This supports the findings of Shaffer et al. (1973), who found that the use of oven film bags required less time in min/kg to cook roasts to 70° and 80°C than was required by dry heat. Conversely, Ferger et al. (1972) found that cooking time for leg of lamb (end point, 75°C) and beef rib roasts (end point, 60°C) cooked in 3M Scotchpak Oven Service Film was not significantly different from cooking time for those cuts cooked by oven-roasting.

For each method of cooking, total losses were greater (P<0.05) for roasts cooked to 70° than those cooked to 60°C. Losses between the two end point temperatures were greatest for OR and least for SC. Juiciness scores were affected (P<0.05) by end point temperature only when roasts were cooked by OR or SC, with juiciness scores being higher for the lower end point temperature. Significant differences (P<0.05) for cooking losses and juiciness scores presented in Table 3 can be attributed to cooking methods, with OR having the greatest influence (Table 5). For all methods, as internal end point temperature and cooking time in min and min/kg increased, total losses increased and juiciness scores decreased. Those results agree with the data of Visser et al. (1960), who found that cooking time and total cooking losses increased; whereas, juiciness scores decreased with an increase in end point temperature for roasts cooked at 149°C by dry heat to 55°, 70° or 85°C.

In the present study, there were no significant differences in total cooking losses among methods when roasts were cooked to 60°C. At that end point temperature, juiciness scores were higher (P<0.05) for OR than for either SC or OFB. The only significant differences in total cooking losses and juiciness scores for roasts cooked to 70°C were between OR and SC. Losses were greater (P<0.05) for OR than for SC; whereas, juiciness scores were higher for SC than for OR. The mean differences between or among methods for cooking losses and juiciness scores (Table 5) were not large enough to result in significant differences for those factors attributable to method (Table 2).

The nonsignificant differences in total cooking losses among methods when roasts were cooked to 60°C are in contrast with the findings of Shaffer et al. (1973). They reported that total cooking losses were greater (P<0.05) for moist heat than for dry heat at end point temperatures of 60°, 70° and 80°C. This may be attributable, in part, to the high volatile cooking losses for OR

that resulted from the low cooking temperature and long cooking time used in this study.

Gardner Rd (reflectance) values were greater for roasts cooked to 70° than for roasts cooked to 60°C, with significant differences between end points for OR and SC. Gardner a+ (redness) values were less (P<0.05) and apparent degree of doneness scores were higher (P<0.05) for roasts cooked to 70° than for those cooked to 60°C by each of the three cooking methods. Significant differences for Gardner Rd (reflectance) and a+ (redness) values and apparent degree of doneness scores (Table 3) can be attributed to all methods of cooking (Table 5), with OR having the greatest influence.

The only difference (P<0.05) in Rd (reflectance) values for roasts cooked to 60°C was between OR and OFB. Gardner a+ (redness) values were greater (P<0.05) and apparent degree of doneness scores were less (P<0.05) for OR than for either OFB or SC, which were not significantly different. The differences among methods for Gardner Rd (reflectance) and a+ (redness) values (Table 5) were not great enough to result in significant differences attributable to method for those factors (Table 2). However, when method of cooking was considered (Table 2) for apparent degree of doneness scores, those differences at 60°C (Table 5) were large enough to result in a difference (P<0.05) between OR and both moist heat treatments. Those results confirm the findings of Schock et al. (1970), Ferger et al. (1972) and Shaffer et al. (1973), who found that the apparent degree of doneness scores were higher (P<0.05, P<0.01, P<0.01, respectively) for roasts cooked by moist heat than for those cooked by dry heat. In the present study, there were no significant differences among cooking methods for Gardner Rd (reflectance) values, Gardner a+ (redness) values and apparent degree of doneness scores when roasts were cooked to 70°C. This can be explained, in part, by the longer cooking time required for OR to

reach 70°C. Roasts cooked by dry heat usually appear less well-done than those cooked by moist heat. However, the longer exposure to heat produced a product comparable in Rd (reflectance) values, a+ (redness) values and apparent degree of doneness scores for OR that was not observed in OR cooked to 60°C.

Differences between raw and cooked muscle

As expected, total moisture, pH and Gardner Rd (reflectance), a+ (redness) and b+ (yellowness) values of raw beef changed when any one of the three cooking methods was used. To further study the changes attributable to heat treatments and end point temperatures, the differences between values for selected characteristics of raw muscle and muscle subjected to each cooking method to either end point temperature was calculated (Table 6).

There was less difference between the raw muscle and that cooked in the SC to either end point temperature for total moisture and pH. The changes in total moisture from raw muscle to cooked were similar for roasts cooked by OR or OFB to either end point temperature. The greatest change in pH from raw to cooked occurred in roasts cooked to 60° or 70°C by OR. For roasts cooked to 60°C, there was less change in all color difference factors for OR than for OFB and SC. For roasts cooked to 70°C, the smallest change for Rd (reflectance) and b+ (yellowness) was in OR; whereas the largest change for a+ (redness) was in OR. These data were not statistically analyzed.

SUMMARY

A split plot design with end point temperatures as the main plots and the types of cooking as the subplots was followed to cook 36 top round beef roasts from the frozen state by one of the following treatments: (1) dry heat

Table 6-Mean values for selected measurements on raw and cooked muscle according to heat treatment and internal end point temperature

Heat treatment[a,b]	Measurement				
	Total moisture, %	pH	Color-difference, Gardner[c]		
			Rd	a+	b+
Muscle cooked to 60°C:					
Raw muscle	69.82	5.62	8.39	15.24	4.94
OR	65.47	5.66	12.86	15.42	9.16
Diff	4.35	0.04	4.47	0.18	4.22
OFB	65.61	5.64	16.52	9.82	10.01
Diff	4.21	0.02	8.16	5.42	5.07
SC	66.36	5.63	14.34	11.87	10.19
Diff	3.64	0.01	5.95	3.37	5.25
Muscle cooked to 70°C:					
Raw muscle	71.26	5.62	9.21	15.12	5.94
OR	62.86	5.68	16.69	2.52	12.30
Diff	8.40	0.06	7.48	12.60	6.36
OFB	62.86	5.66	18.44	3.16	12.84
Diff	8.40	0.04	9.23	11.96	6.90
SC	63.65	5.65	17.45	4.25	13.21
Diff	7.61	0.03	8.24	10.87	7.27

[a] OR--oven roasted; OFB--oven film bag; SC--slow cooker

[b] Diff--the difference between the value for raw and cooked muscle

[c] Rd--reflectance; a+--redness; b+--yellowness

roasting (OR); (2) moist heat cooking in oven film bags (OFB); or (3) moist heat cooking in a slow cooker (SC). A rotary hearth gas oven maintained at 94°C (200°F) was used for the dry heat roasting and for cooking in oven film bags. The slow cooker was maintained at setting No. 3 (approximately 85°C or 185°F). All roasts were cooked to an internal temperature of 60°C (140°F) or 70°C (158°F). Data were analyzed by analysis of variance; when F-values were significant, least significant differences at the 5% level were calculated. Correlation coefficients for selected paired variates were calculated on the basis of end point.

The time required to raise the internal temperature to 0°C and from 0° to 10°C was less for OR than for either OFB or SC. The rate of temperature rise in OR began to slow down after reaching an internal temperature of 10°C, with the time lapse increasing with each temperature interval nearing the end point. There was little difference in the rate of temperature rise from 10°C to the end point between OFB and SC, indicating that the two moist heat treatments had similar effects on rate of heat penetration.

Total cooking time in min and min/kg (P<0.01), total and volatile cooking losses (P<0.01), volume of drip (P<0.01) and total drip cooking losses (P< 0.05) were greater for roasts cooked to 70°C than for those cooked to 60°C. WHC (P<0.05), total moisture (P<0.01) and juiciness scores (P<0.01) decreased with increased end point temperature. Gardner Rd (P<0.01), Gardner b+ (P<0.05) and apparent degree of doneness scores (P<0.01) increased and Gardner a+ values (P<0.01) decreased as end point increased. Samples cooked to 70° were mealier (P<0.01) than those cooked to 60°C.

Total cooking time and cooking time in min/kg for OR were greater (P<0.05) than for either OFB or SC; whereas, drip cooking losses for OR were less (P<0.05) for OFB or SC. Apparent degree of doneness scores were

lower (P<0.05) for OR than for either of the two moist heat methods, which were not significantly different from each other. The "drip" from roasts cooked in open pans formed a charred residue. Slightly more drip was collected for SC than for OFB, but the difference was not significant.

Interactions between end point temperature and method of cooking indicate that differences (P<0.01) for cooking time in min and min/kg as affected by end point temperature can be attributed to each of the three methods of cooking, but the magnitude of difference between means was greatest for OR. As internal end point temperature and cooking time, in both total min and min/kg increased, total losses increased and juiciness scores decreased for all methods. Gardner a+ (redness) values were less (P<0.05), and Gardner Rd (reflectance) values and apparent degree of doneness scores were higher (P<0.05) when roasts were cooked to 70°C by each of the three cooking methods.

There were no significant differences in pH; shear values; and tenderness, softness and flavor scores that were attributable to either method of cooking or end point temperature.

CONCLUSIONS

Under the conditions of this study, it was concluded that:

1. Cooking at a low temperature for a long period of time by roasting in an open pan (dry heat), cooking in an oven film bag (moist heat) or cooking in a slow cooking appliance (moist heat) is satisfactory for preparing beef top round roasts from the frozen state.

   a. In general, the palatability of the meat was similar for roasts cooked by any one of the three methods.

   b. No significant differences occurred among certain objective measurements of the roasts assigned to the three cooking methods.

    c. Using a cooking bag or slow cooking appliance required significantly less cooking time (total min and min/kg) than for oven roasting.

    d. Total cooking losses were similar for the three methods of cooking.

2. Characteristics of meat produced by cooking in an oven at 94°C (200°F) or in a slow cooker at approximately 85°C (185°F) are similar to that cooked at temperatures usually recommended for beef (149°C - 205°C).

3. Cooking in an oven film bag or a slow cooking appliance to 60°C produces beef that appears more well done than beef cooked in an open pan to the same end point temperature.

REFERENCES

Bayne, B.H., Allen, M.B., Large, N.F., Meyer, B.H. and Goertz, G.E. 1973. Sensory and histological characteristics of beef rib cuts heated at two rates to three end point temperatures. Home Econ. Res. J. 2: 29.

Bramblett, V.D., Hostetler, R.L., Vail, G.E. and Draudt, H.N. 1959. Qualities of beef as affected by cooking at very low temperatures for long periods of time. Food Technol. 13: 707.

Bramblett, V.D. and Vail, G.E. 1964. Further studies on the qualities of beef as affected by cooking at very low temperatures for long periods of time. Food Technol. 18: 245.

Bratzler, L.J. 1971. Palatability factors and evaluation. In "The Science of Meat and Meat Products," p. 328-348. W.H. Freeman and Company, San Francisco, California.

Bunyan, M.S. 1958. Comparison of rare, medium-, and well-done roasts from certain beef muscles. Master's Thesis, Kansas State University, Manhattan, Kansas.

Causey, K., Hausrath, M.E., Ramstad, P.E. and Fenton, F. 1950. Effects of thawing and cooking methods on palatability and nutritive value of frozen ground meat. II. Beef. Food Res. 15: 249.

Clark, H.E., Wilmeth, M.C., Harrison, D.L. and Vail, G.E. 1955. The effect of braising and pressure saucepan cookery on the cooking losses, palatability, and nutritive value of the proteins of round steak. Food Res. 20: 35.

Cline, J.A., Trowbridge, E.A., Foster, M.T. and Fry, H.E. 1930. How certain methods of cooking affect the quality and palatability of beef. Bull. 293, Mo. Agr. Expt. Sta., Columbia, Mo.

Cover, S. 1937. The effect of temperature and time of cooking on the tenderness of roasts. Bull. 542, Texas Agr. Expt. Sta., College Station, Texas.

Cover, S. 1938. The effect, on tenderness of meat, of differences in time of cooking produced by oven temperature and other means. J. Home Econ. 30: 586.

Cover, S. 1941. Comparative cooking time and tenderness of meat cooked in water and in an oven of the same temperature. J. Home Econ. 33: 596.

Cover, S. 1943. Effect of extremely low rates of heat penetration on tendering of beef. Food Res. 8: 388.

Cover, S. and Shrode, M.C. 1955. The effect of moist and dry heat cooking on palatability scores and shear force values of beef from animals of different levels of fleshing. J. Home Econ. 47: 681.

Cover, S. and Smith, W.H. 1956. The effect of two methods of cooking on palatability scores, shear force values and collagen content of two cuts of beef. Food Res. 21: 312.

Cover, S., Bannister, J.A. and Kehlenbrink, E. 1957. Effect of four conditions of cooking on the eating quality of two cuts of beef. Food Res. 22: 635.

Cover, S. 1959. Scoring for three components of tenderness to characterize differences among beef steaks. Food Res. 24: 564.

Cover, S., Ritchey, S.J. and Hostetler, R.L. 1962a. Tenderness of beef. I. The connective tissue component of tenderness. J. Food Sci. 27: 469.

Cover, S., Ritchey, S.J. and Hostetler, R.L. 1962b. Tenderness of beef. II. Juiciness and the softness components of tenderness. J. Food Sci. 27: 476.

Cover, S., Ritchey, S.J. and Hostetler, R.L. 1962c. Tenderness of beef. III. The muscle-fiber components of tenderness. J. Food Sci. 27: 483.

Cross, H.R., Carpenter, Z.L. and Smith, G.C. 1973. Effects of intramuscular collagen and elastin on bovine muscle tenderness. J. Food Sci. 38: 998.

Ferger, D.C., Harrison, D.L. and Anderson, L.L. 1972. Lamb and beef roasts cooked from the frozen state by dry and moist heat. J. Food Sci. 37: 226.

Fenton, F., Flight, I.T., Robson, D.S., Beamer, K.C. and How, J.C. 1956. Study of three cuts of lower and higher grade beef, unfrozen and frozen, using two methods of thawing and two methods of braising. Memoir 341, Cornell University Agr. Expt. Sta., Ithaca, New York.

Funk, K., Aldrich, P.J. and Irmiter, T.F. 1966. Forced convection roasting of loin cuts of beef. J. Amer. Diet. Assoc. 48: 404.

Hamm, R. 1966. Heating of muscle systems. In "The Physiology and Biochemistry of Muscle as a Food," p. 363-385. University of Wisconsin Press, Madison, Wisconsin.

Harrison, D.L., Vail, G.E., Hall, J.L. and Mackintosh, D.L. 1953. Household cooking methods for commercial grade beef produced in Kansas. Unpublished Manuscript, Kansas State University, Manhattan, Kansas.

Harrison, D.L., Visser, R. and Schirmer, Sister L. 1959. A resume of the literature related to factors affecting the tenderness of certain beef muscles. Report 10, Kansas Agr. Expt. Sta., Manhattan, Kansas.

Henrichs, J.R. and Whitaker, J.R. 1962. Enzymatic degradation of collagen. J. Food Sci. 27: 250.

Hill, F.E., Leitman, J.D. and Sunderland, J.E. 1967. Thermal conductivity of various meats. Food Technol. 21: 1143.

Hood, M.P., Thompson, D.W. and Mirone, L. 1955. Effects of cooking methods on low grade beef. Bull. 4, Georgia Agr. Expt. Sta., Athens, Ga.

Hood, M.P. 1960. Effect of cooking method and grade on beef roasts. J. Amer. Diet. Assoc. 37: 363.

Hostetler, R.L. and Landmann, W.A. 1968. Photomicrographic studies of dynamic changes in muscle fiber fragments. I. Effects of various heat treatments on length, width and birefringence. J. Food Sci. 33: 468.

Howe, P.E. 1927. The relation of cooking to the study of the quality and palatability of meat. J. Home Econ. 19: 8.

Hunt, F.E., Seidler, L.R. and Wood, L. 1963. Cooking choice grade, top round beef roasts. J. Amer. Diet. Assoc. 43: 353.

Irmiter, T.F., Aldrich, P.J. and Funk, K. 1967. Rate of temperature rise, physical and chemical properties of ground beef cylinders fabricated from selected muscles of the round. Food Technol. 21: 779.

Irvin, L.E. and Cover, S. 1959. Effect of dry heat method of cooking on the collagen content of two beef muscles. Food Technol. 13: 655.

Jacobson, M. and Fenton, F. 1956. Effects of three levels of nutrition and age of animal on the quality of beef. I. Palatability, cooking data, moisture, fat and nitrogen. Food Res. 21: 415.

Kalen, J.K., Miller, E.L., Tinklin, G.L. and Vail, G.E. 1948. The effect of various thawing methods upon the quality of pot roasts and braised steaks. Quick Frozen Foods. 11: 55.

Laakonen, E., Wellington, G.H. and Sherbon, F.W. 1970. Low-temperature, long-time heating of bovine muscle. I. Changes in tenderness, water-binding capacity, pH and amount of water soluble components. J. Food Sci. 35: 175.

Laakonen, E. 1973. Factors affecting tenderness during heating of muscle. Adv. in Food Res. 20: 257-314.

Latzke, E. 1930. Standardizing methods of roasting beef in experimental cookery. Bull. 242, N. Dakota Agr. Expt. Sta., Fargo, N.D.

Lawrie, R.A. 1968. The eating quality of meat. In "Meat Science," p. 270, Pergamon Press, Oxford.

Lentz, C.P. 1961. Thermal conductivity of meats, fats, gelatin gels and ice. Food Technol. 15: 243.

Lind, M.L., Harrison, D.L. and Kropf, D.H. 1971. Freezing and thawing rates of lamb chops: effects on palatability and related characteristics. J. Food Sci. 36: 629.

Lowe, B., Crain, E., Amick, G., Riedesel, M., Pett, L.J., Smith, F.B., McClurg, B.R. and Shearer, P.S. 1952. Defrosting and cooking frozen meat. Bull. 385, Iowa Agr. Expt. Sta., Ames, Iowa.

Lowe, B. 1955. "Experimental Cookery from the Chemical and Physical Standpoint," p. 196-247. John Wiley and Sons, Inc., New York, New York.

Lowe, B. and Kastelic, J. 1961. Organoleptic, chemical, physical and microscopic characteristics of muscle in eight beef carcasses differing in age of animal, carcass grade and extent of cooking. Res. Bull. 495, Iowa Agr. Expt. Sta., Ames, Iowa.

Machlik, S.M. and Draudt, H.N. 1963. The effect of heating time on the shear of beef semitendinosus muscle. J. Food Sci. 28: 711.

Marshall, N., Wood, L. and Patton, M.B. 1959. Cooking choice grade, top round beef roasts. J. Amer. Diet. Assoc. 35: 569.

Marshall, N., Wood, L. and Patton, M.B. 1960. Cooking choice grade, top round beef roasts. J. Amer. Diet. Assoc. 36: 341.

Miller, E.M. and Sunderland, J.E. 1963. Thermal conductivity of beef. Food Technol. 17: 490.

Miller, H.L. and Harrison, D.L. 1965. Effect of marination in sodium hexametaphosphate solution on the palatability of loin steaks. Food Technol. 19: 94.

Morgan, A.F. and Nelson, P.M. 1926. A study of certain factors affecting shrinkage and speed in the roasting of meat. J. Home Econ. 18: 371.

Paul, P.C. 1962. Tenderness and chemical composition of beef. II. Variations due to animal treatment and to extent of heating. Food Technol. 16: 117.

Paul, P.C. 1963. Influence of methods of cooking on meat tenderness. In "Proceedings Meat Tenderness Symposium," p. 225-239. Campbell Soup Company, Cambden, New Jersey.

Paul, P.C. 1972. Meat. In "Food Theory and Application," p. 412-432. John Wiley and Sons, Inc., New York, New York.

Paul, P.C. and Child, A.M. 1937. Effect of freezing and thawing beef muscle upon press fluid losses and tenderness. Food Res. 2: 339.

Paul, P.C., Bean, M. and Bratzler, L.J. 1956. Effect of cold storage and method of cooking on commercial grade cow beef. Bull. 256, Michigan Agr. Expt. Sta., East Lansing, Michigan.

Qashou, M., Nix, G.H., Machan, R.I. and Lowery, G.W. 1970. Thermal conductivity values for ground beef and chuck. Food Technol. 24: 493.

Ramsbottom, J.M., Strandine, E.J. and Koonz, C.H. 1945. Comparative tenderness of representative beef muscles. Food Res. 10: 497.

Ritchey, S.J. and Hostetler, R.L. 1965. The effect of small temperature changes on two beef muscles as determined by panel scores and shear force values. Food Technol. 19: 1275.

Sanderson, M. and Vail, G.E. 1963. Fluid content and tenderness of three muscles of beef cooked to three internal temperatures. J. Food Sci. 28: 590.

Satorius, M.J. and Child, A.M. 1938. Effect of coagulation on press fluid, shear force, muscle cell diameter and composition of beef muscle. Food Res. 3: 619.

Schmidt, J.G., Kline, E.A. and Parrish, F.C. 1970. Effect of carcass maturity and internal temperature on bovine longissimus attributes. J. Animal Sci. 31: 861.

Schock, D.R., Harrison, D.L. and Anderson, L.L. 1970. Effect of dry and moist heat treatments on selected beef quality factors. J. Food Sci. 35: 195.

Shaffer, T.A., Harrison, D.L. and Anderson, L.L. 1973. Effects of end point and oven temperatures on beef roasts cooked in oven film bags and open pans. J. Food Sci. 38: 1205.

Shindell, S. 1964. "Statistics, Science, and Sense." University of Pittsburgh Press, Pittsburgh, Penn.

Szczesniak, A.S. and Torgeson, K.W. 1965. Methods of meat texture measurement viewed from the background of factors affecting tenderness. Adv. Food Res. 14: 33.

Thille, M., Williamson, L.J. and Morgan, A.F. 1932. The effect of fat on shrinkage and speed in the roasting of beef. J. Home Econ. 24: 720.

Tuomy, J.M., Lechnir, R.J. and Miller, T. 1963. Effect of cooking temperature and time on the tenderness of beef. Food Technol. 17: 1457.

Vail, G.E., Jeffery, M., Forney, H. and Wiley, C. 1943. Effect of method of thawing upon losses, shear, and press fluid of frozen beef steaks and pork roasts. Food Res. 8: 337.

Vail, G.E. 1948. Frozen meat preparation. J. Home Econ. 40: 237.

Verzar, F. 1963. The aging of collagen. Sci. Am. 208: 104.

Visser, R.Y., Harrison, D.L., Goertz, G.E., Bunyan, M., Skelton, M.M. and
    Mackintosh, D.L. 1960. The effect of degree of doneness on the tender-
    ness and juiciness of beef cooked in the oven and in deep fat. Food
    Technol. 14: 193.

Wang, H., Rasch, E., Bates, V., Beard, F.J., Pierce, J.C. and Hankins, O.G.
    1954. Histological observations on fat loci and distribution in cooked
    beef. Food Res. 19: 314.

Webb, N.L., Webb, N.B., Cedarquist, D. and Bratzler, L.J. 1961. The effect
    of internal temperature and time of cooking on the palatability of pork
    loin roasts. Food Technol. 15: 371.

Weir, C.E. 1960. Palatability characteristics of meat. In "The Science of
    Meat and Meat Products," p. 212, W.H. Freeman and Co., San Francisco,
    California.

Weir, C.E., Pohl, C., Auerbach, E. and Wilson, G.D. 1963. The effect of
    cooking conditions upon the yield and palatability of pork loin roasts.
    Food Technol. 17: 1567.

Wierbicki, E., Kunkle, L.E., and Deatherage, F.E. 1957. Changes in the
    water-holding capacity and cationic shifts during heating and freezing
    and thawing of meat as revealed by a simple centrifugal method for
    measuring shrinkage. Food Technol. 11: 69.

Winegarden, M.W., Lowe, B., Kastelic, J., Kline, E.A., Plagge, A.R. and
    Shearer, P.S. 1952. Physical changes of connective tissue of beef
    during heating. Food Res. 17: 172.

ACKNOWLEDGMENTS

APPENDIX

Form I. Score Card for the Sensory Evaluation of Beef Top Round Roasts (Semimembranosus and Adductor Muscles)

Judge _____   Code _____   Date _____

Sample no.	Tenderness		Texture		Juiciness[d]	Desirability of flavor[e]	Apparent degree of doneness[f]	Comments
	Chews	Score[a]	Softness[b]	Mealiness[c]				

Descriptive terms for scoring:

a Tenderness

7 Extremely tender
6 Tender
5 Slightly tender
4 Neither tender nor tough
3 Slightly tough
2 Tough
1 Extremely tough

b Softness

7 Extremely soft
6 Soft
5 Slightly soft
4 Firm--neither soft nor hard
3 Slightly hard
2 Hard
1 Extremely hard

c Mealiness

7 Extremely mealy
6 Mealy
5 Slightly mealy
4 Neither mealy nor chewy
3 Slightly chewy
2 Chewy
1 Extremely chewy

d Juiciness

7 Extremely juicy
6 Juicy
5 Slightly juicy
4 Neither juicy nor dry
3 Slightly dry
2 Dry
1 Extremely dry

e Desirability of flavor

7 Extremely desirable flavor
6 Desirable flavor
5 Slightly desirable flavor
4 Neither desirable nor undesirable flavor
3 Slightly undesirable flavor
2 Undesirable flavor
1 Extremely undesirable flavor

f Apparent degree of doneness

3 Well-done
2 Medium-done
1 Rare

Form II. Instructions to Judges for Sensory Evaluation of Beef Top
Round (Semimembranosus and Adductor Muscles).

For scoring palatability characteristics, each judge is to select two cubes
of meat from each casserole. Use one cube for counting the number of chews
and the tenderness score and the other for scoring the texture components,
flavor and juiciness.

Scoring for tenderness

Count the number of chews necessary to completely masticate the 1.3-cm
cube of meat before swallowing, and record the number of chews required.
Record a score from 7 to 1 that describes your impression of the tenderness
of the cube. Refer to 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 30 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.

Scoring for texture

Texture is broken down into two components: softness and mealiness.
Softness to tongue and cheek and softness to tooth pressure (the muscular
force exerted on the meat cube) should be considered when scoring the sample
for softness. Record a score for each sample within a range of 7 to 1, as
indicated on the score card. Mealiness can be thought of as fragmentation
of the meat resulting in tiny, dry and hard pieces of meat that cling to the
cheek, gums and tongue. Record a score for mealiness within a range of 7
to 1 that describes your impression of the sample. Refer to the score card
for descriptive terms corresponding to each numerical score.

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. Record the score describing your
impression of flavor and juiciness at the beginning of the chewing process.

Apparent degree of doneness

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

Form II.   (Concluded)

Comments

  Comments about a sample and/or an explanation of why you gave a particu-
lar score to a sample are helpful.   Take your time to score each sample.
Water is provided for rinsing your mouth between samples.

Table 7-Internal temperature of slow cooker as determined on setting 3 under conditions of dry and moist heat

Time of heating, min	Moist heat, °C[a]	Dry heat, °C[b]	
		Griddle thermometer on rack	Griddle thermometer on bottom of cooker
0	26	24	24
15	36	74	51
30	49	110	74
45	58	115	82
60	66	115	85
70	70	115	85
80	73	115	85
90	77	115	85
100	79	115	85
110	81	115	85
120	83	115	85
130	84	115	85
140	85	115	85
150	86	115	85
160	86	115	85
170	87	115	85
180	86	115	85
190	87	115	85
200	87	115	85
210	87	115	85
220	87	115	85

[a] 1890 ml tap water in cooking pot, 1/3 full

[b] Empty cooking pot

Table 8—Means and F-values for nonsignificant end point temperature x method of cooking interactions

| Measurement | End point temperature, °C | Method of cooking[a] | | | F-values |
		OR	OFB	SC	
Internal wt, g	60	1378.83	1347.33	1376.50	0.51
	70	1311.67	1329.00	1333.33	
Cooking losses,					
% drip	60	1.90	17.98	16.26	3.39
	70	2.31	22.59	23.44	
volatile	60	16.09	----	----	----
	70	29.38	----	----	
Volume of drip, ml	60	----	186.00	204.50	0.0001
	70	----	269.00	287.00	
Total moisture, %	60	66.26	65.32	66.69	0.14
	70	62.87	62.86	63.65	
Water-holding capacity[b]	60	0.71	0.70	0.68	3.22
	70	0.64	0.65	0.70	
pH	60	5.66	5.64	5.63	0.01
	70	5.68	5.66	5.65	
Color-difference, Gardner					
b+ (yellowness)	60	9.17	10.00	10.18	0.02
	70	12.37	12.85	13.20	

Table 8-(Concluded)

Measurement	End point temperature, °C	Method of cooking[a]			F-values
		OR	OFB	SC	
Shear value, kg/1.3 cm core	60	4.12	4.33	4.45	
	70	4.20	5.07	4.72	0.18
Sensory scores					
tenderness[c]	60	5.43	4.73	5.43	
	70	5.38	4.63	5.58	0.70
softness[c]	60	5.25	4.47	4.83	
	70	4.78	4.17	4.88	0.27
mealiness[c]	60	4.25	4.18	4.27	
	70	5.05	4.65	4.83	0.25
flavor[c]	60	4.77	4.58	4.98	
	70	4.70	4.70	4.72	0.80

[a] OR--oven roasting; OFB--oven film bag; SC--slow cooker

[b] 1.0 minus (expressible liquid index); the larger the value, the greater the amount of liquid expressed

[c] 7--(extremely tender, soft, mealy or desirable flavor); 1--(extremely tough, hard, chewy or undesirable flavor)

Table 9—Initial weight of roasts, g

| Method of cooking | End point temperature, °C | | | |
| | 60 | | 70 | |
	Round and roast no.	Weight	Round and roast no.	Weight
Oven roasting	1C	1385	2B	1266
	4B	1368	3D	1367
	5D	1384	6B	1386
	8A	1369	7A	1265
	9C	1384	10A	1218
	11D	1383	12D	1368
Mean		1378.83		1311.67
Oven film bag	1A	1372	2A	1213
	4C	1329	3B	1367
	5B	1280	6C	1369
	8D	1356	7C	1382
	9A	1387	10B	1274
	11C	1360	12B	1369
Mean		1347.33		1329.00
Slow cooker	1B	1382	2D	1202
	4D	1387	3A	1367
	5A	1381	6A	1391
	8C	1369	7D	1345
	9B	1372	10C	1317
	11A	1368	12A	1378
Mean		1376.50		1333.33

Table 10—Rate of heat penetration in minutes to reach 0°C and to increase by increments of 10°C from 0° to 40°C and every 5°C increase from 40°C to 60°C end point temperature

Method of cooking	Temperature, °C								
	n-0	10	20	30	40	45	50	55	60
Oven roasted	167	28	19	8	33	25	31	37	60
	142	40	20	20	30	18	29	28	48
	148	50	11	22	30	22	33	38	66
	149	40	10	20	28	18	24	28	46
	140	40	18	25	29	21	24	28	48
	160	43	12	20	36	23	28	37	56
Mean	151.00	40.17	15.00	19.17	31.00	21.17	28.17	32.67	54.00
Oven film bag	191	35	12	15	27	15	14	22	77
	175	30	20	20	20	17	18	20	21
	167	--	--	8	22	14	24	10	24
	137	66	10	18	21	13	16	18	16
	172	45	12	16	25	22	16	22	24
	143	69	12	16	16	22	--	--	22
Mean	164.17	49.00	11.00	15.50	21.83	17.17	17.60	18.40	30.67

Table 10-(Concluded)

Method of cooking	n-0	10	Temperature, °C						
			20	30	40	45	50	55	60
Slow cooker	172	40	12	12	17	11	13	11	21
	221	21	20	28	30	13	25	23	32
	172	62	14	11	23	14	12	20	87
	191	31	15	18	22	12	13	19	21
	178	37	14	18	19	14	16	17	21
	172	37	16	11	19	12	12	16	30
Mean	184.33	38.00	15.17	16.33	21.67	12.67	15.17	17.67	35.33

Table 11--Rate of heat penetration in minutes to reach 0°C and to increase by increments of 10°C from 0°C to 40°C, and by increments of 5°C from 40°C to 70°C end point temperature

Method of cooking	n-0	Temperature, °C									
		10	20	30	40	45	50	55	60	65	70
Oven roasted	134	38	25	20	40	25	29	38	53	102	136
	182	13	14	21	36	25	29	45	53	95	27
	148	42	19	17	32	38	36	48	12	113	128
	129	--	--	--	27	22	26	43	57	98	76
	134	39	7	15	31	20	24	41	58	115	114
	169	21	--	--	35	20	30	28	54	107	104
Mean	149.33	30.60	11.25	18.25	33.50	25.00	29.00	40.50	47.80	105.00	97.50
Oven film bag	151	45	12	14	21	15	17	17	22	28	37
	166	53	12	15	31	6	12	35	17	29	99
	189	51	15	13	22	19	16	20	20	26	31
	190	--	--	19	18	15	16	20	19	25	40
	168	--	--	27	23	13	14	17	23	20	33
	171	37	15	9	27	15	13	23	20	27	48
Mean	172.50	46.50	13.50	16.17	23.67	13.83	14.67	22.00	20.17	25.83	49.00

Table 11-(Concluded)

Method of cooking		Temperature, °C										
	n-0	10	20	30	40	45	50	55	60	65	70
Slow cooker	194	30	7	16	22	13	13	18	21	28	40
	202	36	13	25	23	20	22	20	33	35	22
	140	62	10	12	22	11	15	15	21	19	35
	138	—	—	12	22	16	16	19	19	30	39
	167	45	20	17	18	13	16	14	25	25	51
	167	48	19	13	22	14	16	19	28	23	33
Mean	168.00	44.20	13.80	15.83	21.50	14.50	16.33	17.50	24.50	26.67	38.00

Table 12—Total cooking time, min

| Method of cooking | End point temperature, °C | | | |
| | 60 | | 70 | |
	Round and roast no.	Time	Round and roast no.	Time
Oven roasting	1C	408	2B	640
	4B	375	3D	600
	5D	365	6B	633
	8A	363	7A	598
	9C	373	10A	600
	11D	415	12A	600
Mean		<u>383.17</u>		<u>611.83</u>
Oven film bag	1A	408	2A	379
	4C	341	3B	475
	5B	326	6C	428
	8D	315	7C	402
	9A	354	10B	368
	11C	349	12B	405
Mean		<u>348.83</u>		<u>409.50</u>
Slow cooker	1B	309	2D	402
	4D	412	3A	461
	5A	357	6A	365
	8C	342	7D	403
	9B	334	10C	411
	11A	325	12A	402
Mean		<u>346.50</u>		<u>407.33</u>

Table 13-Cooking time, min/kg

| Method of cooking | End point temperature, °C | | | | |
| | 60 | | 70 | | |
	Round and roast no.	Time	Round and roast no.	Time	
Oven roasting	1C	294.58	2B	505.53	
	4B	274.12	3D	438.92	
	5D	263.73	6B	456.71	
	8A	265.16	7A	472.73	
	9C	269.51	10A	492.61	
	11D	300.07	12D	438.60	
Mean		277.86		467.52	
Oven film bag	1A	297.38	2A	312.45	
	4C	256.58	3B	347.48	
	5B	254.69	6C	312.64	
	8D	232.30	7C	290.88	
	9A	255.23	10B	288.85	
	11C	256.62	12B	295.84	
Mean		258.80		308.02	
Slow cooker	1B	223.59	2D	344.44	
	4D	297.04	3A	337.24	
	5A	258.51	6A	262.40	
	8C	249.82	7D	299.63	
	9B	243.44	10C	312.07	
	11A	237.57	12A	291.73	
Mean		251.66		306.25	

Table 14—Post-heating temperature rise

| Method of cooking | End point temperature, °C | | | | | |
| | 60 | | | 70 | | |
	Round and roast no.	Time	°C	Round and roast no.	Time	°C
Oven roasting	1C	0	0	2B	0	0
	4B	0	0	3D	0	0
	5D	0	0	6B	0	0
	8A	0	0	7A	0	0
	9C	0	0	10A	0	0
	11D	0	0	12D	0	0
Mean		0	0		0	0
Oven film bag	1A	10	2	2A	0	0
	4C	20	3	3B	0	0
	5B	0	0	6C	0	0
	8D	20	2	7C	0	0
	9A	15	2	10B	0	0
	11C	15	1	12B	0	0
Mean		1.3	1.67		0	0
Slow cooker	1B	15	1	2D	10	1
	4D	10	1	3D	0	0
	5A	5	1	6A	15	1
	8C	25	3.5	7D	0	0
	9B	15	4	10C	0	0
	11A	5	1	12A	0	0
Mean		12.5	1.92		4.2	0.33

Table 15-Percentage total cooking losses

| Method of cooking | End point temperature, °C | | | |
| | 60 | | 70 | |
	Round and roast no.	Loss	Round and roast no.	Loss
Oven roasting	1C	18.11	2B	33.09
	4B	17.03	3D	28.74
	5D	22.83	6B	32.03
	8A	16.28	7A	31.38
	9C	15.31	10A	33.24
	11D	18.43	12D	31.65
Mean		18.00		31.69
Oven film bag	1A	21.64	2A	31.49
	4C	17.30	3B	32.69
	5B	21.01	6C	30.53
	8D	18.87	7C	27.56
	9A	17.51	10B	27.07
	11C	28.67	12B	25.71
Mean		20.83		29.17
Slow cooker	1B	20.76	2D	25.79
	4D	13.26	3A	24.57
	5A	20.63	6A	32.99
	8C	22.42	7D	28.55
	9B	19.74	10C	28.85
	11A	23.67	12A	27.71
Mean		20.08		28.08

Table 16-Percentage drip cooking losses

| Method of cooking | End point temperature, °C | | | |
| | 60 | | 70 | |
	Round and roast no.	Loss	Round and roast no.	Loss
Oven roasting	1C	2.31	2B	1.89
	4B	1.90	3D	1.97
	5D	2.74	6B	1.65
	8A	1.09	7A	2.92
	9C	1.30	10A	2.79
	11D	2.09	12D	2.63
Mean		1.90		2.31
Oven film bag	1A	18.80	2A	26.13
	4C	14.29	3B	28.74
	5B	18.12	6C	25.56
	8D	15.85	7C	23.29
	9A	14.78	10B	15.22
	11C	26.02	12B	16.58
Mean		17.98		22.59
Slow cooker	1B	17.94	2D	21.38
	4D	8.72	3A	19.09
	5A	16.72	6A	29.40
	8C	17.09	7D	23.86
	9B	16.47	10C	23.69
	11A	20.61	12A	23.22
Mean		16.26		23.44

Table 17-Percentage volatile cooking losses

| Method of cooking | End point temperature, °C | | | | |
| | 60 | | 70 | | |
	Round and roast no.	Loss	Round and roast no.	Loss	
Oven roasting	1C	15.80	2B	31.20	
	4B	15.13	3D	26.77	
	5D	20.08	6B	30.37	
	8A	15.19	7A	28.45	
	9C	14.01	10A	30.45	
	11D	16.34	12D	29.02	
Mean		16.09		29.38	

Table 18-Percentage total moisture

| Method of cooking | End point temperature, °C | | | |
| | 60 | | 70 | |
	Round and roast no.	Percentage	Round and roast no.	Percentage
Oven roasting	1C	65.15	2B	63.35
	4B	65.75	3D	61.65
	5D	66.55	6B	65.75
	8A	67.10	7A	61.15
	9C	67.15	10A	62.10
	11D	65.85	12D	63.25
Mean		66.26		62.87
Oven film bag	1A	68.15	2A	62.35
	4C	71.65	3B	62.80
	5B	66.60	6C	63.65
	8D	59.00	7C	61.05
	9A	62.40	10B	64.70
	11C	64.15	12B	62.60
Mean		65.32		62.86
Slow cooker	1B	65.45	2D	62.95
	4D	70.05	3A	65.35
	5A	69.50	6A	64.25
	8C	65.20	7D	63.80
	9B	64.10	10C	62.40
	11A	65.85	12A	63.15
Mean		66.69		63.65

Table 19-Volume of drippings, ml

| Method of cooking | End point temperature, °C | | | |
| | 60 | | 70 | |
	Round and roast no.	Volume	Round and roast no.	Volume
Oven film bag	1A	226	2A	270
	4C	130	3B	350
	5B	194	6C	304
	8D	174	7C	260
	9A	170	10B	250
	11C	222	12B	180
Mean		186		269
Slow cooker	1B	232	2D	236
	4D	96	3A	234
	5A	211	6A	383
	8C	218	7D	294
	9B	204	10C	285
	11A	266	12A	290
Mean		204.50		287

Table 20—Water-holding capacity (WHC)

Method of cooking	End point temperature, °C				
	60		70		
	Round and roast no.	WHC	Round and roast no.	WHC	
Oven roasting	1C	0.74	2B	0.67	
	4B	0.71	3D	0.65	
	5D	0.74	6B	0.65	
	8A	0.68	7A	0.61	
	9C	0.69	10A	0.63	
	11D	0.69	12D	0.66	
Mean		0.71		0.64	
Oven film bag	1A	0.69	2A	0.60	
	4C	0.75	3B	0.69	
	5B	0.68	6C	0.71	
	8D	0.66	7C	0.62	
	9A	0.72	10B	0.66	
	11C	0.69	12B	0.64	
Mean		0.70		0.65	
Slow cooker	1B	0.63	2D	0.66	
	4D	0.72	3A	0.71	
	5A	0.67	6A	0.71	
	8C	0.57	7D	0.71	
	9B	0.74	10C	0.64	
	11A	0.72	12A	0.75	
Mean		0.68		0.70	

Table 21-pH values

Method of cooking	Round and roast no.	pH	Round and roast no.	pH
		End point temperature, °C		
	60		70	
Oven roasting	1C	5.58	2B	5.60
	4B	5.64	3D	5.70
	5D	5.55	6B	5.66
	8A	5.60	7A	5.62
	9C	6.00	10A	5.78
	11D	5.58	12D	5.71
Mean		5.66		5.68
Oven film bag	1A	5.60	2A	5.52
	4C	6.04	3B	5.67
	5B	5.56	6C	5.60
	8D	5.50	7C	5.58
	9A	5.64	10B	5.85
	11C	5.50	12B	5.72
Mean		5.64		5.66
Slow cooker	1B	5.58	2D	5.54
	4D	5.80	3A	5.72
	5A	5.69	6A	5.62
	8C	5.66	7D	5.63
	9B	5.54	10C	5.84
	11A	5.50	12A	5.57
Mean		5.63		5.65

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

| Method of cooking | End point temperature, °C | | | |
| | 60 | | 70 | |
	Round and roast no.	Rd value	Round and roast no.	Rd value
Oven roasting	1C	15.00	2B	19.90
	4B	9.85	3D	19.90
	5D	16.70	6B	23.10
	8A	14.45	7A	18.60
	9C	8.75	10A	20.20
	11D	12.40	12D	16.45
Mean		12.85		19.68
Oven film bag	1A	18.80	2A	19.55
	4C	11.55	3B	20.40
	5B	25.00	6C	20.55
	8D	16.15	7C	16.70
	9A	14.20	10B	18.00
	11C	13.40	12B	15.45
Mean		16.53		18.45
Slow cooker	1B	14.00	2D	14.70
	4D	10.75	3A	19.20
	5A	18.90	6A	21.55
	8C	10.25	7D	15.95
	9B	15.15	10C	17.15
	11A	17.00	12A	16.15
Mean		14.35		17.48

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

| Method of cooking | End point temperature, °C | | | | |
| | 60 | | | 70 | |
	Round and roast no.	a+ value		Round and roast no.	a+ value
Oven roasting	1C	11.10		2B	3.40
	4B	23.05		3D	3.40
	5D	13.90		6B	2.25
	8A	15.45		7A	2.10
	9C	16.60		10A	1.20
	11D	13.40		12D	2.75
Mean		15.57			2.52
Oven film bag	1A	5.20		2A	3.30
	4C	11.20		3B	2.50
	5B	8.80		6C	2.70
	8D	13.40		7C	3.10
	9A	9.45		10B	4.45
	11C	10.90		12B	2.90
Mean		9.82			3.15
Slow cooker	1B	14.40		2D	6.35
	4D	15.85		3A	4.20
	5A	6.50		6A	3.50
	8C	18.90		7D	2.10
	9B	7.15		10C	3.60
	11A	8.40		12A	5.75
Mean		11.87			4.27

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

Method of cooking	End point temperature, °C				
	60			70	
	Round and roast no.	b+ value		Round and roast no.	b+ value
Oven roasting	1C	9.10		2B	10.20
	4B	9.15		3D	14.95
	5D	9.50		6B	19.80
	8A	9.10		7A	9.00
	9C	8.60		10A	10.80
	11D	9.50		12D	9.45
Mean		9.17			12.37
Oven film bag	1A	10.20		2A	19.80
	4C	10.10		3B	9.60
	5B	10.70		6C	19.70
	8D	9.50		7C	9.05
	9A	9.85		10B	10.15
	11C	9.70		12B	8.75
Mean		10.00			12.85
Slow cooker	1B	10.40		2D	19.80
	4D	8.60		3A	10.60
	5A	10.80		6A	19.75
	8C	10.25		7D	8.65
	9B	10.20		10C	10.25
	11A	10.90		12A	10.20
Mean		10.18			13.20

Table 25-Warner-Bratzler shear values, kg/1.3-cm core

| Method of cooking | End point temperature, °C | | | |
| | 60 | | 70 | |
	Round and roast no.	Shear value	Round and roast no.	Shear value
Oven roasting	1C	3.5	2B	3.9
	4B	4.3	3D	5.4
	5D	5.9	6B	2.1
	8A	3.0	7A	5.0
	9C	5.1	10A	4.5
	11D	2.9	12D	4.3
Mean		4.1		4.2
Oven film bag	1A	4.5	2A	6.2
	4C	3.7	3B	4.1
	5B	3.2	6C	3.9
	8D	4.6	7C	5.1
	9A	6.1	10B	6.3
	11C	3.9	12B	4.8
Mean		4.3		5.1
Slow cooker	1B	4.6	2D	6.0
	4D	4.4	3A	3.9
	5A	3.7	6A	6.0
	8C	2.7	7D	3.5
	9B	3.8	10C	3.8
	11A	7.5	12A	5.1
Mean		4.4		4.7

Table 26—Tenderness scores; range, 7.0—extremely tender to 1.0—extremely tough

| Method of cooking | End point temperature, °C | | | |
| | 60 | | 70 | |
	Round and roast no.	Score	Round and roast no.	Score
Oven roasting	1C	5.14	2B	5.57
	4B	4.38	3D	6.50
	5D	6.00	6B	4.13
	8A	6.17	7A	5.38
	9C	4.71	10A	5.14
	11D	6.25	12D	5.63
Mean		5.43		5.38
Oven film bag	1A	6.29	2A	3.43
	4C	3.50	3B	4.25
	5B	4.50	6C	4.00
	8D	5.33	7C	4.75
	9A	3.29	10B	6.43
	11C	5.50	12B	5.00
Mean		4.73		4.63
Slow cooker	1B	6.29	2D	5.71
	4D	6.25	3A	4.75
	5A	5.38	6A	6.38
	8C	6.00	7D	5.50
	9B	3.86	10C	5.29
	11A	4.75	12A	5.75
Mean		5.43		5.58

Table 27-Softness scores; range, 7.0--extremely soft to 1.0--extremely hard

| Method of cooking | End point temperature, °C | | | |
| | 60 | | 70 | |
	Round and roast no.	Score	Round and roast no.	Score
Oven roasting	1C	4.43	2B	4.86
	4B	4.25	3D	5.60
	5D	5.88	6B	3.12
	8A	6.17	7A	5.25
	9C	4.57	10A	4.71
	11D	6.25	12D	5.25
Mean		5.25		4.78
Oven film bag	1A	5.57	2A	3.00
	4C	3.75	3B	3.50
	5B	4.12	6C	3.88
	8D	4.50	7C	4.38
	9A	3.86	10B	6.00
	11A	4.12	12B	5.00
Mean		4.47		4.88
Slow cooker	1B	5.71	2D	4.57
	4D	5.50	3A	3.80
	5A	4.50	6A	5.88
	8C	5.50	7D	5.13
	9B	3.71	10C	4.86
	11A	4.12	12A	5.00
Mean		4.83		4.88

Table 28-Mealiness scores; range, 7.0--extremely mealy to 1.0--extremely chewy

| Method of cooking | End point temperature, °C | | | |
| | 60 | | 70 | |
	Round and roast no.	Score	Round and roast no.	Score
Oven roasting	1C	3.86	2B	4.71
	4B	3.62	3D	5.25
	5D	4.75	6B	4.75
	8A	4.67	7A	5.25
	9C	3.86	10A	5.00
	11D	4.62	12D	5.38
Mean		4.25		5.05
Oven film bag	1A	5.29	2A	3.43
	4C	4.25	3B	4.75
	5B	4.12	6C	5.12
	8D	3.67	7C	4.50
	9A	2.86	10B	5.29
	11C	4.88	12B	4.75
Mean		4.18		4.65
Slow cooker	1B	4.00	2D	4.86
	4D	4.38	3A	4.60
	5A	3.75	6A	4.75
	8C	5.67	7D	4.25
	9B	3.71	10C	4.86
	11A	4.00	12A	5.63
Mean		4.27		4.83

Table 29–Juiciness scores; range, 7.0--extremely juicy to 1.0--extremely dry

Method of cooking	End point temperature, °C			
	60		70	
	Round and roast no.	Score	Round and roast no.	Score
Oven roasting	1C	5.86	2B	3.14
	4B	5.75	3D	4.00
	5D	5.88	6B	2.00
	8A	6.17	7A	4.63
	9C	5.43	10A	3.00
	11D	6.38	12D	3.63
Mean		5.93		3.38
Oven film bag	1A	4.57	2A	2.57
	4C	3.50	3B	3.50
	5B	5.38	6C	2.88
	8D	4.33	7C	4.50
	9A	4.00	10B	4.71
	11C	4.38	12B	3.88
Mean		4.37		3.68
Slow cooker	1B	6.14	2D	4.43
	4D	6.00	3A	4.10
	5A	4.50	6A	3.50
	8C	4.50	7D	3.75
	9B	5.00	10C	3.71
	11A	4.62	12A	3.75
Mean		5.12		3.88

Table 30--Flavor scores; range, 7.0--extremely desirable to 1.0--extremely undesirable

| Method of cooking | End point temperature, °C | | | |
| | 60 | | 70 | |
	Round and roast no.	Score	Round and roast no.	Score
Oven roasting	1C	4.86	2B	4.71
	4B	4.38	3D	4.90
	5D	4.50	6B	4.62
	8A	5.17	7A	4.88
	9C	4.57	10A	4.57
	11D	5.00	12D	4.50
Mean		4.77		4.70
Oven film bag	1A	5.00	2A	5.00
	4C	5.25	3B	4.80
	5B	4.88	6C	4.25
	8D	4.17	7C	5.25
	9A	4.43	10B	4.00
	11C	3.75	12B	5.00
Mean		4.58		4.70
Slow cooker	1B	4.86	2D	4.71
	4D	5.25	3A	4.80
	5A	4.62	6A	5.00
	8C	5.00	7D	4.88
	9B	5.29	10C	4.00
	11A	4.88	12A	4.88
Mean		4.98		4.72

Table 31—Apparent degree of doneness scores (1 = rare, 2 = medium-done, 3 = well-done)

| Method of cooking | End point temperature, °C | | | |
| | 60 | | 70 | |
	Round and roast no.	Score	Round and roast no.	Score
Oven roasting	1C	1.00	2B	3.00
	4B	1.25	3D	2.40
	5D	1.12	6B	3.00
	8A	1.00	7A	2.50
	9C	1.14	10A	2.86
	11D	1.12	12D	2.88
Mean		1.08		2.78
Oven film bag	1A	2.00	2A	2.71
	4C	2.00	3B	2.90
	5B	2.00	6C	2.75
	8D	1.33	7C	2.63
	9A	1.57	10C	2.43
	11C	2.00	12A	2.50
Mean		1.82		2.63
Slow cooker	1B	1.29	2D	2.43
	4D	1.50	3A	2.50
	5A	1.75	6A	2.62
	8C	1.50	7D	2.50
	9B	2.14	10C	2.86
	11A	2.25	12A	2.50
Mean		1.73		2.57

EFFECTS ON BOVINE MUSCLE OF LOW-TEMPERATURE
COOKING FROM THE FROZEN STATE

by

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B. S., Kansas State University, 1972

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AN ABSTRACT OF A MASTER'S THESIS

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The selection of a cooking method for meat is based on the convenience of the method and the effect on end product quality. Oven film cooking bags and slow cooking appliances now are offered to the consumer as convenient methods of moist heat cookery. Advertising for both products implies that those methods result in a juicier, more flavorful roast than one cooked by "traditional" methods. The idea that less tender cuts of meat are suited to cooking in oven film bags or in slow cooking appliances agrees with the usual recommendation that moist heat be used to soften collagenous connective tissue. Manufacturers of slow cooking appliances advocate cooking food for several hours to enhance flavor and aroma.

A split plot design was followed to cook 36 top round beef roasts from the frozen state by one of the following treatments: (1) dry heat roasting (OR); (2) moist heat cooking in oven film bags (OFB); or (3) moist heat cooking in a slow cooker (SC). A rotary hearth gas oven maintained at 94°C (200°F) was used for the dry heat roasting and for cooking in oven film bags. The slow cooker was maintained at setting No. 3 (85°C or 185°F). Roasts were cooked to an internal temperature of 60°C (140°F) or 70°C (158°F).

Rate of heat penetration, total cooking time and cooking time in min/kg were greater, and apparent degree of doneness scores were lower for OR than for either OFB or SC. Cooking time in min and min/kg, total, volatile and drip cooking losses and volume of drip were greater for roasts cooked to 70°C than for those cooked to 60°C. Water-holding capacity, total moisture, juiciness scores and Gardner a+ (redness) values decreased as end point temperature increased; whereas, Gardner Rd (reflectance) and b+ (yellowness) values, apparent degree of doneness scores and mealiness scores increased. Interactions between end point temperature and method of cooking indicate that

significant differences for certain subjective and objective measurements as affected by end point temperature can be attributed to all three methods of cooking, but the magnitude of difference between means was greatest for OR.