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EFFECTS OF LOW-TEMPERATURE, LONG-TIME MOIST HEAT COOKING FROM THE FROZEN STATE ON BEEF ROASTS

by

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INTRODUCTION

Full time employment by the homemaker and maintaining traditional methods of meat cookery, often do not complement each other when related to the time factor. Also tenderness, because of its influence on meat "quality," is the physical property of meat in which the consumer is most interested.

Tenderness of cooked meat is the over-all effect of muscle composition, aging before cooking, heat coagulation of muscle fiber proteins and changes in connective tissues (Harrison et al., 1959). In general, cooking tenderizes collagenous connective tissue by partial hydrolysis of the collagen. Also, toughening of the myofibril proteins occurs through coagulation. Weir (1960) stated that both time and temperature are important considerations relative to those changes, with time the more influential factor for the softening process and temperature for toughening.

Laakkonen et al. (1970) noted that the final internal temperature of the meat has a critical influence on tenderness, as optimal conditions appear to exist when there is maximum softening of connective tissue without excessive toughening of fibers. Other research indicates that use of extremely low oven temperatures over long cooking periods results in more tender meat than when beef roasts are cooked at moderate temperatures for relatively short periods (Cover, 1937, 1943; Bramblett et al., 1959; Bramblett and Vail, 1964). Cover (1943) noted that rather than oven temperature, cooking time, indicative of rate of heat penetration, was important.

Two relatively new variations of traditional moist heat cooking methods now offered to the homemaker are oven film cooking bags and slow cooking appliances. Both of those products appear to create conditions favoring hydrolysis of collagen. No studies were found comparing the effects of low-temperature, long-time cooking on beef cooked by more than one moist heat method. This experiment was designed to study effects on beef rcasts of low-temperature, long-time cooking from the frozen state in oven film bags and in a slow cooking appliance.

REVIEW OF LITERATURE

Gross structure and composition of muscle tissue

Meat is striated, voluntary skeletal muscle. Lowe (1955) defined skeletal muscle as fibers held together by connective tissue and surrounded by a heavier connective tissue sheath.

Each muscle fiber, which appears to be surrounded by a thin membrane called the sarcolemma, is composed of many myofibrils, a variable number of nuclei, and inclusions such as mitochondria, glycogen granules and fat droplets embedded in the sarcoplasm. The portion of the myofibril that is the basic structural and functional muscular unit is the sarcomere (Szent-Gyorgi, 1951; Maximow and Bloom, 1952). A thin layer of collagenous connective tissue known as the endomysium is found between the fibers, and holds them in bundles or fasciculi. Those varying sized bundles are then bound together by the perimysium and are a factor in determining the grain of the meat. A heavy sheath of connective tissue called the epimysium surrounds the muscle as a whole (Hiner et al., 1953; Harrison et al., 1959; Cassens, 1971).

Connective tissue is composed of the fibrillar elements collagen, reticulin and elastic strands, held in an adhesive matrix known as the ground substance. An important property of collagen is that it can be hydrolyzed to gelatin in the presence of moist heat. Elastin, however, does not undergo hydrolysis. Reticular fibers are chemically similar to collagen fibers, and some researchers consider them as immature collagen fibers (Hiner et al., 1955; Miller and Kastelic, 1956). The ground substance is a homogeneous, amorphorus mixture that varies from a fluid to a gel-like consistency (Cassens, 1971).

Fat appears in meat as separable fat, adipose tissue and marbling. Separable fat is that which occurs between muscles and on the surface of individual cuts. Fat cells of adipose tissue and marbling are located in perimysial spaces and are extrafascicular (Cassens, 1971). Some researchers believe that adipose tissue is a special form of connective tissue in which cells lose their characteristic fiber-forming ability and begin to store fat. Those cells begin to accumulate in large masses, and are packed together to crowd out other cells. In marbling, fat cells tend to be smaller in size than in adipose tissue, but are distributed in easily visible quantities (Lowe, 1955; Harrison et al., 1959).

Relation of muscle structure to tenderness. No one factor has been shown to determine tenderness in muscle; rather, it depends on a myriad of factors including breed, age, sex, weight, nutritional status and exercise of the animal. Muscle fiber diameter and quantity and distribution of connective tissue and fat, have been suggested as indicators of tenderness (Harrison et al., 1959; Paul, 1962a).

Reports in the literature concerning the relation of fiber diameter and sarcomere length to tenderness are conflicting. Muscle fibers comprise approximately 3/4 of the muscle volume. Significant correlations have been noted between fiber diameter and the number of fibers per bundle; also between fiber diameter and texture and/or tenderness scores. Some workers found that the smaller the diameter, and thus the greater the number of fibers per bundle, the finer the texture and the more tender the muscle (Satorius and Child, 1938; Strandine et al., 1949). Other workers established a direct relation between sarcomere length and tenderness. Herring et al. (1965) stated that as sarcomere length decreased, fiber diameter increased, and there was a subsequent decrease in tenderness. However, both Paul (1962a) and Romans et al. (1965) indicated no such relationship.

The relation of collagenous and elastic tissues to tenderness has been investigated extensively, and generally, the tenderest roasts came from muscles having the least connective tissue (Hiner et al., 1945; Ramsbottom et al., 1945; Harrison et al., 1949; Paul et al., 1956; Sanderson and Vail, 1963). Muscles of high activity tend to have large well defined muscle bundles, and Hiner et al. (1945) emphasized that those bundles were associated with increased amounts of connective tissue. The composite effect of muscle bundle size and the amount of connective tissue on texture and tenderness scores, has been described by some researchers (Ramsbottom et al., 1945; Strandine et al., 1949).

An age-tenderness relationship was reported by Briskey and Kauffman (1971). Those workers found that rather than a greater quantity of connective tissue per unit of muscle in older than in younger animals, the character of the connective tissue altered with age. Findings of Goll et al. (1964) and Piez (1966) indicated that stronger or more extensive cross linkages occur in muscle collagen of increased age.

Miller and Kastelic (1956) and Cover et al. (1962a) suggested that the reticular fibers and the ground substance in which the connective tissue fibers are embedded may play a more important part in determining tenderness of meat than had been considered.

Contradictory reports concerning the relation of fat content and distribution to tenderness are found in the literature. Whereas Harrison et al. (1953) stated that an increased proportion of fat resulted in more tender meat, Wang et al. (1954) asserted that it was not the total amount, but the way in which the fat was distributed that was important. However, Gilpin et al. (1965), Romans et al. (1965), and McBee and Wiles (1967) noted poor correlation between marbling scores and tenderness.

Effect of cooking method on muscle characteristics

Basically, there are two types of heat treatment used for meat cookery. They are known as "dry" and "moist" heat, both of which refer to the atmosphere surrounding the meat. In dry heat cooking, heat is transferred to the meat via the surrounding air; moist heat cooking involves heat transfer via the steam which forms when heat supplied causes moisture to vaporize in an enclosed environment. As steam conveys heat more rapidly than air, meat cooked in steam is heated at a faster rate than that subjected to dry heat (Paul, 1972). Examples of dry heat methods or cooking in an open container, include roasting, broiling, pan-broiling, and baking. Moist heat methods, or cooking in a closed container, are evident in braising, stewing, steaming, pressure cooking and wrapping in aluminum foil. Few adaptations have been developed for dry heat cookery. However, several relatively new modifications of moist heat cooking methods have been developed, two of which include oven film cooking bags and slow cooking appliances or "crock pots."

Recommendations over the years have been that those cuts expected to be "tender" should be cooked by dry heat, and those expected to be "tough" should be cooked by moist heat. This practice was associated with the fact that partial hydrolysis of collagen enhances tenderness, and the conditions provided by a moist heat environment appear to facilitate this change.

Several general statements may be made concerning the effects of dry and moist heat cookery on meat. Generally, cooking time is longer, but total cooking losses are less for dry heat than for moist heat (Cover et al., 1957; Hood, 1960). Also, when cooked to the same end point, dry heat methods produce an apparently less well-done product than moist heat treatments (Schock et al., 1970; Ferger et al., 1972; Shaffer et al., 1973). In some studies, tenderness, as evaluated by shear values and palatability scores, appears to be enhanced more by dry heat than by moist heat (Paul et al., 1956). This is not supported by other workers who found when comparing the two cooking media that moist heat produced the more tender product (Cover et al., 1962b).

However, it should be noted that the cooking medium is not the only factor determining the characteristics of the end product. Inherent differences in type and cut of meat, as well as time and temperature variations in the cooking process must be considered.

Cooking meat from the frozen state. Vail (1948) stated that those methods recommended for cooking fresh cuts also were suitable for cooking frozen meat. Early studies on frozen meat involved the effects of different thawing methods on cooking time, thawing and cooking losses, and palatability of the cooked product. It was established that meat cooked from the frozen state requires approximately 1/3 to 1/2 longer to cook than fresh or completely thawed meat (Vail et al., 1943; Lowe et al., 1952; Lind et al., 1971). Total cooking losses may be expected to be similar for thawed meat and meat cooked from the frozen state. Vail et al. (1943) found that roasts cooked from the frozen state had greater losses during cooking than thawed meat, but when thawing losses were added to cooking losses for the latter, total losses were approximately the same for meat cooked from the frozen or thawed state. In the studies reviewed, no differences in palatability scores were reported for meat thawed before or during cooking (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 studies compared methods of cooking meat from the frozen state. Ferger et al. (1972) cooked leg of lamb roasts and beef rib roasts from the frozen state by dry heat (roasting) and moist heat (oven film bag). Little difference attributable to type of heat was found in cooking time, percentage total cooking losses and palatability characteristics of the roasts. Shaffer et al. (1973) cooked beef top round from the frozen state and found that a slightly longer time was required, but weight losses were less ($P<0.001$) with dry heat (oven roasting) than with moist heat (oven film bag). However, differences in the palatability scores for flavor, juiciness and over-all acceptability were not significant between types of heat; but dry heat produced more tender beef ($P<0.05$).

Changes in muscle components during heating. Muscle's physical structure is readily altered by heat, the most obvious basic change being a shrinkage of both muscle and collagen fibers. Muscle fiber shrinkage occurs in two phases; a decrease in width, followed by a subsequent length decrease. The temperatures at which those changes occur were studied by Cover et al. (1957). A change in muscle structure that those workers attributed to a decrease in fiber width, was observed to commence soon after heating begins and continue to 62° to 67°C. A decrease in length appears to begin at 50°C, becomes rapid from 55° to 65°C, and continues at a slower rate to cessation at 70° to 80°C. Paul (1963) supported those findings in a study with small blocks of semitendinosus and biceps femoris muscles that were heated, sectioned, stained and examined by microscopic observation. The general decrease in volume varied between muscle fibers; a change attributed to inherent differences.

Associated with changes in muscle fiber volume is a resultant hardness of the muscle, which, according to Cover et al. (1962c) and Tuomy et al. (1963), is attributable to the denaturation and coagulation of the fiber proteins. Hostetler and Landmann (1968) prepared photomicrographs of muscle fiber fragments as the fibers were heated from room temperature to 80°C, or held at constant temperatures of 37°, 45°, 53°, 61°, 67°, or 77°C. They indicated that fiber coagulation begins over a range of 47° to 55°C, and with continued coagulation the hardening process begins. Schmidt et al. (1970) stated that this became apparent at 50°C, whereas, 67°C was indicated by Machlik and Draudt (1963).

Microscopic examination of muscle fiber diameter, as an indication of change in muscle structure led Satorius and Child (1938) to state that coagulation was "complete" at 67°C, because at that point no further decrease in muscle fiber diameter was noted. However, as shown by increased shear values, hardening continued to 75°C. They interpreted their findings to suggest that coagulation may continue at higher temperatures at a decreased rate, thereby contributing to continued fiber hardening.

Machlik and Draudt (1963) heated cylinders of semitendinosus muscles in a water bath at temperatures of 56° or 59°C for 1 hr, and found that, as indicated by shear values, the higher cooking temperature was associated with an increased rate of hardening. At end points of 60°, 70° or 80°C, Shaffer et al. (1973) reported no significant difference in tenderness of top round roasts cooked at 177° or 205°C, as indicated by shear values and tenderness scores.

Changes associated with application of heat also occur in the collagenous and elastic connective tissues. Generally, it is agreed that as related to tenderness, the alteration in collagenous connective tissue is of more importance than heat induced changes in elastic tissue.

Most workers agree that depending on the duration of heating and availability of moisture, collagen is partially or completely solubilized. 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. Machlik and Draudt (1963) investigated the changes that occur in collagenous connective tissue during heating. Below 50°C, little change was observed, but as indicated by changes in shear values, collagen shrinkage became apparent above 55°C. The rate of change increased up to 65°C, with optimal tenderness occurring within the range 60° to 65°C. Such changes contribute to tenderness, but the simultaneously occurring hardening process of muscle fibers, explained previously, also must be considered for its effect on the over-all tenderness of the end product. Winegarden et al. (1952) found a continued softening in collagenous tissue above 80°C. The softening was attributed to hydrolysis of collagen to gelatin, although at no time were shear values as low as those obtained at 60° to 65°C. Those changes are dependent partially on inherent muscle differences and the age of the animal. This latter factor appears to be associated with the increased number of collagen cross linkages that occur with age, thereby making tissue from aged animals more resistant to heat induced changes (Verzar, 1963; Field et al., 1962). Machlik and Draudt (1963) stated that the hardening process slows down and ceases at 80° to 85°C.

The less extensive reporting of changes in elastin attributable to heat may be associated with its characteristic insolubility during heating. The opinion of many researchers is that although alteration of the elastic connective tissue occurs with heating, the effects are not large enough to play a major role in meat tenderness. Lowe and Kastelic (1961) reported differences between muscles of changes in elastin with heating. The longissmus dorsi and psoas major decreased in elastin content with heating, whereas the biceps femoris, semitendinosus and semimembranosus increased in elastin content. By comparing the microscopic appearance of both raw and heated connective tissue, Winegarden et al. (1952) found that although elastic tissue softened, it was not to the same extent as the softening of collagenous tissue. Henrichs and Whitaker (1962) measured the extent of connective tissue solubilization by enzymatic action, and reported that elastic tissue becomes more rigid on heating.

Ramsbottom et al. (1945) reported an increase in tenderness of adipose tissue during heating. Lowe (1955) and Wang and Maynard (1955) attributed such change to a bursting of the collagenous connective tissue membrane, or its conversion to gelatin, thereby allowing the melted fat to escape and flow in droplets along the path of heat degraded collagen fibers.

Effect of end point temperature on muscle characteristics

Degree of doneness. Visible color changes that occur during cooking are related to internal temperature, and are described by Bratzler (1971) as follows: "below 60°C, little or no color change (rare); 65° to 70°C, decreasing pinkness to 70°C (medium); at 75°C, complete loss of pinkness (well-done)." Cooking method influences apparent degree of doneness at a particular temperature. According to Shaffer et al. (1973), roasts cooked by moist heat scored higher for apparent degree of doneness (1-rare; 3-well-done) than those cooked by dry heat to the same internal end point. They noted that roasts cooked by dry heat to an internal temperature of 60°C were bright red in the center fading to grey brown at the edges. With moist heat at 60°C the roast was slightly pink in the center, and faded to a grey brown on the edges. An internal temperature of 70°C resulted in the roast cooked by dry heat with a pink center and rapid fading to grey brown at the edges. When cooked by moist heat, the product was uniformly grey at 70°C. Roasts cooked by moist heat to 80°C appeared similar to those cooked by moist heat to 70°C, but the roast cooked to the same temperature by dry heat was slightly pink in the center with a fading to grey brown throughout the remainder of the meat. Visser et al. (1960) found that deep fat frying at 100°C resulted in a product that appeared rare at 45°C and medium-done at 65°C. Those results were attributed to the influence of the cooking medium on the rate of heat penetration. A fast rate of heat penetration such as occurs with deep fat cooking appeared to produce a product that is more well-done at a particular end point than did cooking at a slower rate.

Cooking time. Visser et al. (1960) and Hunt et al. (1963) indicate that as the internal end point temperature increases, cooking time increases. Bayne et al. (1973) verified those findings in their work with beef roasts cooked at oven temperatures of 107° or 163°C to internal end points of 60°, 70° or 77°C. Regardless of treatment combinations, cooking time increased as the internal end point temperature increased.

Cooking losses. Generally, it is accepted by researchers that as the end point temperature increases, cooking losses increase with a given cooking method. Shaffer et al. (1973) cooked beef top round by both dry and moist heat at 177° or 205°C to internal end points of 60°, 70° or 80°C. Total and volatile losses increased with increased end point temperature. However, drip losses increased slightly between 60° and 70°C, but decreased between 70° and 80°C. Also, they reported that percentage fat in the drippings was unaffected by internal end point temperature.

Palatability characteristics. Several workers have shown that different cuts of meat roasted at different temperatures to the same internal end point temperature, result in products that score similarly for tenderness (Visser et al., 1960; Bayne et al., 1973; Shaffer et al., 1973). Satorius and Child (1938) found that when cooking the semimembranosus muscle to end points of 58°, 67° or 75°C, the major increase in tenderness occurred between 67° and 75°C. However, Harrison et al. (1953) found when cooking by dry heat, U.S. Commercial rib roasts and loin steaks were more tender when cooked to 70°C than when cooked to 80°C. Cover (1959) stressed the importance of cooking method in relation to end point temperature in reporting low tenderness scores for bottom round steak broiled rare, but high tenderness scores when the steak was braised to well-done. Sanderson and Vail (1963) reported differences between muscles in predicting changes in tenderness with end point temperature. The longissimus dorsi muscle differed little in tenderness scores when heated to different end points, but there was an increase in tenderness as beef round muscles were heated to higher temperatures by dry heat.

Generally, it is agreed that an increase in internal temperature results in a drier, less juicy piece of meat (Cover et al., 1962b; Bayne et al., 1973). Bunyan (1958) and Bayne et al. (1973) in their work with hindquarter muscles and rib roasts, respectively, reported increased flavor and aroma scores with increased degree of doneness. However, several other workers reported that end point temperatures had no significant effect on those sensory properties (Marshall et al., 1960; Sanderson and Vail, 1963; Shaffer et al., 1973).

Factors affecting rate of heat penetration

Muscle composition. The complex inter-relationship of its constituents, rather than any single component, influences the rate of heat conductivity through meat. Thille et al. (1932) stated that size and arrangement of muscle fibers may affect over-all rate of heat penetration. Also, they observed that during the initial heating period, muscle fibers conducted heat faster than any other muscle constituent. Lentz (1961) and Hill et al. (1967) reported that heat conductivity in muscle was greater parallel to the fibers than it was perpendicular to them. Thille et al. (1932) stated that in the solid state, fat is a poor conductor of heat, but when melted, it is a good one. By recording temperature rises in lean and fat portions of the muscle during heating, they observed that heat conduction in the muscle fibers slowed down with continued heating, but in fat it increased, thereby indicating that fat distribution in the meat is important in the rate of heat penetration. Irmiter et al. (1967) studied the rate of temperature rise in ground beef cylinders fabricated from selected muscles to contain 10, 20 or 30% fat. They found that in the early stages of cooking, meat with the least fat heated most rapidly, while in the latter stages, it heated most slowly. Several workers reported total fat content to be important in thermal conductivity; when there is a reduced fat content, and thus an increased moisture level, thermal conductivity is increased (Lentz, 1961; Miller and Sunderland, 1963; Hill et al., 1967; Quashou et al., 1970).

Hill et al. (1967) stated that below 0°C, heat conductivity is inversely proportional to the internal temperature of the meat, and above 0°C, conductivity increases with increased temperatures. Protein denaturation, which occurs during heating, is an endothermic reaction, and it is believed such a reaction slows thermal conductivity of meat as internal temperature increases (Lowe, 1955; Visser et al., 1960; Hamm, 1966). Cover et al. (1957) attributed this slowing of the rate of heat penetration to the release of water of hydration. Funk et al. (1966) noted that the rate of temperature rise differed at different depths of the roast, thereby making it possible to obtain a roast with layers of differing degrees of doneness when cooking to a specific end point temperature.

Size and shape of meat. Rate of heat penetration, and thus cooking time, has been related to weight, surface area and distance that the heat must travel to reach the thickest part of the meat. Generally, as those factors increase, the time of cooking increases (Ramsbottom et al., 1945; Lowe, 1955). Jacobson and Fenton (1956) reported that any variation in cooking time decreased markedly with roasts of uniform size and shape.

Cooking medium and temperature. As mentioned previously, moist heat facilitates heat penetration into the muscle more than does dry heat (Harrison et al., 1953; Visser et al., 1960). Cover (1941) cooked beef at 90°C in an open pan and compared it with the same cut that was submerged in a water bath at the same temperature. She found that the samples prepared by the latter method required 1/3 to 1/2 less cooking time than the dry heat method, implying a faster rate of heat penetration in the water bath.

Cover (1943) and Weir et al. (1963) stated that the higher the cooking temperature, the faster the rate of heat penetration, thereby indicating less cooking time. Cover (1943) cooked beef by oven roasting at temperatures of 80° or 125°C, and found that at the lower temperature, 3 to 5 times longer was required to reach a particular end point. Similarly Bramblett and Vail (1964) reported that at lower temperatures, the rate of heat penetration is slower.

Low-temperature cooking. As early as 1937, the tenderizing effects of low-temperature, long-time cooking were reported. Cover (1937) compared the tenderness of round-bone chuck and rump roasts cooked at 125° or 225°C to the well-done stage (80°C). She found a more tender product resulted when the lower temperature was used, and related this to the slow rate of heat penetration and the amount of time the meat was maintained above 65°C (4 to 5 hours). In 1943, she found that well-done chuck and rounds of beef roasted at 80° or 125°C were tender as a result of slow cooking. She noted that if 30 hours or more were required for the meat to lose its pink color, the roasts were always tender. She suggested that tenderness may be related to the slow release of the water of hydration, thereby allowing effective conversion of collagen to gelatin.

Bramblett et al. (1959) cooked beef rounds wrapped in heavy duty aluminum foil at 63° or 68°C for 30 or 18 hours, respectively. They concluded that the amount of time the internal temperature of the roast was between 57° and 60°C was related closely to tenderness, and attributable to minimal hardening of muscle fibers and maximum softening of connective tissue.

Cline et al. (1930) compared meat cooked at temperatures of 125° or 165°C by broiling and roasting, and found that meat cooked by either method at the lower temperature was more uniformly done and more tender than meat cooked at the higher temperature.

Laakkonen et al. (1970) devised a model system to control the rate of heat penetration in 100- to 130-g samples to approximately 0.1°C per minute, thereby simulating the conditions for a 15.7-kg roast cooked at 121°C in an institutional gas heated oven. Samples were rare after heating for 6 hours and well-done after 10 hours of heating. The resulting products were compared to control samples prepared by rapid heating by tempering in a water-bath for one hour at 30°C, then heating to 80°C in 60 min, and held at that temperature for an additional 60 min. The use of the slow rate of heat penetration produced more tender meat than heating rapidly. Also, time was an important factor; meat cooked to the rare stage was only slightly more tender than the control samples.

Cover (1943) reported little difference in cooking losses when roasts were cooked at temperatures of 80° or 125°C. Weir et al. (1963) cooked pork loin roasts at oven temperatures ranging from 149° to 205°C. Although percentage drip loss was similar for all oven temperatures, percentage total losses were higher for roasts cooked at higher temperatures.

Bramblett et al. (1959) reported that percentage total cooking losses were less for beef round roasts cooked by moist heat at 64°C than for those cooked at 68°C. This was attributed to the slower rate of heat penetration when low oven temperatures were used. Visser et al. (1960) also noted that a slow rate of heat penetration was associated with low cooking losses.

Tenderness scores have indicated that when the rate of heat penetration is slow by the use of low oven temperatures, a tender product results (Cover, 1943; Bramblett et al., 1959; Bramblett and Vail, 1964; Laakkonen et al., 1970). Bramblett et al. (1959) found improved juiciness when rate of heat penetration was slow. Bramblett and Vail (1964) noted the opposite effect of heat penetration on juiciness. Cover (1943) noted that flavor did not seem to be affected by rate of heat penetration.

MATERIALS AND METHODS

Six USDA Choice grade top rounds of beef (semimembranosus, SM, and adductor, AD, muscles), were purchased from a local wholesale meat company. External fat was removed, the muscles squared off, and four roasts cut from each top round. At the time of cutting, a slice, approximately 2.5-cm thick, was removed from each roast for analysis of the raw sample (Fig. 1). Weights of the roasts to be cooked ranged from approximately 1360 to 1400 g (3.0 to 3.1 lbs), and dimensions, in cm, were: length, 10 to 17; width, 9.5 to 14; and depth, 8.5 to 11.5.

Each sample for analysis of raw meat and each roast was wrapped individually in heavy duty aluminum foil (0.0015 gauge), with the shiny surface against the meat. They were frozen in a household upright freezer at -19°C (-2°F) and stored 1 to 6 weeks in the same freezer.

The experimental design was a complete block with six replications. One block consisted of four cooking method-end point combinations. Those combinations were: (1) oven film bag, 70°C; (2) oven film bag, 10 hours; (3) slow cooker, 70°C; and (4) slow cooker, 10 hours (Table 1). At each of 12 evaluation periods, two roasts were cooked from the frozen state by moist heat, in either an oven film bag (OFB - Reynold's Brown-In-Bag - nylon 66 with heat stabilizer), or a slow-cooking appliance (SC - West Bend "Lazy Day" Slo-cooker).

Immediately before cooking, the roasts were taken from the freezer, the foil removed, and a hole bored into the center for insertion of a centigrade thermometer. The roast to be cooked in the oven film bag was placed in the bag, closed with a twister tie and the thermometer inserted.

Table 1-Experimental design for cooking and position of raw sample

Cooking period	Replication	Round number	Roast code	Treatment[a]	Position of raw sample
1	1	1	A	II	Proximal
		1	B	IV	Proximal
2	1	1	D	I	Distal
		1	C	III	Distal
3	2	2	D	II	Distal
		2	C	IV	Distal
4	2	2	A	I	Proximal
		2	B	III	Proximal
5	3	3	C	I	Distal
		3	A	III	Proximal
6	3	3	D	II	Distal
		3	B	IV	Proximal
7	4	4	C	II	Distal
		4	A	IV	Proximal
8	4	4	D	I	Distal
		4	B	III	Proximal
9	5	5	C	II	Distal
		5	A	IV	Proximal
10	5	5	B	I	Proximal
		5	D	III	Distal
11	6	6	C	II	Distal
		6	B	IV	Proximal
12	6	6	A	I	Proximal
		6	D	III	Distal

[a] Treatments:
- I Oven film bag, 70°C
- II Oven film bag, 10 hours
- III Slow cooker, 70°C
- IV Slow cooker, 10 hours

Six slits, each approximately 4.0-cm long, were cut in the top of the bag to allow steam to escape and to help prevent breaking of the bag. The entire system was placed on a low rack in a shallow roasting pan, and cooked in a rotary hearth gas oven maintained at 94°C (200°F). The roast to be cooked in the slow-cooking appliance was placed on a rack in the porcelain cooking pot, and the cover of the pot set in position. The closed container was placed on the thermostatically controlled electric base and cooked at setting number 3 (approximately 85°C or 185°F). This setting was established during preliminary work as the one most closely simulating the oven temperature of 94°C, used for cooking in the oven film bag. Roasts cooked by both methods were heated to an internal end point temperature of 70°C (158°F), or for 10 hours, as specified by the experimental design (Table 1).

For objective and sensory evaluation, the crust of each roast was removed. The sampling plan for individual cooked roasts was according to Fig. 1.

Rate of heat penetration, end point of cooking, cooking losses and shrinkage

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, for each 10°C increase from 0°C to 40°C and for each 5°C increase above that temperature to an internal end point of 70°C, or a total cooking time of 10 hours. The final internal temperature was recorded after cooking 10 hours, and cooking time in min/kg was calculated.

Percentage total and dripping losses, based on the weight of the frozen meat, were calculated. Drippings from all roasts were transferred to 250-ml graduated cylinders and allowed to stand 30 min. After the fat had stabilized at the top of the drippings, the total volume of the drippings and the volume of the fat were read; the percentage fat in the drippings was calculated.

Dimensions of the roasts were taken before and after cooking. Percentage shrinkage, based on the initial dimensions, was calculated.

pH and Gardner color-difference

Slurries of both raw and cooked samples were prepared by blending 10 g ground meat with 100 ml distilled, deionized water for 2 min (at high speed) in a Waring Blendor. Each slurry was placed in a beaker and the temperature brought to 25°C (77°F). After stirring 30 sec with a magnetic stirrer, the pH was determined on a Beckman Expanded Scale pH meter. The beaker was rotated 180° and stirred for another 15 sec, after which a second pH reading was made. The pH meter was standardized at 25°C against a pH 6.86 buffer.

Color-difference factors for both raw and cooked samples were measured with a Gardner Color Difference Meter. The instrument was standardized for the raw sample using a satin finished ceramic tile with calculated values of: Rd(reflectance), 5.5; a+(redness), 26.8; and b+(yellowness), 13.0. For the cooked sample, the standard's calculated measurements were: Rd(reflectance), 38.0; a+(redness), 6.6; and b+(yellowness), 14.7. A slice of cooked meat approximately 1.3-cm thick was cut from the center of the roast (Fig. 1). Slices for both raw and cooked analysis were trimmed to a circular shape such that they could be packed into a Gardner plexiglass cell of 5.5-cm diameter. Samples were allowed to bloom 5 min, then placed in individual plexiglass cells so that no light filtered through them. Duplicate measurements were made for each color-difference factor; the cell was rotated 90° between readings.

Shear values

Tenderness was measured on cooked samples (Fig. 1) by shearing three 1.3-cm diameter cores on a Warner-Bratzler shearing apparatus with a 11.4-kg dynamometer. Triplicate measurements were made on each core, and the over-all shear value was the average of the three shear cores.

Water-holding capacity and total moisture

The press method of Miller and Harrison (1965) was used for triplicate measurements of water-holding capacity (WHC) on 0.3-g samples from the cores used for Warner-Bratzler shear values (Fig. 1). The ratio of the area of the pressed muscle to the area of expressed liquid marked on the 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; thus, the larger the value of WHC, the greater amount of 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 weight and shape. Each roast is 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

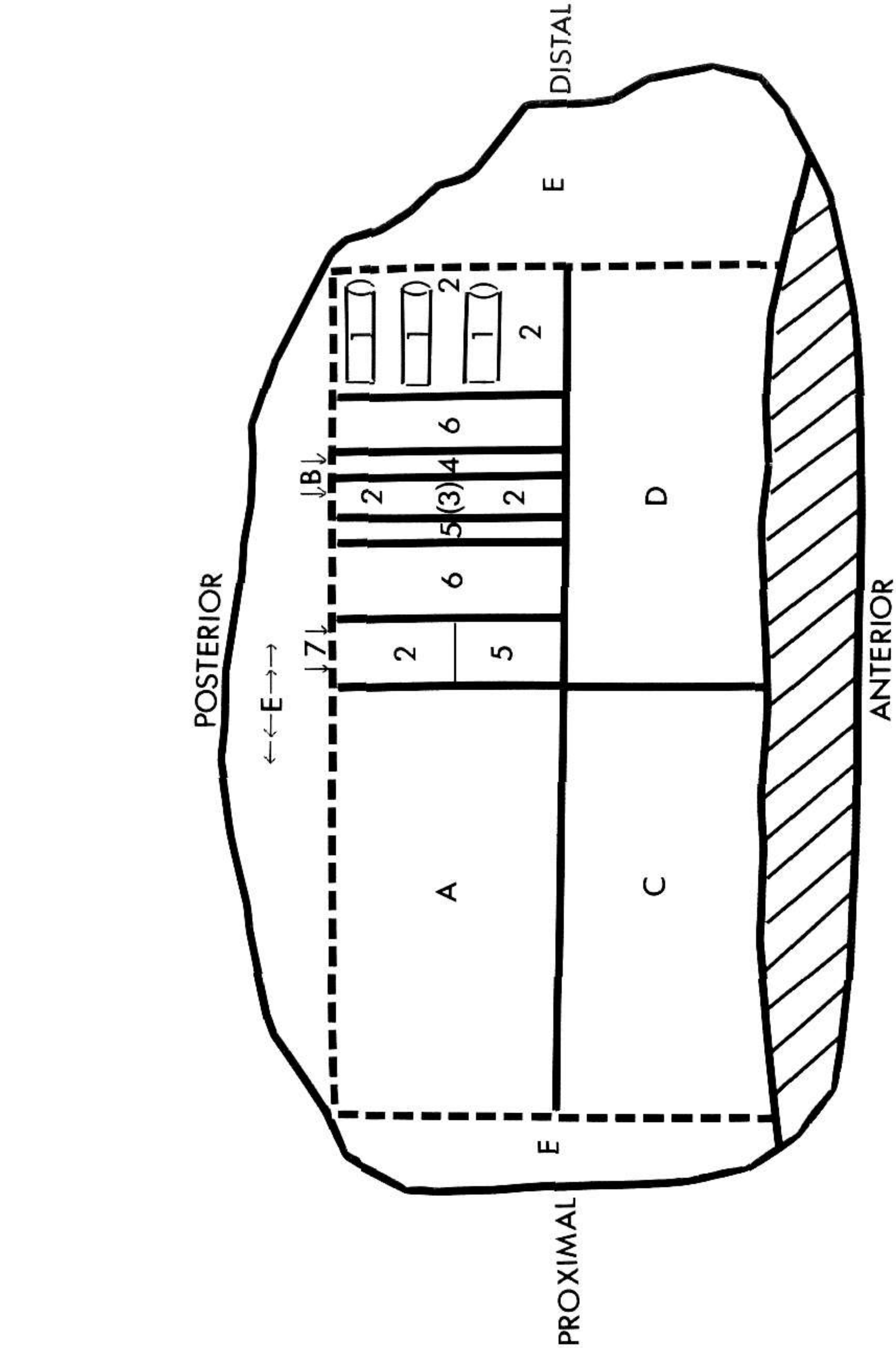
7 -- Raw samples used for pH, total moisture and Gardner color-difference

In roasts A and B, raw samples were cut from the proximal end
In roasts C and D, raw samples were cut from the distal end

E -- Portion of muscle 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.


POSTERIOR
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E
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6

Percentage total moisture was determined in 10-g samples of raw or cooked ground meat, by drying in a C. W. Brabender Semi-Automatic Rapid Moisture Tester at 121°C (250°F). Raw samples were dried 120 min; cooked samples were dried 60 min.

Sensory evaluation

A 6-member panel evaluated 1.3-cm cubes of cooked meat (Fig. 1) for tenderness, juiciness, flavor, and apparent degree of doneness (Form I, Appendix, p. 57). Instructions for evaluation were given to the panel members during preliminary work (Form II, Appendix, p. 58). Samples were presented to the panel in small covered ceramic casserole dishes that were set on an electric hot tray held at approximately 35°C (78°F). There were a sufficient number of cubes so that each panelist could select at random, and evaluate within 30 min of their preparation, two cubes of meat for each heat treatment. Apparent degree of doneness was scored after observing a slice of meat that had been wrapped in transparent household wrap and placed under a Macbeth skylight.

Analysis of data

The analysis of variance used to analyze the data was:

Source of variation	D/F
Replication	5
Method of cooking (M)	1
End point of cooking (T)	1
Interaction (MxT)	1
Error	15
Total	23

Correlation coefficients were calculated for selected paired variates on the basis of end point of cooking.

RESULTS AND DISCUSSION

Initial weight of roasts and rate of heat penetration

Analysis of variance indicated no significant differences among weights of all roasts. Mean weights of roasts assigned to the two methods of cooking differed by 8 g, and mean weights of roasts assigned to the two end points differed by only 2 g.

The rate that heat penetrated the muscle throughout cooking was not affected significantly by method of cooking (Table 11, Appendix, p. 69). Those mean data can be observed in the rate of heat penetration curves in Fig. 2. For the two cooking methods, the rates that heat penetrated the muscle from the initial temperature to 0°C were similar and constant. The time required for that part of the cooking process by OFB and SC was 184 and 190 min, respectively. This indicates that both methods of providing "steam" for cooking allowed the meat to thaw at approximately the same rate. From 0° to 70°C, the internal temperature of roasts in the SC increased at a slightly faster rate than roasts cooked in OFB. The time required for that temperature rise was 37 min longer for OFB and 25 min longer for SC, than for the rise from the initial temperature to 0°C. Vollmar (1974) cooked beef top round roasts of similar weight and conformation, from the frozen state in OFB or SC at 94°C or approximately 85°C, respectively, to end point temperatures of 60° or 70°C. Her roasts cooked in OFB required 168 min, and those by SC 176 min for the internal temperature to rise from the initial temperature to 0°C. The time required for the internal temperature of Vollmar's roasts to increase from 0° to 70°C was 45 min longer for OFB and 66 min longer for SC, than for the rise from the initial temperature to 0°C.

In this study, cooking for a predetermined time of 10 hr resulted in a higher ($P<0.01$) end point temperature for roasts cooked in OFB than for those cooked in SC. The mean internal temperature for the OFB roasts was approximately 82°C, and for the SC roasts, approximately 76°C. Almost the same length of time was required for that part of the cooking period (11 min longer for OFB, and 6 min longer for SC) as was involved in heating from the initial temperature to 0°C (Table 11, Appendix, p. 69). However, the rate of increase above 70°C was reduced markedly as compared to the rate of increase from 0° to 70°C. When Shaffer et al. (1973) cooked top round roasts in OFB at 177° or 205°C to internal end points of 60°, 70° or 80°C, no slowing in the rate of heat penetration occurred above 70°C. Perhaps the low cooking temperature (94°C for OFB and 85°C for SC) used in this study partially accounts for the decrease in the rate that heat penetrated the muscle above an internal temperature of 70°C.

End point of cooking

Cooking time in min and min/kg, total and drip cooking losses, percentage of lipid in drip, WHC, total moisture and sensory scores for juiciness, were affected ($P<0.01$) by end point of cooking. Measurements affected at the $P<0.05$ level were: volume of drip, Gardner a+(redness) and sensory scores for apparent degree of doneness (Table 2).

Table 2-Means and F-values for end point of cooking[a]

Measurement	End point 70°C	End point 10 hr	Difference	F-value
Initial weight, g	1379.2	1381.2	2.0	0.25ns
End point temp, °C	70.00	79.16	9.16	-
Cooking time				
Total, min	403.08	600.00	196.92	752.36**
hr	6.72	10.00	3.28	-
Min/kg	292.22	434.31	142.09	666.50**
Cooking losses, %				
Total	30.19	37.45	7.26	94.99**
Drip	25.56	28.80	3.24	10.98**
Volume of drip, ml	312.33	341.08	28.75	5.81*
Lipid in drip, % of volume	1.33	2.68	1.35	10.56**
Shrinkage, % decrease				
Length	17.47	16.52	0.95	0.13ns
Width	19.10	20.32	1.22	0.06ns
Depth	5.95	2.98	2.97	2.59ns
pH	5.54	5.51	0.03	0.26ns
Color-difference, Gardner				
Rd(reflectance)	15.67	15.17	0.05	0.64ns
a+(redness)	4.19	2.57	1.62	6.54*
b+(yellowness)	9.25	9.35	0.10	0.15ns
Shear value, kg/1.3-cm core	5.06	4.35	0.71	4.37ns
Water-holding capacity[b]	0.710	0.635	0.075	13.21**
Total moisture, %	61.52	57.93	3.59	41.64**

Table 2-concluded

Measurement	End point 70°C	10 hr	Difference	F-value
Sensory scores				
Tenderness[c]	4.99	5.27	0.28	0.98ns
Softness[c]	4.63	4.70	0.07	0.08ns
Mealiness[c]	4.58	4.92	0.36	3.59ns
Juiciness[c]	4.65	3.17	1.48	27.74**
Flavor[c]	5.07	4.74	0.33	4.24ns
Apparent degree of doneness[d]	2.80	3.00	0.20	4.70*

[a] Data irrespective of method of cooking

[b] 1.0 - (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

** $P<0.01$; * $P<0.05$, ns-not significant

Table 3-Significant effects of methods of cooking and significant end point of cooking x method of cooking interactions

Measurement	Method of cooking[a] OFB	SC	Difference	F-value
Final internal temperature, °C[b]	82.2	76.2	6.0	14.59**
Volume of drip, ml	301.8	342.7	40.9	7.16*
Color-difference, Gardner				
Rd(reflectance)	14.41	16.43	2.02	10.66**

End point of cooking x method of cooking interactions

	End point of cooking	Method of cooking OFB	SC	F-value
Total cooking	70°C	30.05[c]	30.32[c]	4.59*
Losses, %	10 hr	38.91	35.99	
Shear value,	70°C	5.43[d]	4.68[d,e]	9.26**
kg/1.3-cm core	10 hr	3.70[e]	5.01[d]	
Total moisture, %	70°C	62.21[f]	60.82[f]	8.15*
	10 hr	57.03	58.82	

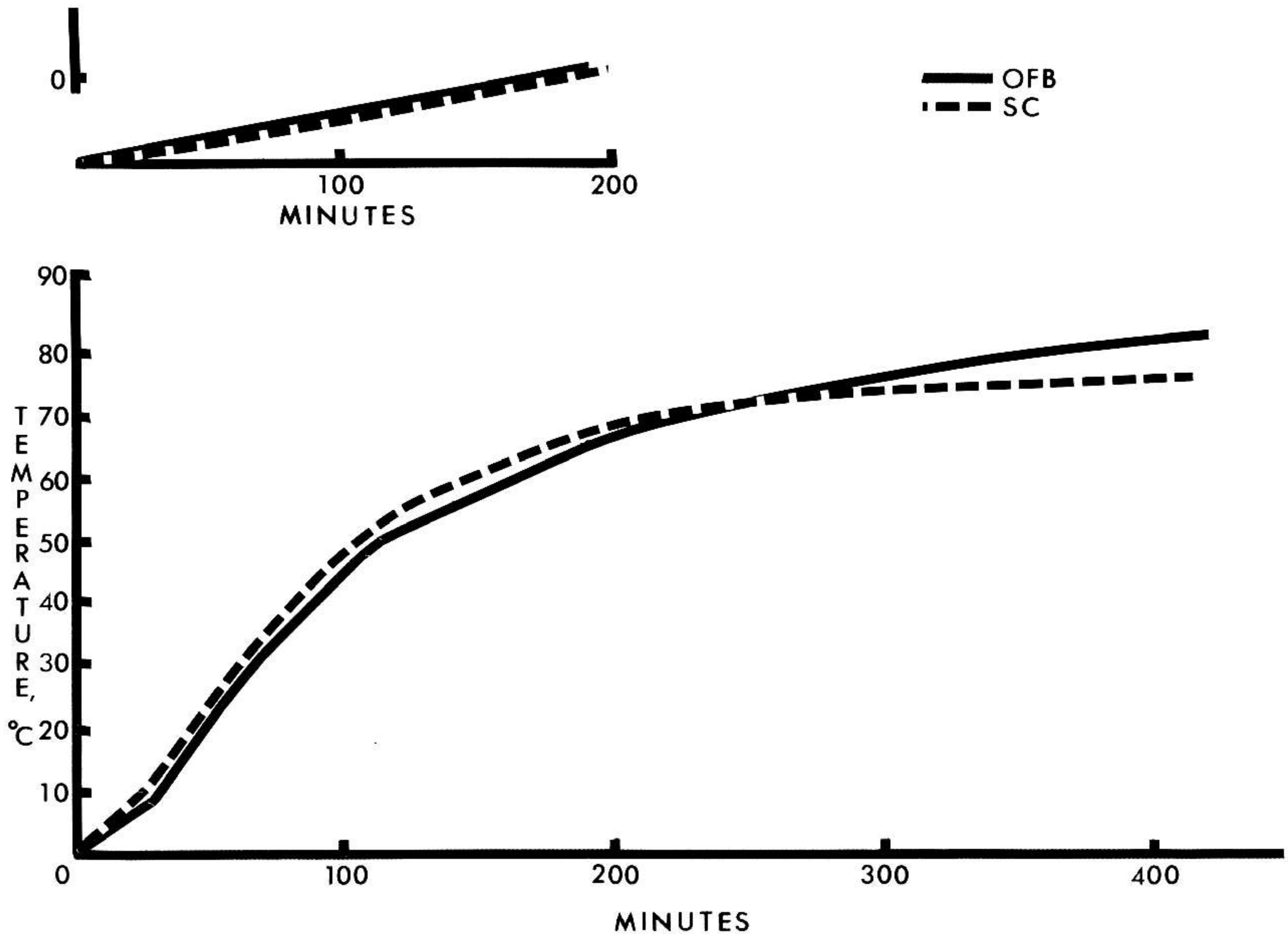
[a] Data irrespective of end point of cooking; OFB-oven film bag, SC-slow cooker

[b] Data after cooking 10 hr

[c,d,e,f] Means sharing the same superscript are not significantly different

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

Fig. 2-Rate of heat penetration from initial temperature to 0°C and from 0°C to end point, after 10 hr cooking of beef top round roasts in OFB and SC at 94°C and approximately 85°C respectively. $n \leq 70$°C, 12; $n > 70$°C, 6


0
100
200
MINUTES
OFB
SC
90
80
70
60
50
40
30
20
10
0
TEMPERATURE, °C
100
200
300
400
MINUTES

Cooking the roasts to an end point temperature of 70°C required a total cooking time of 197 min or 142 min/kg less ($P<0.01$) than when cooking for 10 hr. Also, total and drip cooking losses ($P<0.01$), volume of drip ($P<0.05$) and percentage lipid in drip ($P<0.01$) were less for roasts cooked to 70°C than for roasts cooked 10 hr. Those losses were inversely related to WHC, total moisture and sensory scores for juiciness. At an end point of 70°C where the cooking losses were less than for those cooked 10 hr, WHC, total moisture and sensory scores for juiciness were higher ($P<0.01$). Vollmar (1974), in cooking roasts under conditions similar to those in this study to end points of 60° or 70°C, found when cooking to 60°C that cooking time in min and min/kg was less ($P<0.05$), total cooking losses were lower ($P<0.05$) and juiciness scores were higher ($P<0.05$) than when cooking to 70°C. However, in her study, drip cooking losses, volume of drip, WHC and total moisture were not affected by end point of cooking. Data from this present study support the findings of Bayne et al. (1973) and Shaffer et al. (1973). Bayne et al. (1973), oven roasted beef rib roasts at 107° or 163°C to end points of 60°, 70° or 77°C. As the end point of cooking increased for each cooking temperature, cooking time and cooking losses increased ($P<0.01$) and juiciness scores decreased ($P<0.01$). Shaffer et al. (1973) found that total moisture was greatest in roasts cooked to 60°C, and decreased ($P<0.05$) with each succeeding increase in end point temperature to 80°C.

Gardner a+(redness) and sensory scores for apparent degree of doneness indicate a loss ($P<0.05$) of redness, or a more well-done product, with an increase in cooking time and end point temperature. Those findings confirm the data of Vollmar (1974), who found a decrease in Gardner a+(redness) values ($P<0.05$) and apparent degree of doneness scores ($P<0.01$) when roasts cooked to 70°C were compared with roasts cooked to 60°C. However, Shaffer et al. (1973) found no such differences with increased end point temperature.

Measurements not affected significantly by end point of cooking were: shrinkage in length, width and depth, pH, Gardner Rd(reflectance) and b+(yellowness) values, and sensory scores for tenderness, softness, mealiness and flavor (Table 2). Vollmar (1974), who cooked roasts under conditions similar to those in this study to end points of 60° or 70°C reported similar results. However, as indicated by Gardner Rd(reflectance) values, she found that SC roasts cooked to 70°C were lighter ($P<0.05$), or more well-done, than those cooked to 60°C. No such differences occurred between end points of cooking for OFB roasts.

With 10 hr cooking, the product had a dry appearance, and it was noted by several panel members that this gave an initial impression of toughness. Also, for the product cooked 10 hr, on several occasions a comment was made on the absence of a "distinctive cooked beef flavor."

Although data in Table 2 show no significant differences in Warner-Bratzler shear values between end points of cooking when data for the two cooking methods were combined, that measurement is better explained by data for interactions between end point of cooking x method of cooking (Table 3). Shear values indicated that use of OFB resulted in a more tender ($P<0.01$) roast when cooked for 10 hr than when cooked in OFB to an end point of 70°C. That trend did not apply to SC roasts. Under the conditions of their studies, both Shaffer et al. (1973) and Vollmar (1974) found no differences in shear values attributable to end point of cooking.

Method of cooking and end point of cooking x method of cooking interactions

The various methods of moist heat cooking should induce similar changes in meat, because they all provide "steam" as the cooking environment. In this study, method of cooking had no significant effect on any of the measurements made except final internal temperature, volume of drip and Gardner Rd(reflectance) values (Table 3).

Roasts cooked by SC had higher Gardner Rd(reflectance) values (P<0.01) than roasts cooked in OFB, thereby indicating a lighter, more well-done product. Although differences between cooking methods at each end point of cooking (70°C, 0.70; 10 hr, 3.3; Table 7, Appendix, p. 62) were not significant, those data, which are combined for the two end points of cooking, appear to be influenced by differences between the two methods of cooking when roasts were cooked 10 hr. Also, when drip loss data for end points of cooking were combined, it was observed that such losses were greater (P<0.05) for SC roasts, than for roasts cooked by OFB. Those differences between methods were consistent, although not significant, at each end point of cooking (Table 7, Appendix, p. 62). It appears that both Gardner Rd(reflectance) and volume of drip are related to the inherent nature of the cooking method, because the trend that might be expected to be associated with the final internal temperature was not followed. Roasts cooked 10 hr in OFB had a higher (P<0.01) internal temperature than did those cooked the same length of time by SC. Accordingly, the OFB product may be expected to have higher Gardner Rd(reflectance) values and greater drip losses. However, opposite results were obtained. Data for reflectance and drip losses do not agree with those results reported by Vollmar (1974). At each end point, or when end points of cooking were combined, her data indicated no significant differences for either factor attributable to methods.

The non significant differences between cooking methods for other measurements agree with the data of Vollmar (1974). In her study, when data for the two end points were combined, no significant differences between the two cooking methods were found for the same measurements as for those in this study. Also, for similar measurements used to evaluate beef quality, Schock et al. (1970) found few significant differences between oven braising at 149°C and pressure braising at 10 p.s.i.g. (115°C). Because of the inherent nature of the methods, pressure braising required less ($P<0.05$) cooking time than oven braising. Moreover, oven braising resulted in greater ($P<0.05$) total cooking losses and lower ($P<0.05$) WHC values and sensory scores for juiciness.

Interactions between end point of cooking x method of cooking for total cooking losses, Warner-Bratzler shear values and total moisture are presented in Table 3. For all three measurements, when cooking to 70°C, there were no significant differences between methods of cooking. However, cooking roasts 10 hr resulted in significant differences between roasts cooked in OFB and in SC. Total cooking losses were greater ($P<0.05$) for roasts cooked in OFB, and the resulting product contained less ($P<0.05$) total moisture than roasts cooked in SC. Cooking in OFB also produced lower ($P<0.01$) Warner-Bratzler shear values, indicative of significantly increased tenderness over roasts cooked in SC. Likewise, Vollmar (1974) found no differences in those three measurements when cooking similar top round roasts under the same conditions to end points of 60° or 70°C.

Findings from this study and those reported in the literature indicate that different methods of moist heat cooking result in only small differences in the cooked meat. Any differences that occur tend to be accentuated by longer cooking.

Apparent degree of doneness

Apparent degree of doneness scores were not affected significantly by method of cooking (OFB, 2.93; SC, 2.87; Table 6, Appendix, p. 60). However, as expected, they were higher (1-rare, 2-medium-done, 3-well-done; $P<0.05$) for roasts cooked 10 hr than for those cooked to 70°C (Table 2).

Roasts cooked in OFB to 70°C appeared uniformly pinkish brown throughout. Although they seemed slightly moist, no juices exuded at the cut surface. Cooking 10 hr in OFB resulted in a roast uniformly brown throughout. Those roasts appeared drier than OFB roasts cooked for a shorter time to 70°C. The interior of roasts cooked to 70°C in the SC was slightly pinkish brown, and although differences in Gardner a+(redness) values and apparent degree of doneness scores were not significant, it was noted that upon cutting, roasts cooked in SC appeared slightly more well-done than roasts cooked in OFB to the same end point. Also, the interior of SC roasts appeared slightly drier than OFB roasts. Cooking 10 hr in SC produced roasts that were brown throughout the interior, and looked slightly less dry than when cooking in OFB for the same time. All roasts cooked in the SC had a layer (approximately 2.5-cm thick) at the bottom of the roast that had faded to grey brown. The same phenomenon was not observed in OFB roasts. This might be attributed to the fact that the cooking pot of the

SC was placed directly on the heating element. However, this was not the case for OFB roasts. The surface of all roasts was grey brown, and SC roasts appeared slightly more moist than OFB roasts.

Drip collected from roasts cooked in OFB was dark brown; that from roasts cooked in the SC was orange brown. The drip included both dispersed coagulum and fat that stabilized on top of the drip after it was transferred into graduated cylinders (Fig. 3).

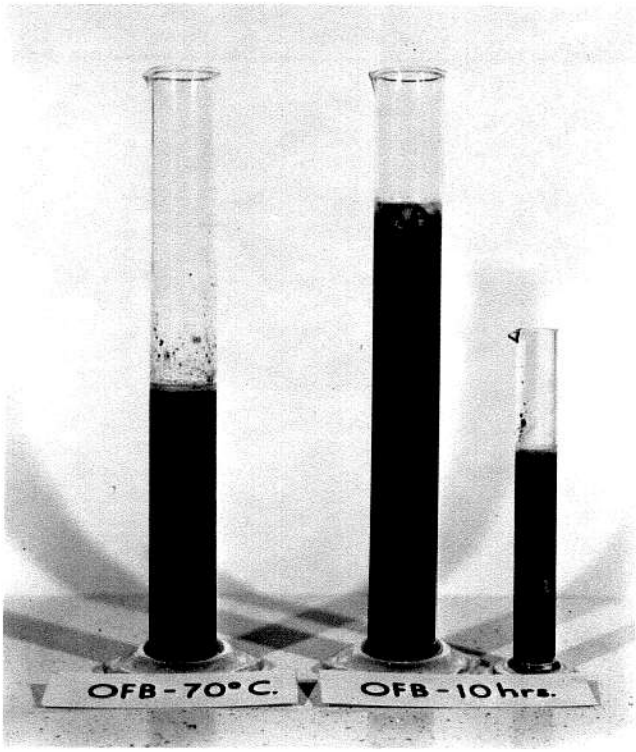
Relationships between selected parameters

Since few significant differences occurred between OFB and SC roasts, correlation coefficients for selected parameters were calculated on the basis of end point of cooking. Relationships will be considered according to Shindall (1964), who stated that irrespective of sign, a coefficient between 0.00 and 0.39 was low and indicative of a poor relationship between variates; a coefficient between 0.40 and 0.79 was designated a moderate relationship; and one above 0.80 was considered a good relationship.

Several workers pointed out that the time the internal temperature of a roast remains within given 5°C intervals in the range 55° to 70°C, may be an important factor affecting tenderness and juiciness of cooked meat (Cover, 1937, 1938; Bramblett et al., 1959; Bramblett and Vail, 1964). Therefore, in this study, correlation coefficients were calculated for the time the internal temperature of roasts remained in temperature intervals of 55° to 60°C, 60° to 65°C or 65° to 70°C and each of selected parameters that give an indication of tenderness or juiciness (Table 4).

When cooking to 70°C, moderate correlations occurred in all three time-internal temperature intervals for softness scores, in two of the

Fig. 3-Volume of drippings, ml, after cooking in OFB and SC to end points of 70°C or 10 hr.


OFB - 70° C.
OFB - 10 hrs.

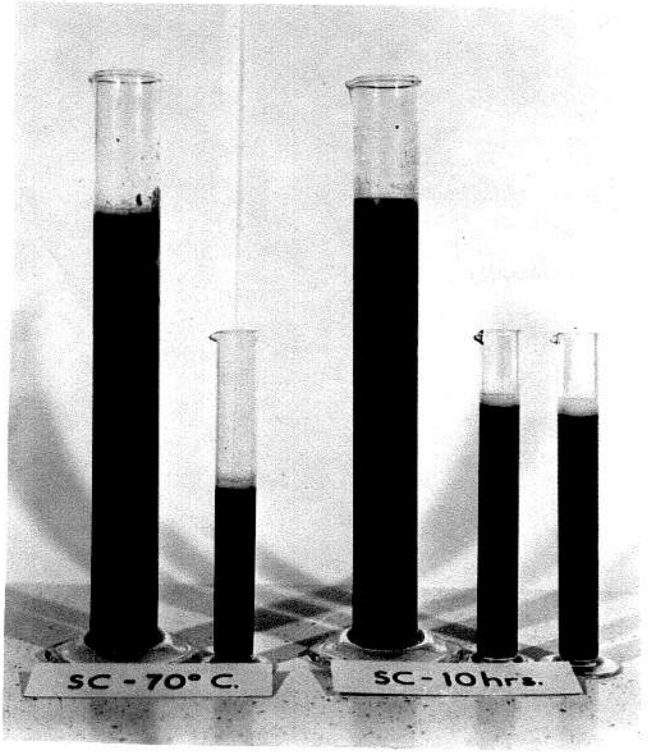

SC - 70° C.
SC - 10 hrs.

Table 4-Correlation coefficients[a] for selected parameters associated with tenderness and juiciness of beef

Tenderness and juiciness parameters for end point of 70°C		Tenderness and juiciness parameters for 10 hr cooking	
Paired variates	r-values	Paired variates	r-values
Softness scores		Total cooking losses	
55° - 60°C	-0.52	55° - 60°C	-0.50
60° - 65°C	-0.57*	60° - 65°C	-0.65*
65° - 70°C	-0.77**	65° - 70°C	-0.66*
Tenderness scores		WHC[b]	
55° - 60°C	-0.48	55° - 60°C	0.42
65° - 70°C	-0.68*	65° - 70°C	0.52
Shear value		Mealiness scores	
65° - 70°C	0.48	55° - 60°C	-0.47
Mealiness scores		60° - 65°C	-0.55
60° - 65°C	-0.43		
65° - 70°C	-0.51		
WHC[b]			
60° - 65°C	0.46		

Table 4-concluded

Tenderness and juiciness parameters for end point of 70°C		Tenderness and juiciness parameters for 10 hr cooking	
Paired variates	r-values	Paired variates	r-values
Tenderness scores		Tenderness scores	
Lipid in drip	0.43	Lipid in drip	0.80**
Softness scores	0.85**	Softness scores	0.78**
Mealiness scores	0.53	Mealiness scores	0.56
Juiciness scores	0.70*		
Shear value		Juiciness scores	
Tenderness scores	-0.48	Total cooking losses	-0.70*
Softness scores	-0.50	Volume of drip	-0.56
		Total moisture	
		WHC[b]	0.55
		Shear value	0.62*

[a] d/f = 10; * $P<0.05$, r = 0.567; ** $P<0.01$, r = 0.708

[b] Water-holding capacity, 1 - (expressible-liquid index)

intervals for tenderness and mealiness scores and in only one interval each for shear value and WHC (Table 4). As length of time in a given interval increased, softness, tenderness and mealiness scores decreased; whereas shear values and WHC increased. This indicates that with increased time in those intervals, the meat became less tender. That differs from data of earlier workers, who found that the longer the internal temperature of beef was held over the intervals indicated in this study, the more tender the product became (Cover, 1937, 1938; Bramblett and Vail, 1964). Vollmar (1974) found low correlation coefficients between tenderness scores and the time-internal temperature intervals of 55° to 60°C or 65° to 70°C. However, when cooking to an end point of 70°C, a moderate negative correlation occurred between shear values and the interval 65° to 70°C, thereby indicating that the longer the meat was held in that interval, the more tender it became.

When cooking 10 hr, moderate relationships occurred between total cooking losses and each of the three time-internal temperature intervals and both WHC and mealiness scores in two of the three intervals. As the length of time the internal temperature of the meat remained in each interval increased, total cooking losses and mealiness scores decreased, and WHC increased. Poor relationships ($r<0.40$) occurred between all other tenderness and juiciness parameters and time-internal temperature intervals studied (Table 8, Appendix, p. 65).

Correlation coefficients (Table 4) for paired parameters usually associated with tenderness or juiciness of beef indicated that at both end points of cooking, the relationship between tenderness scores and lipid in drip, softness scores or mealiness scores was positive and moderate to good.

As the tenderness score increased, lipid in drip increased. That could indicate that intramuscular fat (marbling) may or may not be an important determinant of beef tenderness. If the increased lipid in drip resulted from increased intramuscular fat in the raw meat, and the cooked meat scoring relatively high in tenderness still contained more lipid than meat receiving a lower tenderness score, the intramuscular fat may have some influence on tenderness. Conversely, if an increase of lipid in drip resulted in less lipid in the cooked meat, but the tenderness score still increased, the intramuscular fat may not be important to tenderness. Ether extract of cooked meat was not measured.

At an end point of 70°C, a moderate, negative relationship occurred for shear value and both tenderness scores and softness scores (Table 4). As shear values increased, tenderness and softness scores decreased. With the 70°C end point, the moderate relationship between tenderness and juiciness scores was positive (Table 4).

Cooking 10 hr resulted in negative moderate correlation coefficients for juiciness scores and both total cooking losses and volume of drip (Table 4). Juiciness scores were relatively high when cooking losses and volume of drip were low. Also, with cooking 10 hr, an increase in total moisture was accompanied by an increase in WHC and in shear value.

Correlation coefficients were low for other paired parameters associated with tenderness or juiciness (Table 8, Appendix, p. 65). That indicates those parameters did not measure, in the same manner, the components of tenderness or juiciness of the cooked product.

Differences between raw and cooked muscle

As expected, pH, Gardner Rd(reflectance), a+(redness) and b+(yellowness) values and total moisture of raw beef changed with cooking. To study the changes attributable to cooking method or end point of cooking, the differences between values for selected characteristics of raw muscle and the muscle subjected to each treatment combination were calculated (Table 5).

For each Gardner color-difference factor, differences were less between the raw muscle and that cooked in OFB to either end point of cooking than for muscle cooked in SC to the same end point. Changes in pH and total moisture did not appear to follow a particular trend. Those data were not analyzed statistically.

SUMMARY

A complete block design was used to evaluate the effect of end point of cooking and method of cooking on 24 top round beef roasts (SM and AD muscles) cooked from the frozen state. Roasts were cooked in either oven film bags (OFB) in a rotary hearth gas oven maintained at 94°C (200°F) or in a slow cooking appliance (SC) at setting No 3 (approximately 85°C or 185°F). All roasts were cooked to an internal end point of 70°C (158°F) or for 10 hr. Data were analyzed by analysis of variance. Correlation coefficients were calculated for selected paired variates on the basis of end point of cooking.

Table 5-Mean values for selected measurements on raw and cooked muscle according to end point and method of cooking

Heat treatment[a,b]	Measurement: pH	Color-difference, Gardner: Rd	Color-difference, Gardner: a+	Color-difference, Gardner: b+	Total moisture, %
Muscle cooked to 70°C:					
Raw muscle	5.49	7.22	15.58	4.91	72.07
OFB	5.58	15.31	4.83	9.06	62.21
Diff	0.09	8.09	10.75	4.15	9.86
SC	5.50	16.02	3.55	9.44	60.82
Diff	0.01	8.80	12.03	4.53	11.25
Muscle cooked 10 hrs:					
Raw muscle	5.47	7.25	15.38	5.19	71.18
OFB	5.49	13.51	3.00	9.16	57.03
Diff	0.02	6.26	12.38	3.97	14.15
SC	5.53	16.83	2.15	9.53	58.82
Diff	0.06	9.58	13.23	4.34	12.36

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

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

The rate of heat penetration was not affected by method of cooking. The rate was slower when the internal temperature of the meat was below 0°C than it was when the internal temperature was between 0° and 70°C; but when the internal temperature was above 70°C, the rate of heat penetration was reduced markedly. The final internal temperature after 10 hr cooking was higher ($P<0.01$) for OFB than SC roasts.

Total cooking time in min and min/kg ($P<0.01$), total and drip cooking losses ($P<0.01$), volume of drip ($P<0.05$) and percentage lipid in the drip ($P<0.01$) were greater for roasts cooked 10 hr than for those cooked to 70°C. Meat cooked 10 hr had lower ($P<0.05$) Gardner a+(redness) values and higher ($P<0.05$) apparent degree of doneness scores, than that cooked to 70°C. WHC ($P<0.01$), total moisture ($P<0.01$) and juiciness scores ($P<0.01$) decreased with longer cooking. No significant differences attributable to end point of cooking occurred in shrinkage, pH, Gardner Rd(reflectance) and b+(yellowness) values, shear values and tenderness, softness, mealiness and flavor scores.

The only measurements for which differences between the two cooking methods were significant were volume of drip ($P<0.05$) and Gardner Rd (reflectance) ($P<0.05$) values. Both those measurements were higher for SC roasts.

Interactions between end point of cooking and method of cooking indicate higher total cooking losses ($P<0.05$), and lower shear values ($P<0.01$) and total moisture ($P<0.05$) for OFB than SC roasts only when cooking 10 hr. In general, significant differences between cooking methods (data for end point of cooking combined) are consistent for both methods of cooking.

When cooking to 70°C, moderate correlations indicated that the longer the internal temperature of the meat was held over the interval 55° to 70°C, the less soft, tender and mealy the product was; whereas, shear values and WHC increased. When cooking 10 hr, moderate correlations indicated that the longer the meat remained in the temperature range 55° to 70°C, the lower the total cooking losses and the mealiness scores, but the higher the WHC. Shear values were moderately related to tenderness and softness scores only at 70°C.

CONCLUSIONS

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

1. Low-temperature, long-time cooking by moist heat (oven film bags or a slow cooking appliance) is a satisfactory method for cooking beef top round roasts from the frozen state.
2. Cooking in an oven film bag or a slow cooking appliance results in only small differences in beef cooked to the same end point. Any differences between the two methods in objective measurements of quality tend to be accentuated as cooking time increases.
3. Beef roasts cooked 10 hr are more well-done, have greater cooking losses and are less juicy than roasts cooked to an internal end point of 70°C.

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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					
	Chews	Score[a]	Softness[b]	Mealiness[c]	Juiciness[d]	Desirability of Flavor[e]	Apparent degree of doneness[f]	Comments
1								
2								

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

[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, juiciness and flavor.

Scoring for tenderness

Count the number of chews on a 1.3-cm cube of meat before swallowing. Chew until the cube is masticated completely, then swallow. Record a score of 7 to 1 that describes your impression of the tenderness of the cube. Refer to the score card for descriptive terms of specific scores within the range 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 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 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 juiciness

Record a score 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 juiciness at the beginning of the chewing process.

Scoring for flavor

Record a score for flavor 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 throughout 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.

Comments

Comments about the sample and/or an explanation of why you gave a particular score to the sample are helpful.

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

Table 6-Means and F-values for non significant effects of method of cooking[a]

Measurement	Method of cooking OFB	SC	Difference	F-value
Initial weight, g	1384.5	1376.1	8.4	3.52
Cooking time				
Total, min	504.83	498.25	6.58	0.84
Min/kg	364.50	362.02	2.48	0.20
Cooking losses, %				
Total	34.48	33.16	1.32	3.13
Drip	26.78	27.58	0.80	0.66
Lipid in drip, % of volume	1.90	2.10	0.20	0.24
Shrinkage, %				
Length	17.85	16.14	1.71	0.42
Width	18.10	21.32	3.22	0.42
Depth	4.15	4.79	0.64	0.12
pH	5.54	5.51	0.03	0.16
Color-difference, Gardner				
a+(redness)	3.92	2.85	1.07	2.85
b+(yellowness)	9.11	9.49	0.38	2.40
Shear value,				
kg/1.3-cm core	4.57	4.85	0.28	0.67
Water-holding capacity[c]	0.659	0.686	0.027	1.67
Total moisture, %	59.62	59.82	0.20	0.13
Sensory scores				
Tenderness[d]	5.17	5.09	0.08	0.07

Table 6-concluded

Measurement	Method of cooking		Difference	F-value
	OFB	SC		
Sensory scores				
Softness[d]	4.62	4.72	0.10	0.17
Mealiness[d]	4.81	4.69	0.12	0.44
Juiciness[d]	3.70	4.12	0.42	2.30
Flavor[d]	4.84	4.97	0.13	0.63
Apparent degree of doneness[e]	2.93	2.87	0.06	0.52

[a] Data irrespective of end point of cooking

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

[c] 1.0 - (expressible-liquid index)

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

[e] 3-well-done; 2-medium-done; 1-rare

Table 7-Means and F-values for non significant end point of cooking x method of cooking interactions

Measurements	End point of cooking	Method of cooking[a] OFB	SC	F-value
Initial wt, g	70°C	1382.5	1375.8	0.15
	10 hr	1386.5	1376.3	
Cooking time Total, min	70°C	409.67	396.50	0.84
	10 hr	600.00	600.00	
Min/kg	70°C	296.28	288.15	1.06
	10 hr	432.72	435.90	
Cooking losses, % Drip	70°C	25.21	25.91	0.01
	10 hr	28.36	29.24	
Volume of drip, ml	70°C	295.50	329.17	0.02
	10 hr	326.00	356.17	
Lipid in drip, % of volume	70°C	0.93	1.73	2.08
	10 hr	2.88	2.48	
Shrinkage, % decrease Length	70°C	18.41	16.52	0.01
	10 hr	17.29	15.76	
Width	70°C	20.39	17.82	1.36
	10 hr	15.81	24.83	
Depth	70°C	3.99	7.91	3.16
	10 hr	4.30	1.67	

Table 7-continued

Measurements	End point of cooking	Method of cooking[a] OFB	SC	F-value
pH	70°C	5.58	5.50	0.89
	10 hr	5.49	5.53	
Color-difference, Gardner Rd(reflectance)	70°C	15.31	16.02	4.44
	10 hr	13.51	16.83	
a+(redness)	70°C	4.83	3.55	0.12
	10 hr	3.00	2.15	
b+(yellowness)	70°C	9.06	9.44	0.01
	10 hr	9.16	9.53	
Water-holding capacity[b]	70°C	0.697	0.723	0.01
	10 hr	0.622	0.648	
Sensory scores Tenderness[c]	70°C	4.95	5.03	0.33
	10 hr	5.38	5.15	
Softness[c]	70°C	4.48	4.78	0.70
	10 hr	4.75	4.65	
Mealiness[c]	70°C	4.63	4.53	0.01
	10 hr	4.98	4.85	
Juiciness[c]	70°C	4.38	4.92	0.15
	10 hr	3.02	3.33	

Table 7-concluded

Measurements	End point of cooking	Method of cooking[a] OFB	SC	F-value
Sensory scores				
Flavor[c]	70°C	4.97	5.17	0.23
	10 hr	4.72	4.77	
Apparent degree of doneness[d]	70°C	2.87	2.73	0.52
	10 hr	3.00	3.00	

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

[b] 1.0 - (expressible-liquid index)

[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

Table 8-Correlation coefficients[a] for selected parameters associated with tenderness and juiciness of beef

Tenderness and juiciness parameters for end point of 70°C		Tenderness and juiciness parameters for 10 hr cooking	
Paired variates	r-values	Paired variates	r-values
Mealiness scores		Softness scores	
55° - 60°C	-0.02	55° - 60°C	0.12
WHC[b]		60° - 65°C	-0.17
55° - 60°C	-0.08	65° - 70°C	-0.05
65° - 70°C	0.07	Tenderness scores	
Total cooking losses		55° - 60°C	-0.21
55° - 60°C	0.31	65° - 70°C	-0.23
60° - 65°C	-0.08	Shear value	
65° - 70°C	-0.15	65° - 70°C	0.24
		Mealiness scores	
		65° - 70°C	-0.32
		WHC[b]	
		60° - 65°C	0.24

Table 8-concluded

Tenderness and juiciness parameters for end point of 70°C		Tenderness and juiciness parameters for 10 hr cooking	
Paired variates	r-values	Paired variates	r-values
Juiciness scores		Shear value	
Total cooking losses	0.35	Tenderness scores	-0.17
Volume of drip	0.30	Softness scores	-0.15
Total moisture		Juiciness scores	
WHC[b]	-0.19	Tenderness scores	0.31
Shear value	0.32		

[a] d/f = 10; * $P<0.05$, r = 0.567; ** $P<0.01$, r = 0.708

[b] Water-holding capacity, 1 - (expressible-liquid index)

Table 9-Initial weight of roasts

	Method of cooking			
	Oven film bag		Slow cooker	
End point	Round and roast no.	Weight, g	Round and roast no.	Weight, g
70°C	1 D	1380	1 C	1361
	2 A	1389	2 B	1370
	3 C	1390	3 A	1384
	4 D	1394	4 B	1365
	5 B	1358	5 D	1388
	6 A	1384	6 D	1387
Mean		1382.5		1375.8
10 hr	1 A	1387	1 B	1371
	2 D	1386	2 C	1388
	3 D	1386	3 B	1380
	4 C	1390	4 A	1365
	5 C	1385	5 A	1387
	6 C	1385	6 B	1367
Mean		1386.5		1376.3

Table 10-Means and F-values[a] for rate of heat penetration in minutes to reach 0°C, to increase by increments of 10°C from 0°C to 40°C and 5°C from 40°C to 70°C or cooking for 10 hr, for end point of cooking

Internal temperature interval, °C	End point of cooking[b]		
	70°C	10 hr	F-value
Initial temp to 0°C	183.6	189.7	2.54
0° to 10°C	34.0	29.9	1.18
10° to 20°C	14.7	12.9	0.93
20° to 30°C	16.7	16.5	0.03
30° to 40°C	21.2	21.9	0.18
40° to 45°C	13.0	13.8	0.49
45° to 50°C	16.5	15.1	1.61
50° to 55°C	18.8	17.1	1.56
55° to 60°C	22.6	22.9	0.04
60° to 65°C	26.8	28.6	0.40
65° to 70°C	35.3	37.0	0.15
70° to 75°C	-	71.1	-

[a] All F-values non significant at the $P<0.05$ level

[b] Data irrespective of method of cooking

Table 11-Means and F-values[a] for rate of heat penetration in minutes to reach 0°C, to increase by increments of 10°C from 0° to 40°C and 5°C from 40° to 70°C or cooking for 10 hr, for method of cooking

Internal temperature interval, °C	Method of cooking[b]		
	OFB	SC	F-value
Initial temp to 0°C	183.5	189.8	2.68
0° to 10°C	33.5	30.4	0.68
10° to 20°C	14.5	13.2	0.38
20° to 30°C	17.1	16.0	0.57
30° to 40°C	23.0	20.1	2.69
40° to 45°C	14.3	12.5	2.36
45° to 50°C	16.3	15.3	0.67
50° to 55°C	18.1	17.8	0.03
55° to 60°C	22.7	22.9	0.01
60° to 65°C	26.3	29.1	0.85
65° to 70°C	34.5	37.8	0.59
70° to 75°C	55.6	86.6	1.06

[a] All F-values not significant at the $P<0.05$ level

[b] Data irrespective of end point of cooking

Table 12-Means and F-values[a] for rate of heat penetration in minutes to reach 0°C, to increase by increments of 10°C from 0° to 40°C and 5°C from 40° to 70°C or cooking for 10 hr, for end point of cooking x method of cooking interactions

Internal temperature interval, °C	End point of cooking	Method of cooking		F-value
		OFB	SC	
Initial temp to 0°C	70°C	182.8	184.3	1.55
	10 hr	184.2	195.2	
0° to 10°C	70°C	33.5	34.5	1.18
	10 hr	33.5	26.2	
10° to 20°C	70°C	17.2	12.2	4.08
	10 hr	11.5	14.2	
20° to 30°C	70°C	17.5	15.8	0.17
	10 hr	16.7	16.2	
30° to 40°C	70°C	23.2	19.2	0.37
	10 hr	22.8	21.0	
40° to 45°C	70°C	13.8	12.2	0.02
	10 hr	14.8	12.8	
45° to 50°C	70°C	17.3	15.6	0.45
	10 hr	15.2	15.0	
50° to 55°C	70°C	19.8	17.8	1.56
	10 hr	16.3	17.8	
55° to 60°C	70°C	23.0	22.2	0.36
	10 hr	22.3	23.5	

Table 12-concluded

Internal temperature interval, °C	End point of cooking	Method of cooking		F-value
		OFB	SC	
60° to 65°C	70°C	25.6	27.8	0.03
	10 hr	27.0	30.2	
65° to 70°C	70°C	35.8	34.8	0.99
	10 hr	33.2	40.8	
70° to 75°C	70°C	-	-	-
	10 hr	55.6	86.6	

[a] All F-values not significant at the P<0.05 level

Table 13-Total cooking time in minutes and minutes/kg for roasts cooked to 70°C or for 10 hr, and final internal temperature for roasts cooked 10 hr

	Method of cooking							
	Oven film bag				Slow cooker			
End point	Round and roast no.	Time, min	Time, min/kg	Temp, °C	Round and roast no.	Time, min	Time, min/kg	Temp, °C
70°C	1 D	426	308.6		1 C	382	280.6	
	2 A	418	300.9		2 B	458	334.3	
	3 C	404	290.6		3 A	416	300.5	
	4 D	397	284.7		4 B	364	266.6	
	5 B	402	296.0		5 D	373	268.7	
	6 A	411	296.9		6 D	386	278.2	
Mean		409.6	296.3			396.5	288.2	
10 hr	1 A	600	432.5	83.0	1 B	600	437.6	80.5
	2 D	600	432.9	79.0	2 C	600	432.2	73.0
	3 D	600	432.9	84.0	3 B	600	434.7	75.5
	4 C	600	431.6	86.0	4 A	600	439.5	75.0
	5 C	600	433.2	79.0	5 A	600	432.5	76.0
	6 C	600	433.2	82.0	6 B	600	438.9	77.0
Mean		600.0	432.7	82.16		600.0	435.9	76.16

Table 14-Percentage total and drip cooking losses

	Method of cooking					
	Oven film bag			Slow cooker		
End point	Round and roast no.	Total loss	Drip loss	Round and roast no.	Total loss	Drip loss
70°C	1 D	31.22	22.24	1 C	33.50	25.64
	2 A	29.36	25.41	2 B	27.94	21.89
	3 C	29.20	24.38	3 A	31.21	27.60
	4 D	28.90	25.46	4 B	29.44	26.59
	5 B	30.69	27.09	5 D	31.90	28.81
	6 A	30.92	26.66	6 D	27.96	24.94
Mean		30.04	25.20		30.32	25.91
10 hr	1 A	41.74	31.29	1 B	34.64	25.82
	2 D	38.15	27.77	2 C	32.27	25.14
	3 D	38.81	26.98	3 B	39.12	33.84
	4 C	39.99	29.49	4 A	36.10	30.32
	5 C	36.09	25.77	5 A	36.83	29.19
	6 C	38.69	28.88	6 B	37.01	31.16
Mean		38.91	28.36		35.60	29.25

Table 15-Volume of drip, and percentage fat in drip

	Method of cooking					
	Oven film bag			Slow cooker		
End point	Round and roast no.	Volume drip, ml	Percent-age fat	Round and roast no.	Volume drip, ml	Percent-age fat
70°C	1 D	257	0.77	1 C	321	0.93
	2 A	300	0.66	2 B	267	1.12
	3 C	270	0.37	3 A	350	1.42
	4 D	304	0.98	4 B	342	1.75
	5 B	320	1.25	5 D	375	2.66
	6 A	322	1.55	6 D	320	2.50
Mean		295.5	0.93		329.2	1.73
10 hr	1 A	363	0.82	1 B	320	1.87
	2 D	302	1.32	2 C	312	2.88
	3 D	313	3.19	3 B	340	4.11
	4 C	350	2.85	4 A	381	0.26
	5 C	294	3.40	5 A	378	1.58
	6 C	334	5.68	6 B	406	4.18
Mean		326.0	2.88		356.2	2.48

Table 16-Percentage shrink in length, width, and depth

	Method of cooking							
	Oven film bag				Slow cooker			
End point	Round and roast no.	Length shrink, %	Width shrink, %	Depth shrink, %	Round and roast no.	Length shrink, %	Width shrink, %	Depth shrink, %
70°C	1 D	19.23	25.00	8.69	1 C	13.33	9.09	15.00
	2 A	16.67	29.16	0.06	2 B	16.00	8.00	0.00
	3 C	14.28	0.00	10.00	3 A	28.00	0.00	5.26
	4 D	16.67	27.27	5.26	4 B	26.67	34.78	0.00
	5 B	21.42	22.72	0.00	5 D	15.15	33.33	16.67
	6 A	22.22	18.18	0.00	6 D	0.00	21.73	10.52
Mean		18.42	20.39	3.99		16.53	17.82	7.91
10 hr	1 A	8.00	16.67	10.00	1 B	13.33	9.09	10.00
	2 D	17.85	13.63	5.26	2 C	15.38	19.04	0.00
	3 D	14.81	27.27	0.00	3 B	16.67	42.85	0.00
	4 C	20.00	14.28	5.00	4 A	23.07	18.18	0.00
	5 C	23.07	12.50	0.00	5 A	10.71	28.00	0.00
	6 C	20.00	10.52	5.55	6 B	15.38	31.81	0.00
Mean		17.20	15.81	4.30		17.76	24.83	1.67

Table 17-pH, raw and cooked

	Method of cooking					
	Oven film bag			Slow cooker		
End point	Round and roast no.	Raw pH	Cooked pH	Round and roast no.	Raw pH	Cooked pH
70°C	1 D	5.36	5.99	1 C	5.36	5.46
	2 A	5.50	5.49	2 B	5.38	5.45
	3 C	5.31	5.43	3 A	5.38	5.44
	4 D	5.74	5.55	4 B	5.38	5.44
	5 B	5.91	5.49	5 D	5.35	5.34
	6 A	5.51	5.53	6 D	5.74	5.88
Mean		5.55	5.58		5.43	5.49
10 hr	1 A	5.43	5.46	1 B	6.08	5.54
	2 D	5.36	5.48	2 C	5.42	5.54
	3 D	5.41	5.62	3 B	5.59	5.62
	4 C	5.34	5.39	4 A	5.41	5.43
	5 C	5.37	5.44	5 A	5.31	5.36
	6 C	5.50	5.58	6 B	5.48	5.67
Mean		5.40	5.49		5.55	5.52

Table 18-Gardner color-difference Rd(reflectance) values, raw and cooked

	Method of cooking					
	Oven film bag			Slow cooker		
End point	Round and roast no.	Raw Rd value	Cooked Rd value	Round and roast no.	Raw Rd value	Cooked Rd value
70°C	1 D	5.55	12.25	1 C	5.45	14.40
	2 A	5.35	15.80	2 B	7.95	15.65
	3 C	6.10	16.75	3 A	10.25	16.10
	4 D	10.25	13.90	4 B	9.75	19.60
	5 B	7.00	18.60	5 D	10.60	17.10
	6 A	4.45	14.55	6 D	3.95	13.30
Mean		6.45	15.30		7.99	16.02
10 hr	1 A	8.30	10.35	1 B	4.45	16.75
	2 D	5.90	13.10	2 C	5.25	14.00
	3 D	7.05	13.55	3 B	9.10	18.40
	4 C	5.45	14.60	4 A	5.95	18.15
	5 C	8.45	15.80	5 A	14.50	18.05
	6 C	5.95	13.65	6 B	6.65	15.65
Mean		6.85	13.50		7.65	16.83

Table 19-Gardner color-difference a+(redness) values, raw and cooked

	Method of cooking					
	Oven film bag			Slow cooker		
End point	Round and roast no.	Raw a+ value	Cooked a+ value	Round and roast no.	Raw a+ value	Cooked a+ value
70°C	1 D	14.85	7.80	1 C	14.15	3.60
	2 A	14.65	7.90	2 B	17.25	1.45
	3 C	17.10	3.80	3 A	16.50	3.90
	4 D	12.55	2.30	4 B	19.30	4.40
	5 B	17.50	3.65	5 D	14.80	3.05
	6 A	14.10	3.55	6 D	14.25	4.90
Mean		15.12	4.83		16.04	3.55
10 hr	1 A	16.45	4.55	1 B	12.25	1.40
	2 D	13.90	2.35	2 C	15.45	2.95
	3 D	14.85	2.85	3 B	14.50	2.25
	4 C	14.90	3.10	4 A	16.15	1.00
	5 C	18.10	2.75	5 A	18.65	2.70
	6 C	13.80	2.40	6 B	15.60	2.60
Mean		15.30	3.00		15.43	2.15

Table 20-Gardner color-difference b+(yellowness) values, raw and cooked

End point		Method of cooking					
		Oven film bag			Slow cooker		
		Round and roast no.	Raw b+ value	Cooked b+ value	Round and roast no.	Raw b+ value	Cooked b+ value
70°C		1 D	2.80	8.65	1 C	2.80	9.55
		2 A	2.50	9.60	2 B	5.85	9.60
		3 C	4.55	9.35	3 A	4.70	9.50
		4 D	4.00	8.95	4 B	3.40	10.25
		5 B	7.30	9.40	5 D	10.05	9.55
		6 A	6.05	8.40	6 D	4.95	8.20
	Mean		4.53	9.06		5.29	9.44
10 hr		1 A	6.40	9.35	1 B	1.45	9.65
		2 D	3.50	8.75	2 C	4.50	8.45
		3 D	4.40	8.40	3 B	2.70	10.05
		4 C	9.25	9.50	4 A	9.40	9.35
		5 C	1.70	9.60	5 A	5.20	9.60
		6 C	6.50	9.35	6 B	7.30	10.10
	Mean		5.29	9.15		5.09	9.53

Table 21-Warner-Bratzler shear (kg/1.3-cm core), and water holding capacity

	Method of cooking					
	Oven film bag			Slow cooker		
End point	Round and roast no.	Shear value	WHC	Round and roast no.	Shear value	WHC
70°C	1 D	5.56	0.700	1 C	5.73	0.728
	2 A	6.32	0.642	2 B	5.29	0.726
	3 C	5.98	0.719	3 A	5.32	0.716
	4 D	4.95	0.707	4 B	5.20	0.697
	5 B	4.29	0.648	5 D	2.81	0.719
	6 A	5.51	0.759	6 D	3.76	0.740
Mean		5.44	0.696		4.69	0.721
10 hr	1 A	4.89	0.681	1 B	7.52	0.693
	2 D	4.34	0.557	2 C	5.72	0.739
	3 D	4.36	0.532	3 B	5.98	0.612
	4 C	2.14	0.697	4 A	4.65	0.578
	5 C	3.31	0.686	5 A	3.75	0.617
	6 C	3.18	0.671	6 B	2.42	0.650
Mean		3.70	0.621		5.00	0.648

Table 22-Percentage total moisture, raw and cooked

	Method of cooking					
	Oven film bag			Slow cooker		
End point	Round and roast no.	Raw percentage	Cooked percentage	Round and roast no.	Raw percentage	Cooked percentage
70°C	1 D	73.30	66.40	1 C	71.75	62.40
	2 A	74.95	60.15	2 B	68.75	58.95
	3 C	72.20	61.85	3 A	69.10	61.80
	4 D	75.65	61.95	4 B	73.20	62.85
	5 B	71.20	61.95	5 D	69.10	60.25
	6 A	71.20	60.95	6 D	74.50	58.70
Mean		73.08	62.20		71.06	60.82
10 hr	1 A	73.15	58.65	1 B	75.15	61.10
	2 D	68.20	55.00	2 C	68.75	59.35
	3 D	70.30	57.55	3 B	74.50	60.00
	4 C	71.15	56.50	4 A	70.90	56.50
	5 C	71.75	58.75	5 A	69.45	57.30
	6 C	67.95	55.75	6 B	72.95	58.70
Mean		70.41	57.03		71.95	58.82

Table 23-Tenderness[a] and apparent degree of doneness[b] scores

	Method of cooking					
	Oven film bag			Slow cooker		
End point	Round and roast no.	Tenderness score	Apparent degree of doneness	Round and roast no.	Tenderness score	Apparent degree of doneness
70°C	1 D	5.3	2.9	1 C	4.7	2.9
	2 A	4.3	2.9	2 B	4.1	3.0
	3 C	5.4	3.0	3 A	4.3	3.0
	4 D	4.7	2.5	4 B	6.0	1.8
	5 B	5.3	2.9	5 D	5.6	3.0
	6 A	4.7	3.0	6 D	5.5	2.7
Mean		4.9	2.8		5.0	2.7
10 hr	1 A	4.3	3.0	1 B	5.1	3.0
	2 D	5.0	3.0	2 C	5.7	3.0
	3 D	5.7	3.0	3 B	5.9	3.0
	4 C	6.0	3.0	4 A	4.1	3.0
	5 C	5.3	3.0	5 A	5.0	3.0
	6 C	6.0	3.0	6 B	5.1	3.0
Mean		5.4	3.0		5.2	3.0

[a] Range: 7-(extremely tender); 1-(extremely tough)

[b] 3-well-done; 2-medium done; 1-rare

Table 24-Softness and mealiness scores[a]

	Method of cooking					
	Oven film bag			Slow cooker		
End point	Round and roast no.	Softness score	Mealiness score	Round and roast no.	Softness score	Mealiness score
70°C	1 D	4.4	4.4	1 C	4.9	4.7
	2 A	4.3	4.4	2 B	4.1	4.0
	3 C	4.6	5.3	3 A	4.1	4.3
	4 D	4.5	4.5	4 B	5.5	4.3
	5 B	4.9	4.7	5 D	5.1	4.9
	6 A	4.2	4.5	6 D	5.0	5.0
Mean		4.5	4.6		4.8	4.5
10 hr	1 A	3.9	5.0	1 B	4.7	4.9
	2 D	4.0	4.7	2 C	5.1	4.9
	3 D	4.6	4.7	3 B	5.3	4.9
	4 C	5.1	5.6	4 A	3.6	3.9
	5 C	5.8	4.5	5 A	4.5	5.2
	6 C	5.1	5.4	6 B	4.7	5.3
Mean		4.8	5.0		4.7	4.8

[a] Range: 7-(extremely soft or mealy); 1-(extremely hard or chewy)

Table 25-Juiciness and flavor scores[a]

	Method of cooking					
	Oven film bag			Slow cooker		
End point	Round and roast no.	Juiciness score	Flavor score	Round and roast no.	Juiciness score	Flavor score
70°C	1 D	4.9	5.2	1 C	5.3	5.0
	2 A	3.0	4.1	2 B	4.0	4.6
	3 C	5.1	5.4	3 A	4.6	5.3
	4 D	4.7	5.2	4 B	5.8	5.7
	5 B	4.6	4.9	5 D	5.3	5.6
	6 A	4.0	5.0	6 D	4.5	4.8
Mean		4.4	5.0		4.9	5.2
10 hr	1 A	2.0	4.7	1 B	4.0	5.0
	2 D	3.1	4.6	2 C	3.6	4.7
	3 D	3.4	4.7	3 B	3.4	5.3
	4 C	2.3	4.1	4 A	2.9	4.4
	5 C	4.0	5.3	5 A	3.0	4.5
	6 C	3.3	4.9	6 B	3.1	4.7
Mean		3.0	4.7		3.3	4.8

[a] Range: 7-(extremely juicy or desirable flavor); 1-(extremely dry or undesirable flavor)

EFFECTS OF LOW-TEMPERATURE, LONG-TIME MOIST HEAT COOKING FROM THE FROZEN STATE ON BEEF ROASTS

by

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Selection of a cooking method usually is based on convenience of the method and the effect on end product quality. Oven film bags (OFB) and slow cooking appliances (SC) are a variation of braising, a traditional method of moist heat cookery, which generally is recommended for less tender cuts to soften collagenous connective tissue. OFB and SC are advertised for their conveniences and for their effectiveness in producing juicy, flavorful meat.

A complete block design was used to evaluate the effect of end point of cooking and method of cooking on 24 top round beef roasts (SM and AD muscles) cooked from the frozen state. Roasts were cooked in either OFB in a rotary hearth gas oven maintained at 94°C (200°F) or in SC at setting No 3 (approximately 85°C or 185°F). All roasts were cooked to an internal end point of 70°C (158°F) or for 10 hr. Data were analyzed by analysis of variance. Correlation coefficients were calculated for selected paired variates on the basis of end point of cooking.

The rate of heat penetration was not affected by method of cooking. The rate was slower when the internal temperature of the roast was below 0°C than it was when the internal temperature was between 0° and 70°C; but when the internal temperature was above 70°C, the rate of heat penetration was reduced markedly. The final internal temperature after 10 hr cooking was higher ($P<0.01$) for OFB than SC roasts.

Total cooking time in min and min/kg ($P<0.01$), total and drip cooking losses ($P<0.01$), volume of drip ($P<0.05$) and percentage lipid in the drip ($P<0.01$) were greater for roasts cooked 10 hr than those cooked to 70°C. Meat cooked 10 hr had lower ($P<0.05$) Gardner a+(redness) values and higher ($P<0.05$) apparent degree of doneness scores, than that cooked to 70°C. WHC

($P<0.01$), total moisture ($P<0.01$) and juiciness scores ($P<0.01$) decreased with longer cooking. No significant differences attributable to end point of cooking occurred in shrinkage, pH, Gardner Rd(reflectance) and b+(yellowness) values, shear values and tenderness, softness, mealiness and flavor scores.

The only measurements for which differences between the two cooking methods were significant were volume of drip ($P<0.05$) and Gardner Rd (reflectance) ($P<0.05$) values. Both those measurements were higher for SC roasts.

Interactions between end point of cooking and method of cooking indicate higher total cooking losses ($P<0.05$), and lower shear values ($P<0.01$) and total moisture ($P<0.05$) for OFB than SC roasts only when cooking 10 hr. In general, significant differences between cooking methods (data for end points of cooking combined) are consistent for both methods of cooking.

When cooking to 70°C, moderate correlations indicated that the longer the internal temperature of the meat was held over the interval 55° to 70°C, the less soft, tender and mealy the product; whereas, shear values and WHC increased. When cooking 10 hr, moderate correlations indicated that the longer the meat remained in the temperature range 55° to 70°C, the lower the total cooking losses and the mealiness scores, but the higher the WHC. Shear values were moderately related to tenderness and softness scores only at 70°C.