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THE UNIVERSITY OF ALBERTA

EFFECTS OF CURRENT HOME FREEZING, STORAGE AND THAWING METHODS ON SELECTED CHARACTERISTICS OF BEEF STEAKS

by

(C) ARLENE ROYDEN SMITH

A THESIS

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The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Effects of current home freezing, storage and thawing methods on selected characteristics of beef steaks" submitted by Arlene Royden Smith in partial fulfillment of the requirements for the degree of Master of Science in Foods.

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Date October 18, 1976

ABSTRACT

Beef LD steaks were frozen and stored 10 days or 187 days in each of three types of household freezers, F(1), one-door refrigerator-freezer; F(2), two-door 'frostfree' refrigerator-freezer; F(3), upright household freezer. The frozen LD steaks were thawed by three methods, refrigerator temperature (RF); room temperature (RT); and oven temperature (OT, cooked directly from the frozen state). Fresh LD steaks served as a control.

Fresh LD steaks and LD steaks frozen and stored 10 days were similar in appearance and color. Percent total losses for steaks frozen and stored 10 days were higher than the total losses of comparable fresh steaks. Percent cooking losses for both the fresh and the frozen steaks stored 10 days were similar. Frozen steaks stored 10 days were softer, more tender, had less residual connective tissue, and were more meaty but less juicy than comparable fresh steaks. Initial flavor and overall acceptability scores for both the fresh steaks and frozen steaks stored 10 days were similar. Percent ether extract, percent total moisture, water holding capacity, shear value and TBA number were not significantly affected by 10 days of frozen storage.

Steaks frozen and stored for 10 days were superior in appearance and color to comparable LD steaks frozen and stored for 187 days. Percent total losses, drip in pan,

total cooking and volatile losses increased significantly between 10 and 187 days frozen storage. Frozen steaks stored 10 days were rated significantly higher for each of the palatability characteristics evaluated than comparable samples stored 187 days. Frozen steaks stored 187 days had a greater water holding capacity than comparable steaks frozen for the short period of time. Warner Bratzler shear values were not significantly affected by length of frozen storage.

Steaks frozen and stored in F(3) were superior in appearance to steaks frozen and stored in either F(1) or F(2). Total losses and drip in thaw of LD steaks frozen and stored in F(3) and F(2) were significantly lower than the total losses and drip in thaw of comparable steaks frozen and stored in F(1). Percent cooking losses were similar for steaks frozen and stored in each of the household freezers. Steaks frozen and stored in F(3) and F(2) were softer and had lower shear values than comparable steaks frozen and stored in F(1). However, LD steaks frozen and stored in each of the home freezers were similar in juiciness, tenderness, residual connective tissue, meatiness and overall acceptability. Initial flavor scores for steaks frozen and stored in F(3) and F(1) were significantly higher than scores for comparable steaks frozen and stored in F(2).

Frozen steaks thawed prior to or during cooking took longer (P<0.01) to reach the 61° endpoint temperature than did comparable fresh LD steaks. The cooking time for OT steaks was significantly longer than the cooking time of comparable RT and RF steaks. Percent total losses for LD steaks thawed before or during cooking were significantly higher than the losses of fresh LD steaks. Generally there were no significant differences in the cooking losses of either fresh and RT steaks or fresh and RF steaks. However, total cooking and volatile losses of the OT steaks were higher than similar losses of comparable fresh steaks. There were only slight differences in the palatability of fresh steaks and frozen steaks thawed prior to or during cooking. The eating quality of RT steaks was slightly more desirable than that of RF and OT steaks, however, all the steaks thawed before or during cooking were judged moderately desirable.

Data for the combined effects of freezing, storage and thawing indicate that the best consumer practice to use is frozen storage in F(3) followed by thawing at either RT or RF, regardless of the length of frozen storage. Frozen storage (10 or 187 days) in F(1) combined with OT thawing is the least desirable practice to use.

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INTRODUCTION

According to Williams (1966), approximately 80% of all red meat purchased in supermarkets is later frozen at home and stored until used. Differences in the methods of freezing meat and in the handling of frozen meats in the home are attributed to the facilities available, knowledge of using frozen meats and personal preference. A survey of people who freeze meat (Baldwin et al., 1972) revealed that 46% of the respondents used home freezers, 34% used two-door refrigerator-freezers, and 28% used one-door refrigerators. The effects of current home freezing methods on the palatability of beef have not been studied extensively. In addition, the effects of the 'frostfree' refrigerator-freezer, currently popular with consumers, on the quality characteristics of beef require investigation. The 'frostfree' refrigerator-freezer differs from other current home freezers in that the internal temperature of the freezing section rises above 0° during the defrost cycle.

The survey of Benson and Ivey (1961) revealed that one day was the median length of fresh meat storage time for beef roasts and steaks, while the median length of frozen storage for similar meat cuts was two weeks. Weidenhamer et al., (1969) reported that lengths of home storage time for frozen meat varied from one week or less to six months, or more. Research is needed to evaluate the effects of short and long freezer storage times, currently utilized by consumers, on the palatability of meat held under typical home conditions.

Weidenhamer et al., (1969) reported that 67% of the respondents who froze meat usually thawed the meat completely before cooking it, while only 5% generally cooked the meat from the frozen state. Results of a consumer survey conducted by Benson and Ivey (1961) indicated that 88% of the responding homemakers defrosted frozen meat before cooking it. Of the homemakers who defrosted meat, 80% thawed it at room temperature, while 19% defrosted the meat in the refrigerator. Numerous research reports have discussed the effects of thawing on the palatability of beef. However, information available in the literature comparing the quality of frozen meat defrosted by consumer techniques and fresh meat is limited. Research is needed to evaluate the effects of consumer freezing, storage and thawing practices on the eating quality of meat.

Much of the published information concerning the effects of freezing, storage, or thawing methods on the palatability of beef has been obtained from studies with steers. However, increasing consumer demand for quality lean meat and rising production and marketing costs of beef have stimulated interest in the production of beef from bulls. The effects of consumer handling practices on the palatability of meat from bulls require investigation. Therefore it is important from the standpoint of the consumer, the producer and the processor to study the relative effects of current home freezing, storage and thawing methods on the palatability of meat from bulls. This study was designed to determine the effect of three home freezing methods and the effect of three commonly used thawing techniques, on selected characteristics of beef longissimus dorsi (LD) steaks, which were obtained from bulls, and frozen and stored under typical home conditions for 10 and 187 days. Fresh LD steaks were used as a control.

LITERATURE REVIEW

Factors Related to the Freezing of Muscle Tissue

Before the effects of freezing, storage and thawing are discussed, it may be beneficial to consider the structure of a normal fiber from voluntary muscle and how it is affected by freezing. Observations made by Hiner et al., (1945) concerning the histological characteristics of beef showed that normal fibers tend to be round or oval in cross section but variable in diameter and length. Each fiber is made up of contractile muscle substance enclosed in a tight sheath, the sarcolemma. A number of these fibers held together by interstitial connective tissue (endomysium) make up a bundle, and in turn, a number of bundles make up a muscle.

A muscle consists of approximately 75% water, depending on its fatness (Paul, 1972, p. 353). A large proportion of this water is held within the muscle fiber. Changes in the amount of water present and in the extent to which it is bound by the muscle components are considered to influence the tenderness, texture and juiciness of meat.

When water within the muscle freezes, it tends to crystallize as pure water (Hiner et al., 1945). The number and size of the crystals formed depend on the rate of nucleation and the rate of crystal growth, which are temperature dependent (Meryman, 1956). Crystal nucleation is the aggregation of a group of molecules into a tiny ordered particle (Fennema and Powrie, 1964, p. 244). Crystal nucleation occurs rapidly at low temperature, when critical size, the size at which there is an equal chance for the nucleus to grow or diminish, is small. Thus nucleation occurs between the temperatures of 0° and -39° (Meryman, 1956). In contrast to crystal nucleation rates, the rate of ice crystal growth decreases with decreasing temperature.

Hiner and Hankins (1947) reported that when beef cubes were frozen at -7° (slow freezing) the water was withdrawn from the fibers and frozen between them, creating large ice areas and irregular bunches of muscle fibers. When the freezing temperature was lowered to -18°, the transfer of water into the spaces between the cells decreased, and intrafiber ice crystals formed. As the freezing temperature decreased from -7° to -80°, the size of the ice crystals between the fibers decreased, with some splitting of the fibers. Furthermore, as the freezing rate increased, precipitated proteins and nuclear fragments were more and more in evidence. Similar descriptions of ice crystal formation were given by Ramsbottom and Koonz, 1939; Ramsbottom and Koonz, 1941; Hiner et al., 1945; Ramsbottom et al., 1950; Meryman, 1956.

Crystal size could be controlled if all crystals, once formed, remained unchanged in size during subsequent frozen storage and thawing (Fennema and Powrie, 1964, p. 253). However, ice crystals tend to enlarge (recrystallization) during frozen storage and the early stages of thawing. Recrystallization, defined as the preferential growth of large crystals at the expense of smaller ones (Meryman, 1956), is temperature dependent. Low and uniform temperatures minimize recrystallization during frozen storage. At very low temperatures, recrystallization is relatively slow; at temperatures near the melting point, recrystalization is rapid (Meryman, 1956). Moran and Hale (1932) observed a marked increase in the crystal size of frozen meat stored at -3°. However, no crystal growth was observed in frozen beef steaks stored for one year at -12° or -34° (Ramsbottom and Koonz, 1941). Recrystallization that occurs during thawing can be minimized by rapid thawing (Fennema and Powrie, 1964, p. 257).

Effects of Freezing, Storage and Thawing on Selected Characteristics of Meat

Color and Appearance

Ramsbottom and Koonz (1941) stated that the large ice crystals formed when meat is frozen slowly cause the meat to appear dark, whereas small crystals formed in more rapidly frozen meat result in more light scattering and a lighter appearance. However, if the optical effect produced by the ice crystals were the only factor affecting color, defrosted meat would have a surface color similar to fresh unfrozen meat. Rikert et al., (1956) reported that previously frozen and thawed meat was initially lower in redness value (darker) than fresh meat. The additional color changes are the result of pigment oxidation (Ramsbottom and Koonz, 1941). In the frozen condition, ice crystals and surface oxidation of myoglobin contribute to the dark color, whereas only the effects of surface oxidation are responsible for the permanent discoloration observed in thawed cuts.

Guenther and Henrickson (1962) noted little difference in the color of thawed steaks with respect to freezing temperatures ranging from -4° to -85°. Jakobsson and Bengtsson (1973) observed that after thawing, slowly frozen meat (-[illegible]°) appeared darker than more rapidly frozen meat (-35°).

Du[illegible]er storage, myoglobin and oxymyoglobin are oxidized t[illegible]globin, producing a darkened brownish color. Ram[illegible] (1947) studied the relationship between lean color [illegible] temperature. Beef samples were stored at six temperatures ranging from -3° to -29°. Meat stored at -3° was discolored in less than 30 days, whereas comparable samples stored at -29° were still good in color and appearance after one year of storage. Ramsbottom and Koonz (1941) froze and stored steaks at -12° and -34° for one year. Steaks frozen and stored at -12° appeared darker than comparable steaks frozen and stored at -34°. This darker color was attributed to the combined effects of large ice crystals formed during freezing and accelerated oxidation of myoglobin to metmyoglobin at the higher storage temperature. Cuts frozen and stored at -34° were relatively light in both the frozen and thawed states.

Freezer burn may develop on the surface of frozen stored meat. At temperatures of -12°, -18°, -23° and -29°, the amount of freezer burn was in direct relationship to temperature, being very slight on meat samples stored at -29° for one year, and extensive on samples stored for one year at -12° (Ramsbottom, 1947). Jakobsson and Bengtsson (1973) found no evidence of freezer burn on beef slices frozen at three different rates (liquid nitrogen, air blast and still air) and stored for up to nine months. Bannister (1971) occassionally observed spots of dehydration or frosting or both, on liquid nitrogen frozen and home frozen pork loin chops stored for up to four weeks, but neither dehydration nor frosting were extensive.

Drip in Thaw

Several investigators have reported that drip in thaw is related to freezing temperature; slow freezing resulting in greater loss and rapid freezing in less loss (Ramsbottom and Koonz, 1941; Hiner et al., 1945; Hiner and Hankins, 1947; Jakobsson and Bengtsson, 1969). The higher drip loss associated with the slow freezing temperatures is believed due to moisture freezing largely outside the muscle fibers. On thawing, the moisture is not reabsorbed by the dehydrated fibers, and consequently drips from the meat (Hiner et al., 1945). In contrast, Pearson and Miller (1950) observed that there were no significant differences for drip in thaw between beef steaks frozen at each of three freezing rates (slow, intermediate and rapid). Jakobsson and Bengtsson (1973) reported similar findings for beef slices frozen with liquid nitrogen, by air blast and in still air. Ramsbottom and Koonz (1939) stated that the freezing rate-drip relationship existed only where the exposed cut surface area was large in relation to the volume of meat.

Percent drip in thaw increases as the length of freezer storage is increased (Ramsbottom and Koonz, 1941; Pearson and Miller, 1950; Awad et al., 1968), due to the tendency of ice crystals to enlarge during storage. Moran and Hale (1932) stated that frozen storage temperature was very important in regulating the amount of drip from defrosted beef and that increased drip occurred at higher temperatures. However, Ramsbottom and Koonz (1941) reported temperature of freezer storage had little or no effect on regulating drip.

Thaw temperature and time appear to influence the volume of drip in thaw from defrosted meat. Average defrosting losses (drip in thaw) were greater for steaks thawed in the refrigerator (6° for 48 hours) than for steaks thawed at room temperature (23° for 8 hours) (Brown, 1961). Westerman et al., (1949) reported greater percent drip in thaw for steaks defrosted at room temperature in comparison with refrigerator thawed steaks, however, the time-temperature relationships were not mentioned.

Empey (1933) reported that drip in thaw was primarily a function of hydrogen ion concentration and that freezing and thawing had no influence on drip. Little or no drip is evident when the pH of beef muscle is between 6.2 and 6.4 (Empey, 1933; Sair and Cook, 1938) however, as pH decreases, the volume of drip in thaw gradually increases to a maximum at pH 5.

Cooking Time and Losses

Freezing and frozen storage temperatures do not appear to influence cooking time. There were no significant differences in the cooking times for pork loin chops frozen and stored in three types of home freezers (-9°, -20° and -22°) for one and four weeks (Bannister, 1971).

Meat cooked from the frozen state requires approximately two to three times longer to cook than fresh or thawed meat (Vail et al., 1943; Lind, 1969; Bannister, 1971). Brown (1961) reported the average total cooking times for steaks defrosted at room or refrigerator temperatures were similar, although the initial internal temperature of the steaks thawed at room temperature was higher than the initial internal temperature of comparable steaks thawed in the refrigerator.

Cooking losses (total, volatile and drip) for frozen meat are higher than losses for fresh meat (Pearson and Miller, 1950; Smith et al., 1969; Bannister, 1971; Berry et al., 1971). In contrast, Smith et al., (1968) reported that freezing did not affect the cooking losses of frozen lamb chops.

Lind (1969) noted that total cooking and drip losses tended to be greater for lamb rib chops frozen with liquid nitrogen (-106.5°) than for chops frozen in moving air (-29°) or in still air (-18°), but the differences were not always significant. Cooking losses were similar for chops frozen at either -29° or -18°. Bannister (1971) reported that total cooking and drip losses were higher for pork chops frozen by liquid nitrogen than for chops frozen by home methods. There were no significant differences in cooking losses between chops frozen in each of three household freezers.

Pearson and Miller (1950) found that freezing rate (slow, intermediate and rapid) did not influence the cooking losses of beef steaks. However, as the length of freezer storage (-18°) was increased from 0 to 90 days, there was a significant increase in cooking losses. Law et al., (1967) reported that cooking losses (total, volatile and drip) for beef loin and top-round steaks did not increase between one week and six months frozen storage at -18° to -23°. Total cooking and volatile losses for the loin steaks increased ($P<0.01$) after a storage period of nine months. However, there were no significant differences in drip losses for loin steaks or in total cooking, volatile and drip losses for the top-round steaks, attributable to nine months frozen storage.

Bannister (1971) stated that total and volatile cooking losses for pork chops increased between one and four weeks of frozen storage, whereas drip losses decreased. Differences between storage periods were significant only for volatile losses.

The effects of thawing method on cooking losses vary among studies. Vail et al., (1943) thawed two-inch loin steaks by three methods: room temperature (15 hours) refrigerator temperature (3° for 23 hours) or during cooking (200° oven). The results indicated that differences in the cooking losses attributable to thawing method were not statistically significant. When losses owing to evaporation and drip in thaw were added to the cooking losses of thawed steaks (room temperature or refrigerator temperature), the percent total losses of thawed steaks were similar to the percent total losses of steaks cooked directly from the frozen state.

Lowe et al., (1952) defrosted loin steaks at room temperature (25°), at refrigerator temperature (4°), during cooking (175° oven) and in running water (49°). Total cooking losses for steaks thawed prior to cooking were lower than the total cooking losses from steaks cooked directly from the frozen state. However, total losses (drip in thaw and total cooking losses) for cuts thawed prior to cooking were greater than the total cooking losses of oven thawed steaks.

Smith et al., (1969) thawed rib steaks in the refrigerator (2°) or during cooking (176° oven). Thawing steaks prior to cooking had no significant effect on either cooking losses or total losses. Berry et al., (1971) reported that frozen chops cooked from the frozen state had greater cooking losses than frozen chops thawed at room temperature. When the drip in thaw and cooking losses of the chops thawed before cooking were combined and compared with the cooking losses of chops cooked from the frozen state, the differences were not significant. The cooking losses for beef steaks thawed at room temperature (23° for 8 hours) or refrigerator temperature (3° for 48 hours) were similar (Brown, 1961).

Brady et al., (1942) thawed quick frozen and slow frozen round steaks at room temperature and during cooking. Greater total, volatile and drip losses were found when slow frozen steaks were room temperature thawed prior to broiling, than when quick frozen steaks were broiled directly from the frozen state. Jakobsson and Bengtsson (1973) found a significant interaction for yield (cooking losses) between cooking method and freezing rate. The interaction for yield was mainly caused by higher losses for liquid nitrogen frozen beef slices when cooked after previous thawing at room temperature.

<u>Tenderness</u>

Opinions vary in the literature as to what effect freezing and frozen storage have on the palatability of beef, particularily on tenderness. Hankins and Hiner (1940) reported that fresh beef loin steaks had higher shear values (less tender) than frozen steaks. Dawson et al., (1959) found little difference in tenderness between frozen beef and unfrozen beef.

Hiner and Hankins (1947) reported that as temperatures of freezing were lowered from -7° to -80°, resistance to shearing decreased (tenderness increased). They attributed this change to the increased fiber splitting and breaking or stretching of the interstitial connective tissue surrounding the muscle fibers and bundles by the ice crystals. Guenther and Henrickson (1962) reported steaks frozen at -23° or below were slightly more tender than unfrozen controls, both immediately after freezing and after 12 weeks of frozen storage.

Smith et al., (1969) compared fresh and frozen stored boneless beef rib steaks in a two part study. Treatments for the first part were: fresh, unwrapped at 2°; wrapped, frozen and stored at -23°; unwrapped, frozen and stored at -23°; and wrapped, frozen and stored at -34°. Storage periods consisted of 12 to 18 hours for fresh steaks and four to six weeks for frozen steaks. For the second part of the study, treatment groups were as follows: fresh, unwrapped at 2°; and wrapped, frozen and stored at -34°. Storage periods consisted of 12 to 18 hours for fresh steaks and three to 16 weeks for frozen steaks. There were no significant differences in shear value attributable to freezing, for steaks frozen at -23° and -34°. However, freezing decreased the shearing resistance of steaks frozen and stored at -34°. The authors (Smith et al., 1969) attributed the contrasting effects on tenderness, resulting from freezing, to differences in the length of frozen storage. Findings from the second part of the study, in which steaks were stored four months prior to cooking, in contrast to the shorter (four to six weeks) storage period for all other steak pairs, indicated that the length of frozen storage may have a significant effect on the tenderness of beef steaks.

Field et al., (1966) stated that long periods of frozen storage (12 to 355 days) at -23° resulted in significantly lower shear force values for beef. In contrast, Pearson and Miller, (1950) found steaks sheared at 0 days were significantly more tender than steaks stored for 90 and 180 days. Law et al., (1967) reported that frozen storage of up to nine months at -18° to -23° did not influence the tenderness of boneless loin steaks.

Reports in the literature indicate that no significant differences in meat tenderness result from variations in the thawing of frozen meat. Smith et al., (1969) found no significant difference in tenderness when paired steaks were cooked from either the frozen or thawed states. Vail et al., (1943) compared the tenderness of beef steaks thawed by three methods: room temperature (15 hours), refrigerator temperature (23 hours) and during cooking (200° oven). The data for Warner Bratzler shear indicated that cooking directly from the frozen state was the least desirable method of thawing. Brown (1961) thawed beef steaks at room temperature (8 hours) and in the refrigerator (48 hours). Initial tenderness scores were significantly higher for steaks thawed in the refrigerator than for steaks thawed at room temperature. However, there were no significant differences in tenderness scores, based on the number of chews, attributable to thawing method. Shear force values were higher ($P<0.05$) for the steaks thawed at room temperature.

Flavor

The major problem encountered with frozen meats is the deterioration of flavor caused by the development of oxidative rancidity during prolonged freezer storage. Law et al., (1967) stored boneless loin steaks at -18° to -23° and reported that frozen storage up to nine months did not influence the flavor scores, although thiobarbituric acid values increased significantly between one week and six months and between six and nine months frozen storage. Baldwin et al., (1972) noted that flavor scores for beef patties frozen and stored at high temperatures (-9°) were lower after six weeks of frozen storage, and declined as storage time at this temperature lengthened, than the flavor scores for beef patties frozen and stored at low temperatures (-18°) for similar lengths of time. The mean scores for flavor clearly reflected the detrimental influence of high storage temperature. Bannister (1971) found that flavor scores for pork loin chops decreased between one and four weeks frozen storage at -7° and -12°, but there was little change in the flavor scores of chops stored at -20°.

In general, reports in the literature agree that flavor is not seriously affected by method of thawing. Brown (1961) found no significant difference between the flavor of beef steaks thawed at room temperature and steaks thawed in the refrigerator. Berry et al., (1971) compared fresh pork chops to chops frozen at -18° or -196°. The frozen chops were thawed at room temperature or cooked directly from the frozen state. Unfrozen chops were given significantly higher flavor ratings than were chops from any other treatment, except chops frozen at -18° and cooked frozen. There were no significant differences in the flavor scores of fresh chops and chops frozen at -18° and cooked frozen.

Juiciness

Guenther and Henrickson (1962) reported that juiciness scores for fresh beef steaks were higher than the scores for frozen steaks. Similar results for pork loin chops were reported by Harrison et al., (1973). Anderson (1959) reported that taste panel scores for the juiciness of fresh steaks and steaks frozen at temperatures ranging from -18° to -85° were similar, with no significant difference due to freezing. Press fluid determinations (an objective measurement of juiciness) failed to support the taste panel data. A larger moisture area (press fluid) was obtained from frozen steaks in contrast to the fresh. The larger moisture area was attributed to protein denaturation during freezing, with subsequent release of water from the bound form to free form.

Law et al., (1967) stored boneless loin steaks for one week, six and nine months at -18° to -23°. Differences in juiciness scores and percent moisture occurred predominantly between the six and nine month periods. Juiciness scores and percent moisture decreased during this time. Henrickson et al., (1962) observed a decrease in juiciness scores for beef steaks as freezer storage was extended from 0 to 12 weeks.

Vail et al., (1943) evaluated the effects of three thawing methods (room, refrigerator and oven temperature) on the juiciness of beef steaks. The least press fluid was obtained from steaks thawed at room temperature and the most from steaks thawed in the refrigerator. In contrast, Love et al., (1952) reported that defrosting the meat in the refrigerator or at room temperature did not affect any of the palatability factors (including juiciness) of beef steaks. Jakobsson and Bengtsson (1973) observed that juiciness scores were higher for beef slices cooked directly from the frozen state than for the slices thawed at room temperature.

Eating Quality of Meat from Bulls

Reports in the literature concerning the eating quality of meat from bulls compared to meat from steers are varied. No significant differences were found in the taste panel scores for tenderness and flavor between loin steaks from bulls and steers (Champagne et al., 1969). Juiciness ratings indicated that bull meat was scored slightly higher than meat from steers. Warner Bratzler shear values for steaks from bulls and steers were similar.

Field et al., (1966) compared the palatability of roasts from bulls, steers and heifers at four age groups. There were no significant differences in the tenderness, juiciness and flavor of roasts from animals 300 to 399 days old (10 to 13.5 months) attributable to sex. Shear force values and taste panel scores reported by Brown et al., (1962) for steaks from bulls and steers of similar age support these data.

Field et al., (1966) also observed that cuts from bull carcasses were slightly less palatable than cuts from steers at 400 to 499 days of age (13.5 to 16.5 months), although the differences were not significant. Roasts from bulls 500 to 599 and 600 to 699 days old (16.5 to 20 months and 20 to 23.5 months) were less tender than comparable roasts from steers. Flavor and juiciness scores of steer roasts were significantly higher than the scores for roasts from bulls in the older age groups. Similar results for the palatability of beef steaks were reported by Hedrick et al., (1969). In addition, these authors suggested that chronological age may have a greater adverse effect on the tenderness of longissimus dorsi steaks from bulls than from steers.

Field et al., (1964) compared consumer acceptance of retail cuts from bulls and steers averaging 16 months of age. Consumers rated steaks from bulls significantly lower in flavor and tenderness than steaks from steers. Chuck roasts from bulls were described as more desirable because of less intermuscular fat, than roasts from steers.

McLandress (1972) evaluated the palatability of the longissimus dorsi and biceps femoris muscles from bulls and steers of different crossbreeds (Limousin x Angus, Limousin x Hereford, Limousin x Shorthorn, Simmental x Angus, Simmental x Hereford and Simmental x Shorthorn). Panelists rated steer meat higher in juiciness and meatiness and lower in chewiness than meat from bulls. McAndrews (1976) investigated the effects of sex, breed and age (12, 13.5 and 15 months) of animal on meat quality. Steaks from the longissimus dorsi of crossbred bulls (Charolais X Hereford, Charolais X Angus, Charolais X Shorthorn, Simmental X Hereford, Simmental X Angus and Simmental X Shorthorn) were significantly less tender, as measured by shear force and taste panel scores, than longissimus dorsi steaks from comparable crossbred steers.

EXPERIMENTAL PROCEDURE

Experimental Design and Statistical Analysis

Pairs of frozen longissimus dorsi (LD) steaks were evaluated according to an incomplete block design in which carcasses (animals) were blocks. The experimental design was taken from Cochran and Cox, 1968, p. 474. This design provided for three types of home freezers (a one-door refrigerator-freezer, a two-door 'frostfree' refrigerator-freezer and an upright household freezer) and three methods of thawing (refrigerator, room, and oven temperature). The incomplete block design was repeated for the two storage periods (10 and 187 days). Steaks from the left side of the animals were assigned to the short storage period while steaks from the right side were assigned to the long storage period. One pair of steaks from each animal was held unfrozen and cooked fresh to provide a basis for studying the effects of the freeze-thaw combinations (Table 1). The experimental design required the panelists to evaluate only six treatments per session, instead of the nine treatments of a complete block design. The design also allowed for the removal of animal variations as block effects. Where necessary, weight was used as a covariate (freezing rate).

The data for all measurements were subjected to analysis of variance procedures. Data from fresh steaks

Table 1. Freezing-thawing-storage treatment combinations for beef LD steaks stored for 10 (left side) or for 187 (right side) days.

Treatment combination number	Treatment combinations: Freezing conditions[1]	Thawing conditions[2]
1	F(2)	RF
2	F(3)	RF
3	F(2)	OT
4	F(1)	RT
5	F(2)	RT
6	F(3)	RT
7	F(1)	OT
8	F(1)	RF
9	F(3)	OT
10	Unfrozen	Unfrozen

[1]F(1), one-door refrigerator-freezer
F(2), two-door 'frostfree' refrigerator-freezer
F(3), upright household freezer.

[2]RF, refrigerator thaw
RT, room temperature thaw
OT, oven thaw.

were analyzed separately and compared with data for frozen steaks using the Student's 't' test (Steel and Torrie, 1960). Multiple comparisons of means were made using Duncan's Multiple Range Test (Steel and Torrie, 1960).

Treatment of Animals and Meat

Twelve young crossbred bulls (average age 17 months) of mixed breeds (4 Dairy synthetic, 5 Dairy crossbred and 3 Beef synthetic) were selected from the University of Alberta Research Ranch at Kinsella. Details of breeding, management and feeding of the animals were described by Berg (1975). Three bulls were slaughtered every two weeks. The marketing of the animals was done over a liveweight range of approximately 604 to 694 kg with an average weight of 654 kg. The warm carcass weight ranged from 354 to 425 kg.

Half carcasses were returned to the Edmonton Research Station Meat Laboratory and aged seven days at 2°. The longissimus dorsi (LD) muscle from each left and right hindquarter was excised and trimmed of fat. The excised muscles were stored overnight (2°), quick chilled (-3° for 90 minutes) to facilitate neat accurate slices of uniform thickness, and cut serially into ten pairs of steaks, 3.2 cm thick. A pair consisted of one steak from the left LD muscle and one from the same region of the right LD muscle of the same carcass. The steaks were refrigerated (2°) a minimum of two hours. This holding period ensured a uniform internal temperature in the meat when the steaks were placed in the freezers.

Pairs of steaks, numbered 1 to 10 from anterior to posterior, were designated for testing as follows. The first six steak pairs were systematically assigned to the treatment combinations under study (Table 2). The 7th pair of steaks was held unfrozen and cooked fresh to provide a basis for studying the effects of the freeze-thaw treatment combinations. The remaining steak pairs (8 - 10) were used for color determinations and chemical analysis of either the frozen and stored samples (8 and 9), or the fresh samples (10). In addition, the 8th and 9th steaks from each left LD muscle were used to monitor the freezing rate.

Prior to freezing, each of the steaks was placed in a polyethylene bag sealed with a twister and drugstore wrapped in waxed freezer paper. This packaging technique was modified slightly for steaks used to monitor the freezing rate. The freezer paper and polyethylene bag were punctured with a thin skewer. A copper constantan thermocouple was inserted through the small holes in the packaging material, lengthwise into the center of the steak. The steak was then wrapped, with the wire end of the thermocouple protruding from the package.

Table 2. Experimental design for treatment and evaluation of beef LD steaks.

Treatment combination number	Frozen Storage											
	Animal I		Animal II		Animal III		Animal IV		Animal V		Animal VI	
	10 days	187 days	10 days	187 days	10 days	187 days	10 days	187 days	10 days	187 days	10 days	187 days
1	L1	R1			L1	R1	L1	R1	L1	R1		
2	L2	R2	L1	R1			L2	R2			L1	R1
3			L2	R2	L2	R2			L2	R2	L2	R2
4	L3	R3			L3	R3			L3	R3	L3	R3
5	L4	R4	L3	R3			L3	R3	L4	R4		
6			L4	R4	L4	R4	L4	R4			L4	R4
7	L5	R5			L5	R5	L5	R5			L5	R5
8	L6	R6	L5	R5					L5	R5	L6	R6
9			L6	R6	L6	R6	L6	R6	L6	R6		
10 Unfrozen	L7	R7	L7	R7	L7	R7	L7	R7	L7	R7	L7	R7

Steak codes: L, left side
R, right side
1-7, steaks numbered anterior to posterior of the LD muscle.

Table 2. concluded.

Treatment combination number	Frozen Storage											
	Animal VII		Animal VIII		Animal IX		Animal X		Animal XI		Animal XII	
	10 days	187 days	10 days	187 days	10 days	187 days	10 days	187 days	10 days	187 days	10 days	187 days
1	L1	R1	L1	R1					L1	R1	L1	R1
2			L2	R2	L1	R1			L2	R2	L2	R2
3	L2	R2			L2	R2			L3	R3	L3	R3
4			L3	R3	L3	R3	L1	R1	L4	R4		
5	L3	R3			L4	R4	L2	R2	L5	R5		
6	L4	R4	L4	R4			L3	R3	L6	R6		
7	L5	R5			L5	R5	L4	R4			L4	R4
8	L6	R6	L5	R5			L5	R5			L5	R5
9			L6	R6	L6	R6	L6	R6			L6	R6
10 Unfrozen	L7	R7	L7	R7	L7	R7	L7	R7	L7	R7	L7	R7

Steak codes: L, left side
R, right side
1-7, steaks numbered anterior to posterior of the LD muscle.

Freezing and Thawing

The three types of household freezers utilized for this study were: F(1), the freezing compartment of a one-door refrigerator-freezer combination with a temperature range of -9° to -5° and an average temperature of -7°; F(2), the freezing section of a two-door 'frostfree' refrigerator-freezer combination with a temperature range of -15° to -9° and an average temperature of -12°; and F(3), the lower freezing shelf of an upright household freezer with a temperature range of -20° to -13° and an average temperature of -17°. The temperature fluctuation ranges and average temperatures of each freezer were determined in preliminary work. For each freezer, the Manufacturer's (Westinghouse of Canada Ltd.) recommended 'coldness' setting was used. The 'frostfree' refrigerator-freezer differed from the other home freezers (F(1) and F(3)) in that the internal temperature of the freezing section of F(2) rose above 0° during the defrost cycle.

The steaks which were to be refrigerator thawed, monitored or used for chemical determinations after storage, were frozen the day the meat was obtained. The remaining steaks were packaged and frozen the following day.

The three thawing methods used in this study were: RF, refrigerator thaw, 2° for 24 hours; RT, room temperature thaw, 22° for 5 hours; and OT, oven thaw (cooked from the frozen state), oven temperature 176°. The internal temperature of the thawed steaks ranged from 0° to 15.5°, with an average temperature of 4°. RF and RT steaks were thawed in their packaging.

Cooking Procedure

Each steak was placed on a flat wire rack set across a shallow roasting pan. The internal temperature of each steak was monitored by two copper constantan thermocouples and a Honeywell recording potentiometer. Precautions were taken to locate the thermocouples in the exact center of each steak so that the true internal temperature would be recorded. An electric drill was used to bore two 1.6 mm holes into the center of each frozen (OT) steak so that the thermocouples could be inserted. The LD steaks were individually broiled in the same household oven (Frigidaire, model RDG 309C) at a temperature of 176°. Fresh (unfrozen) and thawed steaks were turned at 37 ± 1°; oven thawed steaks were turned at 16 ± 1°. All steaks were cooked to an internal temperature of 61°. After cooling to 50°, the cooked steaks were wrapped in plastic wrap (Saran) and refrigerated (2°) overnight before being sampled.

Three pairs of fresh steaks were cooked on each of the four days meat was obtained. Three steaks from alternate left and right LD muscles were also cooked for thiobarbituric acid (TBA) analysis of the fresh meat. Following either 10 or 187 days frozen storage, the 8th steaks were defrosted and cooked for TBA analysis. The steaks assigned to the various freeze-thaw treatment combinations were cooked according to the experimental design (Table 2).

Laboratory Testing

Sensory Evaluation of Raw Steaks

The steaks stored for 10 or 187 days were subjectively evaluated for freezer burn (dehydration) by the researcher. A seven point scale, with 7 representing no visible freezer burn and 1 representing extreme freezer burn was used (Appendix, Figure 1, page 113).

Sensory Evaluation of Cooked Steaks

A six-member taste panel consisting of staff from the Faculty of Home Economics, University of Alberta, participated in the study. Panelists were selected on the basis of their ability, interest in the project and availability to participate for the six month period.

1. Training Sessions

Training sessions were divided into three relatively separate stages and consisted of three one-hour sessions per week for a six-week period. The initial stage was designed to acquaint the panelists with the terms used in general texture description. Panelists ranked, in order of decreasing intensity, the standard foods used as anchors for softness, juiciness and meatiness (McLandress, 1972; Forbes, 1973). For example, foods representing the different intensities of softness included cream cheese, Cheddar cheese, Swiss cheese, water chestnuts and baking peanuts.

During the second stage of training, meat samples were presented along with the food standards for the anchor scale. Throughout the second stage, panel members rated the meat samples in relation to the food standard on the scale. For example, for juiciness, a panelist might rate the sample equal to the mushroom or mushroom plus. As training progressed, the descriptive terms used, the size of the food standards, and the methods used to judge the meat samples (Figure 1) were clarified by trial and subsequent discussion, and finalized. The anchor scales were altered and refined so that food standards, representing a narrower range for the intensities of softness, juiciness and meatiness, were used. The food standards were assigned values along seven point scales, with a value of 7 representing the highest intensity and a value of 1 representing the lowest intensity. The anchor scales formulated by the panel for use in sensory evaluation are

SOFTNESS: is the lack of force required to compress a 1.3 cm cube of meat across the grain, between the molar teeth.

JUICINESS: is the amount of moisture in the mouth after six chews between the molar teeth, on a 1.3 cm cube of meat.

MEATINESS: is the intensity of the meaty flavor remaining in the mouth after complete mastication of a 1.3 cm cube of meat.

Figure 1. Definitions of the sensory characteristics used in the evaluation of beef LD steaks

shown in Table 3.

The final stage of training was designed to reduce inter-panelist variability in judgment, that is to calibrate the judges, one to the other. This involved presenting each panel member with samples of the same LD steak and requiring them to rate the samples numerically in relation to the food standards on the anchor scales. Each panelist evaluated the coded meat samples individually for the three parameters, then the group discussed the ratings, under the guidance of the panel leader. If there was disagreement, the panelists retasted the food standards, beginning with the lowest intensity, and then the meat samples, until unanimously acceptable levels of softness, juiciness and meatiness were agreed upon. This procedure enabled judges to define accurately a certain level for each parameter. Training was considered to be adequate when the panel members were able to judge a set of four samples, within a range of two points on the seven point scale, with no retasting being necessary.

Throughout the training period, the judges were also asked to evaluate the meat samples for initial flavor, tenderness, amount and type of residual connective tissue, and overall acceptability. Initial flavor was evaluated on a one to seven point descriptive scale, with 7 indicating the highest quality. Each panelist standardized her tenderness scores by the number of chews required to

Table 3. Anchor scales used by panelists for sensory evaluation of beef LD steaks.

Texture Characteristic	Intensity	Anchor	Brand	Particulars	Preparation
Softness	6	Cheddar cheese	Kraft	medium	1.3 cm cubes
	4	Swiss cheese	Kraft	---	1.3 cm cubes
Juiciness	6	Canned mushroom	Moneys	whole button	1/4 of a mushroom cap
	4	Raisin	Woodwards	light seedless	one raisin
Meatiness	6	Monosodium glutamate	Accent	---	45 milligrams %
	4	Monosodium glutamate	Accent	---	35 milligrams %

masticate the cube completely. Residual connective tissue was scored on a one to seven point scale, with 7 indicating no connective tissue. Overall acceptability was evaluated on a desirability scale of 7 (extremely desirable) to 1 (extremely undesirable).

Additional panel sessions were scheduled for the alternate weeks when no data for the study was collected and prior to the second series of panel sessions (after 187 days frozen storage) to maintain the panelists' acuity. Fresh meat samples from the LD, obtained from a local supermarket, were evaluated at these sessions.

2. Evaluation by the Trained Sensory Panel

The six panelists evaluated six sets of coded meat samples at each session following the technique developed during the training period. Sampling procedures were standardized (Figure 2) for the LD steaks. The cooked steaks were trimmed at one end, and cut into nine slices, 1.3 cm thick, with an electric meat slicer. Two 1.3 cm cubes were removed from each slice and allowed to come to room temperature (22°). Each panelist received a tray (Figure 3) consisting of the coded meat samples, the food standards for softness, juiciness and meatiness, the appropriate set of evaluation forms (Appendix, Figure 2, page 114), and other necessary items. The trays were arranged immediately before panel sessions to ensure

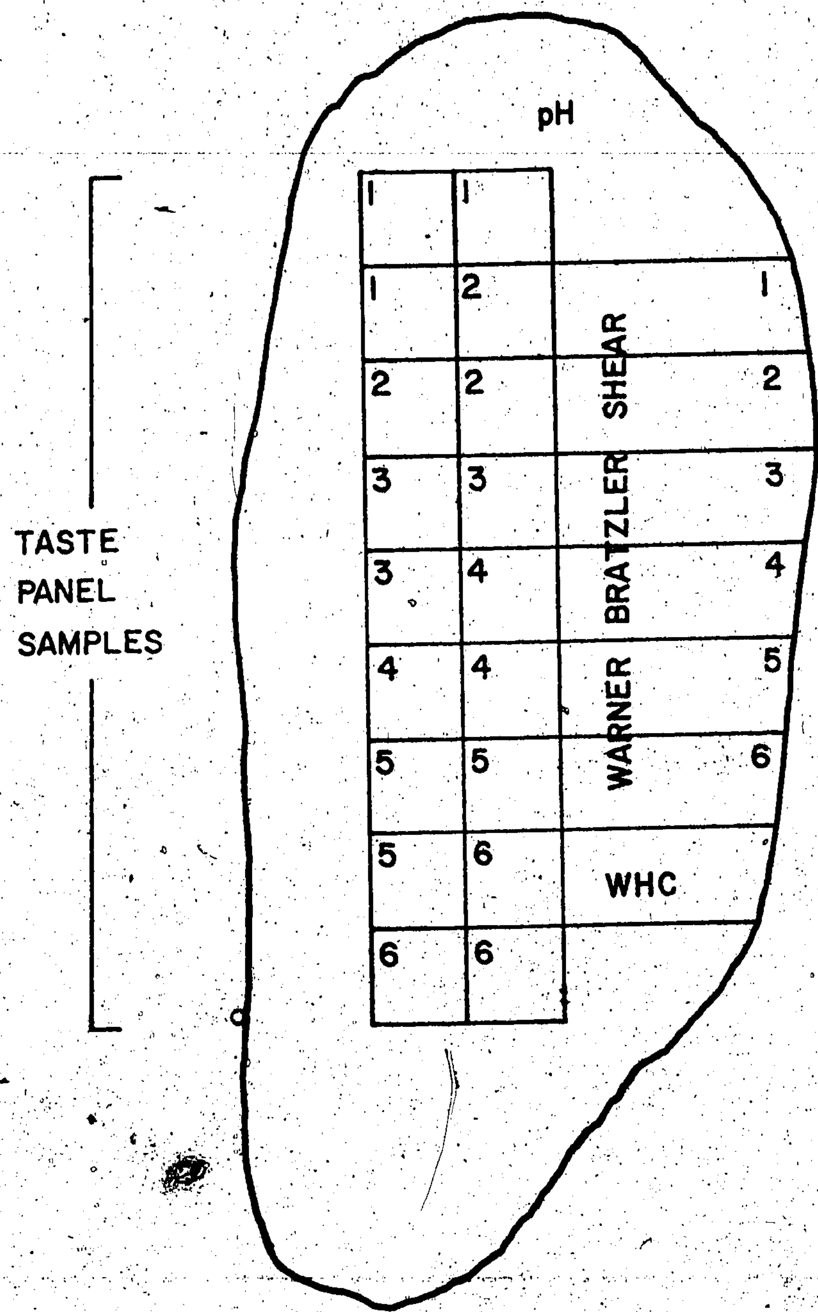
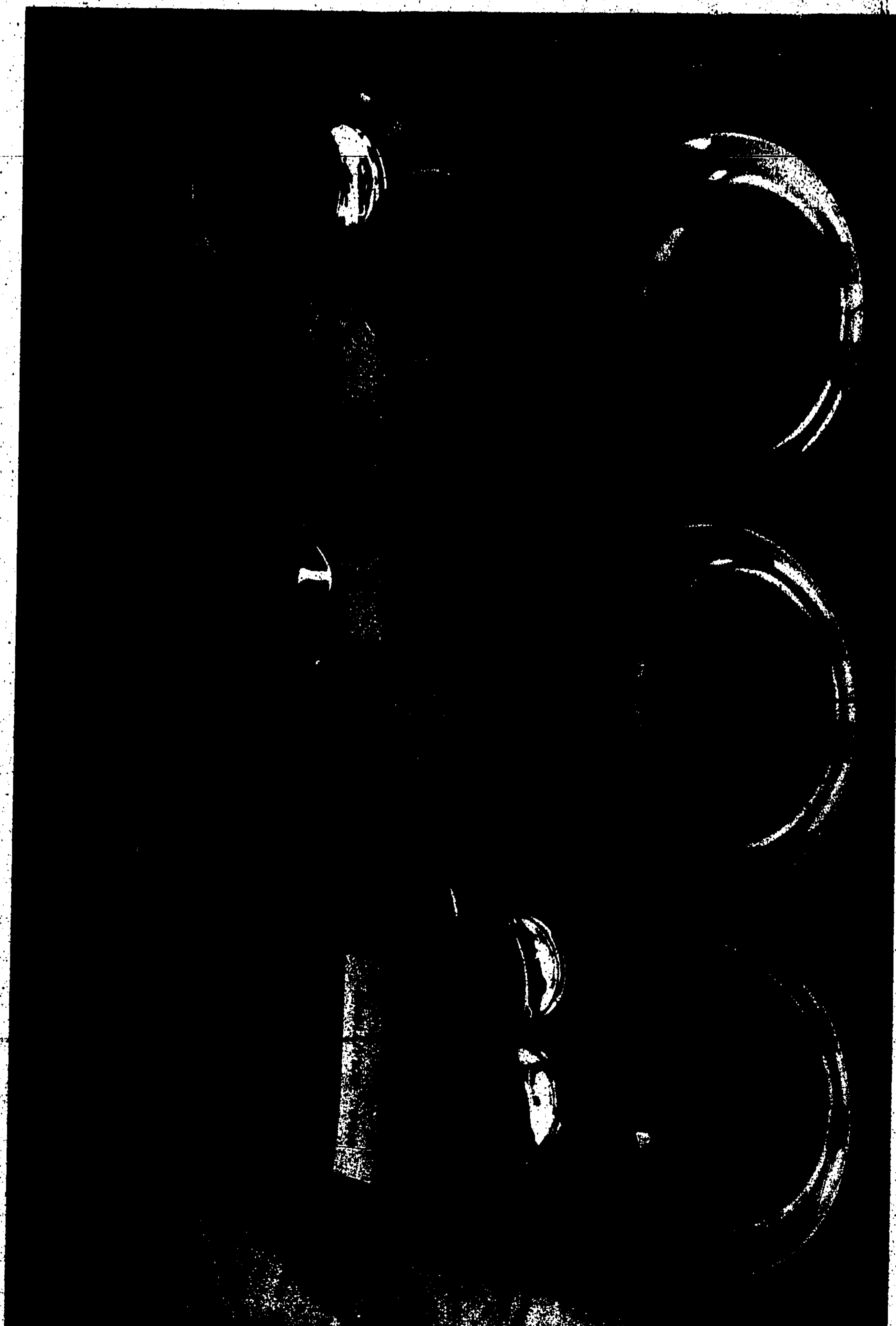


Figure 2. Location of samples for subjective and objective evaluation of cooked LD steaks.

Figure 3. Arrangement of a taste panel tray for the sensory evaluation of cooked beef LD steaks.



freshness of the standards and samples. All samples and standards were served at room temperature (22°).

Panel sessions were held at 10:15 a.m. and/or 2:30 p.m. each testing day in an air-conditioned sensory panel room. Each panelist was seated at a well-lighted booth and was instructed to rate the six sets of samples individually. A set of samples consisted of three 1.3 cm cubes; the first cube was evaluated for softness, juiciness and initial flavor; the second cube was rated for tenderness (chew count), amount and type of residual connective tissue, meatiness and overall acceptability; and the third cube was saved for retasting, if necessary. Samples from the same relative sections of the steak were presented randomly to each of the judges. The judges were permitted to swallow or expectorate the meat samples, and were given as much water (22°) to drink between samples as they wished.

When the judges had scored all the samples, the booth sections were removed and the group discussed the parameters of softness, juiciness and meatiness, under the direction of the panel leader; retasting followed, if necessary. This final step provided for continuous training and maintenance of panelists motivation throughout the tasting period. Individual judges' scores for each parameter were tabulated for statistical analysis.

Objective Tests on Raw Steaks

The fresh (unfrozen) steak samples for objective analysis were removed alternately from the left and right LD muscles. All frozen steaks stored 10 or 187 days and used for objective tests, were thawed using the RT technique (22° for 5 hours). Sampling procedures for the objective tests were standardized.

1. Color

Color was determined on duplicate samples from each of twelve raw (unfrozen) LD steaks at four wavelengths (485, 545, 625 and 655 nm) with a Bausch and Lomb Spectronic 20 Colorimeter with reflectance attachment standardized against $MgCO_3$. Similar duplicate determinations were made on four samples taken from each type of freezer for the two storage periods.

2. Moisture and Fat

The percentage of moisture and fat (ether extract) in twelve fresh (unfrozen) LD steaks and steaks representing each of the freezing treatments were determined by methods of the Association of Official Agricultural Chemists (AOAC, 1965). A portion of each raw steak was trimmed of connective tissue, ground and mixed. Moisture was determined by freeze-drying each of the ground samples and then drying them for an additional 18 hours at 105°.

Percent ether extract was obtained with a Goldfisch extraction apparatus.

3. pH

A Fisher Accumet Model 230 pH/ion meter was used to determine the pH of the fresh (unfrozen) steaks. Twenty gram samples were blended with 100 ml distilled water for two minutes and filtered into two beakers to give duplicate readings.

4. Freezing Rate

Steaks 8 and 9 from the left LD muscles were weighed, randomly assigned to one of each of the three types of household freezers and frozen. During freezing, the internal temperature of the steaks was monitored by a copper constantan thermocouple and a Honeywell recording potentiometer. Freezing rates were calculated for three portions of each freezing curve as outlined by Costello and Henrickson (1964) with the following modifications in temperature:

(a) initial temperature to 0° (cooling),

(b) 0° to -1.5° (freezing), and

(c) below -1.5° (cooling of frozen meat).

The internal temperature of each of the freezer units was also monitored to determine the effects of scheduled, timed refrigerator-freezer 'openings'. In order to simulate home usage of the freezer units, data for the frequency and duration of refrigerator-freezer openings involved during daily meal preparation for a period of one month were obtained from ten homemakers. A schedule for opening each of the freezer units (based on this average freezer usage) was employed throughout the duration of the study (Appendix, Table I, page 103).

5. Percent Drip in Thaw

The weight of drip in thaw was determined and expressed as a percentage, based on the weight of the steak prior to freezing.

Objective Tests on Cooked Steaks

Meat samples for each of the objective measurements related to sensory evaluation were removed after cooking from the same relative position in each of the steaks and cut adjacent to those used for subjective evaluation.

1. Cooking Time

Cooking time for each steak was recorded as the minutes required to reach an internal temperature of 61°.

2. Cooking losses

Percentage total, volatile and drip losses, based on the weight of the fresh, thawed or frozen steak, were calculated.

3. Total Losses

Total losses for frozen-defrosted steaks were calculated by adding drip in thaw plus total cooking loss.

4. Warner Bratzler Shear Values

Six cores, 1.3 cm in diameter, cut parallel to the muscle fibers, were taken from each steak. The cores were sheared on a Warner Bratzler Shear equipped with a 22.7 kg dynamometer. The overall shear value of each steak was the average of the six shear readings.

5. Water Holding Capacity (WHC)

Water holding capacity was measured by the method of Miller and Harrison (1965) as modified by Forbes (1973). Triplicate 0.5 gram samples from each steak were sandwiched between a sheet of Whatman No. 1 qualitative filter paper and a piece of aluminum foil, and alternately stacked between four plexiglass plates. This unit was pressed in a Carver Laboratory Press under a total pressure of 878.8 kg/cm² for 30 seconds.

The area of expressed fluid and pressed meat were obtained using a Hugh-Owens compensating planimeter (Model 349 1830). The ratio of the area of pressed meat to the area of expressed liquid was designated as the expressible liquid index. Unity arbitrarily was assumed as the maximum expressible liquid index for any particular cooked meat sample, and the relative WHC as: 1.00 minus expressible liquid index (Miller and Harrison, 1965).

6. pH

PH was determined using a Fisher Accumet Model 230 pH/ion méter. Duplicate 20 gram samples from each cooked steak were blended with 100 ml distilled water for two minutes and filtered into two beakers to give duplicate readings. The number of steaks tested was decreased to three per LD muscle (steaks 3, 4 and 7) when no treatment differences in pH were observed.

7. Thiobarbituric Acid Values (TBA)

Thiobarbituric acid values (TBA), for the determination of oxidative rancidity, were determined by employing the procedure of Tarladgis et al., (1964). Fresh (unfrozen) steaks were alternately taken from the left and right LD muscles, cooked, trimmed of all outside edges and ground twice. Duplicate 10 gram samples were blended with 50 ml glass distilled water for two minutes. A second set of samples from the same steak, was blended with 1 X 10^{-5} M 1,1,3,3-tetraethoxypropane (TEP) for percent recovery determinations. The resulting slurries were quantitatively transferred, with an additional 50 ml of the appropriate solvent, into funnels lined with Whatman No. 1 filter paper. The samples were filtered by gravity into 100 ml volumetric flasks. Two 5 ml aliquots from each flask were pipetted into test tubes.

Standard curves were prepared by making appropriate dilutions of TEP standard solution to give amounts equivalent to a range of 1×10^{-9} to 1×10^{-8} moles of malonaldehyde in 5 ml. Five milliliters of 0.02 M TBA reagent were added to each of the standards and samples. Following the addition of TBA reagent, the standards and samples were held a minimum of 17 hours at room temperature. Absorbance was read against an appropriate reagent blank at 532 nm using a Pye Unicam SP 1800 Ultraviolet Spectrophotometer. Similar duplicate determinations were made on four samples taken from each type of freezer for the two storage periods.

The TBA number was calculated by multiplying the absorbance by K constants obtained from the standard curves and the known dilution as described by Tarladgis et al., (1960).

RESULTS AND DISCUSSION

Throughout the discussion, F(1) refers to the freezing compartment of a one-door refrigerator-freezer combination; F(2), the freezing section of a two-door 'frostfree' refrigerator-freezer combination; and F(3), the lower freezing shelf of an upright household freezer. Tables containing detailed data for the freeze-thaw treatment combinations are presented in the Appendix, Tables II, III and IV, pages 104, 105 and 106.

Quality of the Fresh LD Steaks

The data for the objective and subjective measurements for fresh steaks (controls) from the left and right side of the twelve animals are presented in Table 4. Analysis of variance showed no significant differences in raw weight, cooking time, or losses (total, volatile and drip) between fresh steaks from the left and right side of the carcass. Taste panel evaluation indicated that fresh steaks from the left and right side were similar for each of the palatability characteristics evaluated. All the fresh steaks were described as moderately desirable to desirable. Objective data for juiciness (water holding capacity) and tenderness (Warner Bratzler shear) substantiate taste panel scores, which indicated that there were no significant

Table 4. Means and SED[1] for the objective and subjective measurements for fresh LD steaks from the left and right side of 12 animals.

Measurements	Left	Right	SED
Raw weight[2] (g)	342.4	329.7	7.38
Cooking time[2] (min)	20.4	19.6	0.27
Cooking losses[2] (%)			
Total	15.13	14.88	2.50
Volatile	13.90	13.49	0.85
Drip	1.23	1.38	0.34
Taste panel data[3]			
Softness	5.2	5.3	0.24
Juiciness	5.4	5.4	0.00
Initial flavor	5.1	5.0	0.13
Tenderness	5.4	5.4	0.00
Connective tissue	5.7	5.8	0.28
Meatiness	5.2	5.3	0.05
Overall acceptability	5.2	5.2	0.00
Water holding capacity[4]	0.71	0.68	0.01
Shear force[5] (kg/1.3 cm core)	3.2	3.2	0.00

[1]Standard error of mean difference.

[2]Values are the averages of 12 determinations.

[3]7 (extremely soft, juicy, tender or desirable), to 1 (extremely hard, dry, tough or undesirable). Values are the averages of 12 judgements by each of six panelists.

[4]1.0 - (expressible liquid index); the larger the value, the greater the amount of liquid expressed. Values are the averages of 36 determinations, three per replicate.

[5]Values are the averages of 72 determinations, six per replicate.

differences in eating quality between fresh steaks from the left and right side of the twelve young bulls. Ferger (1970) reported similar results for beef ribs. Lind (1969) found that there were no significant differences in total cooking and drip losses between lamb chops from the left and right side of the carcass.

Storage

Spectrophotometric (color) evaluations of the thawed lean of frozen stored steaks and the lean of fresh LD steaks are presented in Table 5. The lean of the fresh LD steaks was superior (redder) to the lean color of frozen stored steaks, at two wavelengths (485 and 545 nm). However, no significant differences in color were found between fresh LD steaks and frozen LD steaks stored 10 days (Table 6), indicating that freezing per se had no significant affect on the color of the lean.

Lentz (1971) froze beef steaks and assessed the color of the meat samples before freezing, immediately after freezing and after 1, 3, 7, 14, 30, 60, 90 and 120 days of frozen storage, under light and dark conditions. Color changes caused by freezing were small and tended to make the samples more reddish. Samples stored without light darkened after freezing; however, these color changes were noted only after one to two months freezer storage. Fenton et al.,

Table 5. Means and SED[1] for objective and subjective[2] measurements for fresh vs frozen stored beef LD steaks.

Measurements	Fresh	Frozen Stored	SED
Color[3] (raw samples)			
485 nm	12.9	10.3	0.86**
545 nm	8.7	6.7	0.68**
625 nm	28.5	24.0	2.43
655 nm	32.7	29.6	2.79
Total losses[4] (%)	15.00	18.12	0.79**
Drip in thaw[4] (%)	——	1.29	
Cooking losses[4] (%)			
Total	15.00	16.83	0.80*
Volatile	13.70	15.80	0.69*
Drip	1.30	1.03	0.15
Taste panel data[5]			
Softness	5.2	5.3	0.07
Juiciness	5.4	5.1	0.09**
Initial flavor	5.0	4.9	0.12
Tenderness	5.4	5.7	0.11**
Connective tissue	5.8	6.1	0.09**
Meatiness	5.2	5.3	0.16
Overall acceptability	5.2	5.1	0.83
Ether extract[3] (%)	2.64	3.07	0.39
Total moisture[3] (%)	74.30	73.25	0.51*
Water holding capacity[6]	0.70	0.72	0.01
Shear force[7] (kg/1.3 cm core)	3.2	3.2	0.00
TBA number[3]	0.56	0.82	0.35
pH[3] (cooked samples)	6.1	6.1	0.00

[1]Standard error of mean difference.

[2]Highest possible score, 7 points.

[3]Values for fresh steaks are means of 24 determinations, two per replicate; values for frozen steaks are means of 48 determinations, two per replicate.

[4]Values for fresh steaks are means of 24 determinations; values for frozen steaks are means of 144 determinations

[5]Values for fresh steaks are means of 24 judgments by each of six panelists; values for frozen steaks are means of 144 judgments by each of six panelists.

[6]1.0-(expressible liquid index); the larger the value, the greater the amount of liquid expressed. Values for fresh steaks are means of 72 determinations, three per replicate; values for frozen steaks are means of 432 determinations, three per replicate.

[7]Values for fresh steaks are means of 144 determinations, six per replicate; values for frozen steaks are means of 864 determinations, six per replicate.

* Significant at $P<0.05$. ** Significant at $P<0.01$.

Table 6. Means and SED[1] for objective and subjective[2] measurements for fresh LD steaks and frozen LD steaks stored 10 days.

Measurements	Fresh	Frozen 10 days	SED
Freezer burn[3]	7.0	7.0	0.00
Color[4] (raw samples)			
485 nm	12.9	12.0	0.75
545 nm	8.7	8.3	0.53
625 nm	28.5	26.9	2.81
655 nm	32.7	33.0	4.29
Total losses[3] (%)	15.13	17.47	1.04*
Drip in thaw[3] (%)	---	1.21	
Cooking losses[3] (%)			
Total	15.13	16.26	0.99
Volatile	13.90	15.29	0.90
Drip	1.23	0.97	0.17
Taste panel data[5]			
Softness	5.2	5.5	0.10**
Juiciness	5.4	5.2	0.10*
Initial flavor	5.1	5.2	0.15
Tenderness	5.4	5.9	0.16**
Connective tissue	5.7	6.3	0.19**
Meatiness	5.2	5.4	0.01*
Overall acceptability	5.2	5.5	0.19
Ether extract[4] (%)	2.64	2.79	0.50
Total moisture[4] (%)	74.30	73.62	0.63
Water holding capacity[6]	0.71	0.69	0.01
Shear force[7] (kg/1.3 cm core)	3.2	3.2	0.00
TBA number[4]	0.56	1.05	0.45

[1]Standard error of mean difference.

[2]Highest possible score, 7 points.

[3]Values for fresh steaks are means of 12 determinations; values for frozen steaks are means of 72 determinations.

[4]Values for fresh steaks are means of 24 determinations, two per replicate; values for frozen steaks are means of 24 determinations, two per replicate.

[5]Values for fresh steaks are means of 12 judgments by each of six panelists; values for frozen steaks are means of 72 judgments by each of six panelists.

[6]1.0-(expressible liquid index); the larger the value the greater the amount of liquid expressed. Values for fresh steaks are means of 36 determinations, three per replicate; values for frozen steaks are means of 216 determinations, three per replicate.

[7]Values for fresh steaks are means of 72 determinations, six per replicate; values for frozen steaks are means of 432 determination, six per replicate.

* Significant at $P<0.05$. ** Significant at $P<0.01$.

(1956) reported higher redness values for unfrozen meat than for frozen meat.

Total losses (which include drip in thaw and total cooking losses), total cooking and volatile losses for the frozen stored LD steaks were significantly higher than the losses of comparable fresh LD steaks (Table 5). However, drip losses for both the fresh and frozen stored steaks were similar.

Smith et al., (1969) reported that freezing beef steaks increased the cooking losses in relation to losses sustained by unfrozen cuts. Bannister (1971) observed greater cooking losses (total, volatile and drip) for pork loin chops frozen and stored in home freezers than for fresh chops. In contrast, Anderson (1959) obtained smaller total cooking losses for frozen beef steaks than for fresh pair mates, although the difference was not significant.

Taste panel evaluation of the LD steaks indicated that both the fresh and frozen stored steaks were similar in softness, initial flavor, meatiness and overall acceptability (Table 5). However, panelists scored the juiciness of fresh samples higher ($P<0.01$) than the juiciness of comparable frozen stored samples. Judges rated the frozen stored LD steaks as more tender and as having less residual connective tissue than comparable fresh steaks. All the meat samples were described as moderately desirable. Harrison et al., (1973) investigated the effects of home freezing methods on selected characteristics of pork loin chops. Taste panel evaluation indicated that fresh chops were juicier than frozen chops, although the difference [illegible] not significant. Tenderness scores for both the fres[illegible]en chops were similar. Flavor and overall accept[illegible]es for the fresh chops were higher than the [illegible] frozen chops.

Percent ether extract was not significantly affected by frozen storage (Table 5). However percent total moisture for fresh steaks was higher ($P<0.05$) than for comparable frozen stored LD steaks. Water holding capacity data, Warner Bratzler shear force values, TBA number and pH were similar for both the fresh and frozen stored steaks.

Law et al., (1967) observed that there were no significant differences in Warner Bratzler shear force values, percent total moisture and percent lipid attributable to frozen storage. Henrickson et al., (1962) and Harrison et al., (1973) reported that Warner Bratzler shear force values were not significantly affected by frozen storage.

A comparison of fresh LD steaks and frozen steaks stored 10 days (Table 6) indicated that there were no significant differences in freezer burn data and color reflectance values attributable to short storage. The average percent total losses for the steaks stored 10 days were higher ($P<0.05$) than the total losses of comparable fresh steaks (due to the addition of drip in thaw for frozen steaks). Percent cooking losses (total, volatile and drip) for both the fresh steaks and the frozen steaks stored 10 days were similar.

Henrickson et al., (1962), investigating the effects of freezer storage on beef steaks, reported similar cooking losses for fresh steaks and steaks frozen and stored one week. Berry et al., (1971) reported that frozen and stored chops had greater cooking losses (total, volatile and drip) than did fresh chops.

Sensory evaluation of the LD steaks (Table 6) indicated that frozen steaks stored 10 days were softer, more tender, had less residual connective tissue, and were rated more meaty but less juicy than comparable fresh steaks. There were no significant differences in initial flavor and overall acceptability between the fresh steaks and the frozen steaks stored 10 days. Percentage ether extract, percent total moisture, water holding capacity, shear force and TBA number were not significantly affected by 10 days of frozen storage.

Henrickson et al., (1962) observed that tenderness as measured by shear force values and taste panel scores, was not significantly affected by short storage. Flavor scores tended to increase with storage time (0 to 12 weeks), although flavor scores for both fresh steaks and steaks frozen and stored one week were similar. Average juiciness scores showed a decrease as freezer storage was extended, however, this difference was not significant. Berry et al., (1971) found that there were no significant differences in juiciness, tenderness, flavor and overall acceptability attributable to short freezer storage. In contrast, pork chops frozen and stored one week were less juicy and had lower flavor and overall acceptability scores than did comparable fresh chops (Bannister, 1971).

Table 7 presents the data for the objective and subjective measurements of fresh steaks and frozen steaks stored 187 days. Fresh steaks were superior in appearance to frozen steaks stored for 187 days, as indicated by freezer burn data and color reflectance values. Similar results for beef steaks frozen and stored 180 days were reported by Ramsbottom (1947).

The average percent total losses, total cooking and volatile losses of frozen steaks stored 187 days were significantly higher than the losses of comparable fresh steaks (Table 7). Drip losses for both fresh steaks and

Table 7. Means and SED[1] for objective and subjective[2] measurements for fresh LD steaks and frozen LD steaks stored 187 days.

Measurements	Fresh	Frozen 187 days	SED
Freezer burn[3]	7.0	4.3	0.36**
Color[4] (raw samples)			
485 nm	12.9	8.7	0.96**
545 nm	8.7	5.2	0.62**
625 nm	28.5	21.0	2.98*
655 nm	32.7	26.2	3.35
Total losses[3] (%)	14.88	18.77	1.13**
Drip in thaw[3] (%)	----	1.37	
Cooking losses[3] (%)			
Total	14.88	17.40	1.22*
Volatile	13.49	16.32	1.03**
Drip	1.39	1.08	0.23
Taste panel data[5]			
Softness	5.3	5.2	0.00
Juiciness	5.4	4.9	0.17**
Initial flavor	5.0	4.5	0.21*
Tenderness	5.4	5.5	0.09
Connective tissue	5.8	6.0	0.15
Meatiness	5.3	5.2	0.08
Overall acceptability	5.2	4.8	0.22
Ether extract[4] (%)	2.64	3.36	0.49
Total moisture[4] (%)	74.30	72.80	0.68*
Water holding capacity[6]	0.68	0.75	0.02**
Shear force[7] (kg/1.3 cm core)	3.2	3.2	0.00
TBA number[4]	0.56	0.59	0.21

[1]Standard error of mean difference.

[2]Highest possible score, 7 points.

[3]Values for fresh steaks are means of 12 determinations; values for frozen steaks are means of 72 determinations.

[4]Values for fresh steaks are means of 24 determinations, two per replicate; values for frozen steaks are means of 24 determinations, two per replicate.

[5]Values for fresh steaks are means of 12 judgments by each of six panelists; values for frozen steaks are means of 72 judgments by each of six panelists.

[6]1.0-(expressible liquid index); the larger the value the greater the amount of liquid expressed. Values for fresh steaks are means of 36 determinations, three per replicate; values for frozen steaks are means of 216 determinations, three per replicate.

[7]Values for fresh steaks are means of 72 determinations, six per replicate; values for frozen steaks are means of 432 determinations, six per replicate.

* Significant at $P<0.05$. ** Significant at $P<0.01$.

frozen steaks stored 187 days were similar.

Henrickson et al., (1962) observed increased cooking losses (P<0.01) for beef steaks frozen and stored for 12 weeks. Pearson and Miller (1950) compared the effects of length of freezer storage (0, 90 and 180 days) on the cooking losses of beef LD steaks. As the length of freezer storage was increased from 0 to 90 days, there was a significant increase in cooking losses and total weight losses. However, no further changes in cooking losses were detected as the storage period was increased from 90 to 180 days.

A second experiment (Pearson and Miller, 1950), comparing the effects of 0, 60, 120 and 180 days frozen storage on beef steaks, indicated that unfrozen control steaks had significantly lower total losses than any of the frozen steaks. Percent drip in thaw, cooking losses and total losses for the frozen steaks were higher than the losses of comparable fresh steaks.

Fresh steaks and frozen steaks stored 187 days were similar in softness, tenderness, residual connective tissue, meatiness and overall acceptability (Table 7). Judges rated the juiciness and initial flavor of the LD steaks which were frozen and stored 187 days significantly lower than that of comparable fresh steaks. Pearson and Miller (1950) observed that steaks tested at 0 days (fresh) were more tender than steaks stored for 90 days. However, no further change in tenderness was detected when the storage period was increased from 90 to 180 days. There were no significant differences in percent ether extract attributable to freezing (Table 7). However, frozen steaks stored for 187 days had a lower ($P<0.05$) percent total moisture than comparable fresh steaks. Water holding capacity data increased ($P<0.01$) with 187 days frozen storage. Shear force values and TBA number for both the fresh steaks and frozen steaks stored 187 days were similar.

Length of frozen storage had a significant affect on the appearance of the LD steaks (Table 8). Frozen steaks stored for 10 days showed no visible sign of freezer burn, whereas LD steaks frozen and stored for 187 days exhibited slight to moderate freezer burn. The color of the thawed lean of frozen LD steaks darkened significantly between 10 and 187 days frozen storage, as indicated by a decrease in color reflectance values at each of the four wavelengths. Freezer burn and color data support similar findings by Ramsbottom (1947) which indicate that prolonged freezer storage seriously affects the appearance and color of fresh frozen meat.

The average percent total losses, drip in thaw, total cooking and volatile losses increased significantly between

Table 8. Means and SE[1] for objective and subjective measurements for beef LD steaks frozen and stored 10 or 187 days.

Measurements	Length of Frozen Storage		
	10 days	187 days	SE
Freezer burn[3]	7.0	4.3	0.21**
Color[4] (thawed raw samples)			
485 nm	12.0	8.7	0.12**
545 nm	8.3	5.2	0.11**
625 nm	26.9	21.0	0.74*
655 nm	33.0	26.2	4.08*
Total losses[3] (%)	17.47	18.77	0.03**
Drip in thaw[3] (%)	1.21	1.37	0.04*
Cooking losses[3] (%)			
Total	16.26	17.40	0.04**
Volatile	15.29	16.32	0.04**
Drip	0.97	1.08	0.05
Taste panel data[5]			
Softness	5.5	5.2	0.00*[illegible]
Juiciness	5.2	4.9	0.00**
Initial flavor	5.2	4.5	0.01**
Tenderness	5.9	5.5	0.01**
Connective tissue	6.3	6.0	0.02**
Meatiness	5.[illegible]	5.2	0.00**
Overall acceptability	5.5	4.8	0.00**
Ether extract[4] (%)	2.79	3.36	0.30
Total moisture[4] (%)	73.62	72.88	0.37
Water holding capacity[6]	0.69	0.75	0.00**
Shear force[7] (kg/1.3 cm [illegible])	3.2	3.2	0.00
TBA number[4]	1.05	0.59	0.15

[1]Standard error.

[2]Highest possible score, 7 points.

[3]Values for frozen steaks are means of 72 determinations.

[4]Values are the means of 24 determinations, two per replicate.

[5]Values are the means of 72 judgments by each of six panelist.

[6]1.0-(expressible liquid index); the larger the value the greater the amount of liquid expressed. Values are means of 216 determinations, three per replicate.

[7]Values are the means of 432 determinations, six per replicate.

* Significant at P<0.05. ** Significant at P<0.01.

10 and 187 days frozen storage (Table 8). Drip losses for frozen steaks stored either 10 or 187 days were similar.

Law et al., (1967) studied the effect of storage intervals on cooking losses of beef loin steaks. Cooking losses (total, volatile and drip) for the steaks did not increase between one week and six months frozen storage. However, total cooking and volatile losses of the frozen loin steaks stored nine months were significantly higher than the losses of comparable loin steaks frozen and stored either one week or six months. Percent drip loss for the loin steaks was not significantly affected by the length of freezer storage.

The taste panel data (Table 8) show that frozen LD steaks stored for 10 days were rated significantly higher for each of the palatability characteristics evaluated than comparable frozen samples stored 187 days. Judges described the samples frozen and stored 10 days as desirable; the samples frozen and stored for 187 days were rated acceptable to moderately desirable. In contrast, Law et al., (1967) reported that differences in tenderness and flavor were not significant for beef steaks frozen and stored one week, six months or nine months. Juiciness scores decreased after nine months frozen storage. Baldwin et al., (1972) reported a significant decline in the flavor of frozen beef patties between six and 12 weeks frozen storage.

No significant differences for percent ether extract and percentage total moisture of the LD steaks frozen and stored 10 or 187 days were found (Table 8). However, steaks frozen and stored 187 days had less total moisture than comparable fresh steaks (Table 7). Law et al., (1967) observed no significant differences in the percent lipid and percent total moisture for beef steaks frozen and stored one week, six or nine months.

Water holding capacity data for frozen LD steaks indicated that frozen steaks stored 187 days had a greater water holding capacity than either comparable frozen steaks stored 10 days or comparable fresh steaks (Tables 7 and 8). Anderson (1959) found a larger moisture area was obtained from frozen steaks in contrast to fresh steaks. He attributed this difference to the denaturation of protein during freezing and subsequent release of bound water.

Tenderness, as measured by shear force, was not significantly affected by the length of freezer storage (Table 8). However, the trained panel indicated frozen steaks stored 10 days were softer, more tender and had less residual connective tissue than frozen pair mates stored 187 days. Law et al., (1967) reported that there were no significant differences in tenderness, as measured by shear force, attributable to prolonged freezer storage.

The TBA number for the frozen steaks stored 10 or 187 days was similar (Table 8), although initial flavor and meatiness scores were significantly lower for steaks frozen and stored 187 days. In contrast, Law et al., (1967) observed that TBA number increased significantly between one week and six months frozen storage. In the present experiment, meat samples for TBA analysis were trimmed of all outer edges to provide a representative sample similar to that received by the panelists. By trimming away the outer edges, differences due to freezer storage may have been minimized. A more sensitive test may have provided a better indication of the oxidative changes occurring within the meat evaluated in this study.

In general, the data (Tables 6, 7 and 8) indicate that only slight differences in the eating quality of beef steaks resulted from short periods of frozen storage. Prolonged storage (187 days) resulted in a marked deterioration of eating quality. In contrast, Law et al., (1967) reported that storage of up to six months at -18° to -23° had little effect on the eating quality of loin steaks, but significant changes occurred between six and nine months.

Freezing and Storage Conditions

Freezing Rate

The average freezing curves for beef LD steaks frozen in three types of household freezers are presented in Figure 4. Costello and Henrickson (1964) indicated freezing curves could be divided into three distinct stages: cooling (initial temperature to -2°); freezing (-2° to -3°); and cooling the frozen meat (below -3°). In the present study, the same three stages were observed:

(a) initial temperature to 0° (cooling),

(b) 0° to -1.5° (freezing), and

(c) below -1.5° (cooling of frozen meat).

No reasons for the temperature differences found in the three stages of the freezing curves of this study compared with those of Costello and Henrickson (1964) are readily apparent. The time required for the steaks to reach each of the three stages in the freezing curves was calculated. Analysis of covariance (Appendix, Table V, page 107) of the data of the individual steaks indicated that at each stage of freezing, there were significant ($P<0.01$) differences attributable to freezer type.

Beef steaks placed in F(1) took significantly longer to cool (1.5 hours) than steaks placed in either F(2) or F(3) (Figure 4). The cooling time was 0.5 hours for LD steaks in

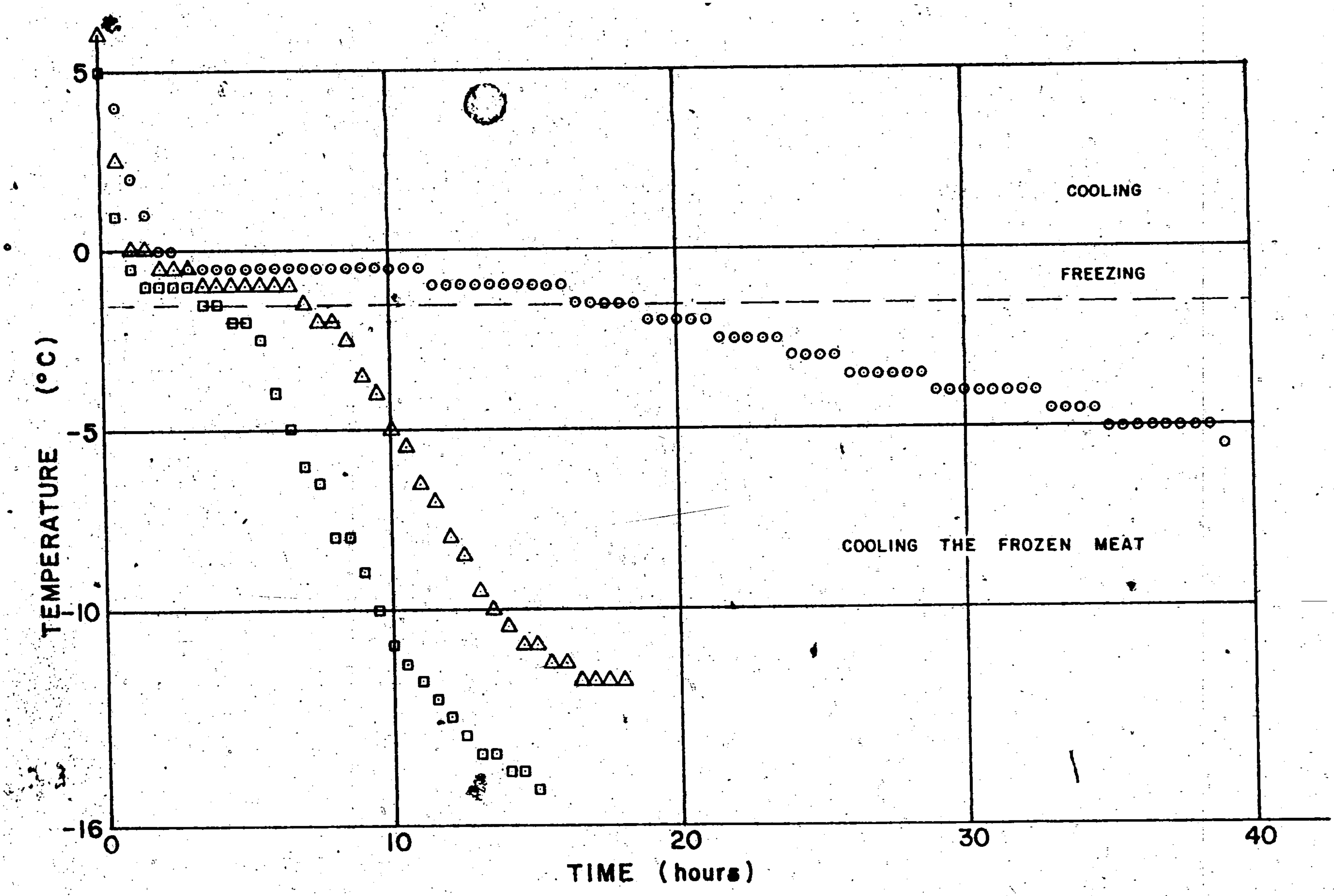
Figure 4. Average freezing curves for beef LD steaks (3.2 cm thick) frozen in three types of household freezers.

- ⊙ F(1), one-door refrigerator-freezer combination
- △ F(2), two-door 'frostfree' refrigerator-freezer combination
- ⊡ F(3), upright household freezer

Cooling, initial temperature to 0°

Freezing, 0° to -1.5°

Cooling the frozen meat, below -1.5°


COOLING
FREEZING
COOLING THE FROZEN MEAT
TEMPERATURE (°C)
TIME (hours)
5
0
-5
-10
-16
0
10
20
30
40

both F(2) and F(3).

A total of 16.0 hours was required for LD steaks in F(1) to complete the freezing stage. This time was significantly longer than the freezing stage time for steaks in either F(2) (6.5 hours) or F(3) (3.5 hours). There were no significant differences in the time required to complete the freezing stage for LD steaks placed in F(2) or F(3).

Steaks frozen in F(1) required significantly longer (21.5 hours) to cool the frozen meat to the maximum low temperature (-5.5°), than did comparable steaks frozen in either F(2) (9.5 hours) or F(3) (11.5 hours). There were no significant differences in the times required to complete the third stage (cooling the frozen meat, below -1.5°) between steaks placed in F(2) and F(3).

Steaks frozen in F(1) required a total of 39.0 hours to reach the maximum low temperature; F(2), 16.5 hours; and F(3), 15.5 hours (Figure 4). Maximum low temperatures for steaks in F(1), F(2) and F(3) were -5.5°, -12° and -15°, respectively.

The 'defrost cycle' of the 'frostfree' two-door refrigerator-freezer combination (F(2)), did not appear to influence the freezing curve. When the temperature of the freezers was monitored in preliminary work, the internal temperature of F(2) peaked at 4° to 10° during the defrost cycle. The defrost cycle occurred every 40 to 48 hours and was of a 30 minute duration.

Quality

The LD steaks frozen and stored in F(3) were scored higher ($P<0.01$) in appearance than LD steaks frozen and stored in either F(1) or F(2) (Table 9). Frozen LD steaks stored in either F(1) (-7°) or F(2) (-12°) exhibited a slight amount of freezer burn; however, comparable steaks frozen and stored in F(3) (-17°) showed little or no visible signs of freezer burn.

Ramsbottom (1947) demonstrated the relationship between the temperature of storage and the color and appearance of beef steaks. Steaks stored at -3° were discolored in less than 30 days, whereas steaks stored at -29° were still scored 'good' in color and appearance after one year of frozen storage. At temperatures of -12°, -18°, -23° and -29°, the amount of freezer burn was directly related to temperature, being very slight on steaks stored at -29° for 180 days, and extensive on steaks stored for 180 days at -12°.

The color of thawed raw samples of frozen LD steaks which had been stored in each of the three household freezers was similar (Table 9). In contrast, Jakobsson and Bengtsson (1973) observed that after thawing, meat frozen at

Table 9. Means and SE[1] for objective and subjective[2] measurements for beef LD steaks frozen and stored in three types of home freezers.

Measurements	Freezer Type[3] F(1)	F(2)	F(3)	SE
Freezer burn[4]	5.2^{b}	5.3^{b}	6.4^{a}	0.18**
Color[5] (thawed raw samples)				
485 nm	10.0	10.9	10.1	0.54
545 nm	6.9	7.0	6.3	0.50
625 nm	21.4	25.2	25.2	1.83
655 nm	27.4	30.2	31.1	2.14
Total losses[4] (%)	18.74^{a}	17.94^{b}	17.68^{b}	0.23**
Drip in thaw[4] (%)	1.73^{a}	1.12^{b}	1.01^{b}	0.11**
Cooking losses[4] (%)				
Total	17.01	16.82	16.67	0.23
Volatile	16.04	15.73	15.63	0.19
Drip	0.97	1.09	1.04	0.07
Taste panel data[6]				
Softness	5.2^{b}	5.4^{a}	5.4^{a}	0.04**
Juiciness	5.1	5.0	5.1	0.04
Initial flavor	4.9^{a}	4.8^{b}	4.9^{a}	0.04*
Tenderness	5.7	5.7	5.7	0.05
Connective tissue	6.1	6.2	6.1	0.06
Meatiness	5.4	5.3	5.3	0.03
Overall acceptability	5.1	5.1	5.2	0.03
Ether extract[5] (%)	3.10	3.05	3.06	0.50
Total moisture[5] (%)	72.95	73.49	73.31	0.65
Water holding capacity[7]	0.72	0.71	0.73	0.00
Shear force[8] (kg/1.3cm core)	3.4^{a}	3.2^{b}	3.0^{c}	0.02**
TBA number[8]	0.63	1.11	0.72	0.23

[1]Standard error.

[2]Highest possible score, 7 points.

[3]F(1), one-door refrigerator freezer; F(2), two-door 'frostfree' refrigerator freezer; F(3), upright household freezer

[4]Values are the means of 48 determinations.

[5]Values are the means of 16 determinations, two per replicate.

[6]Values are the means of 48 judgments by each of six panelists.

[7]1.0-(expressible liquid index); the larger the value the greater the amount of liquid expressed. Values are the means of 144 determinations, three per replicate.

[8]Values are the means of 288 determinations, six per replicate.

abc Values without a common letter in their superscript are significantly different (P<0.05).

* Significant at P<0.05. ** Significant at P<0.01.

a very slow freezing rate (-20°) was darker in color than meat samples frozen at higher rates (-35° and with liquid nitrogen).

The average percent total losses and drip in thaw for steaks frozen and stored in F(1) were higher ($P<0.01$) than the total losses and drip in thaw of comparable steaks frozen and stored in either F(2) or F(3) (Table 9). Cooking losses (total, volatile and drip) showed no significant differences attributable to type of home freezer.

Pearson and Miller (1950) found total weight losses, drip in thaw and cooking losses were similar for beef steaks frozen at three different rates (slow, intermediate and rapid). Hiner et al., (1945) observed that drip in thaw decreased as freezing temperatures were lowered from -8° to -81°. The authors believed an increase in intrafibrillar freezing and rupturing of fibers permitted the proteins to reabsorb a large proportion of the water originally frozen in the meat, reducing the volume of drip in thaw. Bannister (1971) found no significant differences in cooking losses (total, volatile and drip) for pork loin chops frozen in each of three types of household freezers.

Judges scored the softness of LD steaks frozen and stored in F(2) and F(3) significantly higher than the softness of comparable samples frozen and stored in F(1)

(Table 9). LD steaks frozen and stored in each of the three types of home freezers were similar in juiciness, tenderness, residual connective tissue, meatiness and overall acceptability. Initial flavor scores for steaks frozen and stored in F(2) were lower ($P<0.05$) than the scores for comparable steaks frozen and stored in either F(1) or F(3).

Harrison et al., (1973) found that pork chops frozen and stored in the freezing compartment of a refrigerator-freezer (H1) were more tender than comparable chops frozen in either the freezing section of a two-door refrigerator freezer (H2) or an upright household freezer (H3). There were no significant differences in juiciness scores between pork chops frozen in each of the three types of household freezer. Flavor scores were higher for frozen chops stored in (H1), but the difference was not significant. The overall acceptability ratings for chops stored in (H1) were higher than the ratings for chops stored in either (H2) or (H3).

Data for chemical composition and objective measurements for LD steaks frozen and stored in the three household freezers are also summarized in Table 9. There were no significant differences in percent ether extract, percent moisture and water holding capacity attributable to freezer type. Shear force values were lowest (most tender) for LD steaks frozen and stored in F(3) and highest (least tender) for LD steaks frozen and stored in F(1). The TBA number for steaks frozen and stored in F(2) was higher than the number for comparable steaks frozen and stored in either F(1) or F(3), however the difference was not significant.

Hankins and Hiner (1940) reported that steaks frozen at -23° and -40° were more tender (required less force to shear) than steaks frozen at -7°. Bannister (1971) found no significant differences in percent moisture, water holding capacity and shear force for pork chops frozen and stored in each of three types of household freezers.

The data (Table 9) indicate that the low frozen storage temperature of F(3), (-17°) was important in contributing to a desirable appearance for frozen LD steaks. In addition, low temperatures such as those in F(3) and F(2) minimize the total losses and drip in thaw of the LD steaks, and result in higher softness scores and lower shear force values. Initial flavor scores for LD steaks frozen and stored in F(3) and F(1) were similar and higher than scores for comparable LD steaks frozen and stored in F(2). In contrast, the high frozen storage temperature in F(1) appears to have a less desirable effect on the quality of the meat.

Objective and subjective data for each of the three household freezers were analyzed separately for the two storage periods and are presented in Tables 10 and 11. No visible signs of freezer burn were observed on LD steaks frozen and stored 10 days in any of the three household freezers (Table 10). However, LD steaks frozen and stored 187 days in F(3) were superior (P<0.01) in appearance to comparable LD steaks frozen and stored in either F(1) or F(2) (Table 11). When thawed, there were no significant differences in the raw lean color of LD steaks frozen and stored in each of the three household freezers within each storage period.

Total losses were highest (P<0.01) for LD steaks frozen and stored 10 days in F(1) and lowest for LD steaks frozen and stored 10 days in F(3) (Table 10). In addition, total losses were significantly higher for the frozen LD steaks stored 187 days in F(1) than the losses of comparable frozen steaks stored 187 days in either F(2) or F(3) (Table 11). Percent drip in thaw was higher for the LD steaks stored in F(1) than the percent drip in thaw of comparable steaks stored in either F(2) or F(3), regardless of the length of frozen storage (Tables 10 and 11). Cooking losses (total, volatile and drip) for frozen LD steaks stored 10 or 187 days were not significantly affected by freezer type.

Taste panel evaluation of the LD steaks frozen and stored for 10 days in each of the three household freezers

Table 10. Means and SE[1] for objective and subjective[2] measurements for beef LD steaks frozen and stored 10 days in three home freezers.

Measurements	Freezer Type[3] F(1)	F(2)	F(3)	SE
Freezer burn[4]	7.0	7.0	7.0	0.00
Color[5] (thawed raw samples)				
485 nm	11.2	12.2	12.5	0.73
545 nm	8.2	8.7	7.9	0.70
625 nm	22.6	27.9	30.3	2.59
655 nm	27.9	33.7	37.2	3.03
Total loss[illegible]	18.07^a	17.32^{ab}	17.01^b	0.27**
Drip in th[illegible]	1.65^a	1.02^b	0.95^b	0.11**
Cooking lo[illegible] (%)				
Total	16.42	16.30	16.06	0.26
Volatile	15.49	15.32	15.06	0.22
Drip	[illegible]93	0.98	1.00	0.07
Taste panel data[4]				
Softness	5.4	5.6	5.5	0.05
Juiciness	5.2	5.1	5.2	0.06
Initial flavor	5.3	5.2	5.2	0.06
Tenderness	5.8	5.9	5.9	0.06
Connective tissue	6.3	6.3	6.2	0.09
Meatiness	5.5	5.4	5.4	0.04
Overall acceptability	5.5	5.4	5.5	0.05
Ether extract[5] (%)	2.34	2.69	3.34	0.50
Total moisture[5] (%)	74.01	73.85	73.00	0.65
Water holding capacity[7]	0.69^a	0.68^b	0.69^c	0.00
Shear force[8] (kg/1.3cm core)	3.3	3.2	2.9	0.02**
TBA number[5]	0.73	1.49	0.93	0.32

[1]Standard error.

[2]Highest pos[illegible] score, 7 points.

[3]F(1), one-door refrigerator freezer; F(2), two-door 'frostfree' refrigerator freezer; F(3), upright household freezer.

[4]Values are the means of 24 determinations.

[5]Values are the means of 8 determinations, two per replicate.

[6]Values are the means of 24 judgments by each of six panelists.

[7]1.0-(expressible liquid index); the larger the value the greater the amount of liquid expressed. Values are the means of 72 determinations, three per replicate.

[8]Values are the means of 144 determinations, six per replicate.

abc Values without a common letter in their superscript are significantly different (P<0.05).

** Significant at P<0.01.

Table 11. Means and SE[1] for objective and subjective[2] measurements for beef LD steaks frozen and stored 187 days in three home freezers.

Measurements	Freezer Type[3] F(1)	F(2)	F(3)	SE
Freezer burn[4]	3.4^b	3.6^b	5.9^a	0.26**
Color[5] (thawed raw samples)				
485 nm	8.8	9.5	7.8	0.73
545 nm	5.5	5.2	4.8	0.70
625 nm	20.3	22.4	20.2	2.59
655 nm	26.9	26.7	25.1	3.03
Total losses[4] (%)	19.41^a	18.55^b	18.34^b	0.28**
Drip in thaw[4] (%)	1.81^a	1.23^b	1.07^b	0.13**
Cooking losses[4] (%)				
Total	17.60	17.32	17.27	0.30
Volatile	16.6[illegible]	16.12	16.20	0.24
Drip	1.00	1.20	1.07	0.10
Taste panel data[6]				
Softness	5.0^b	5.3^a	5.3^a	0.06*
Juiciness	4.9	4.9	5.0	0.05
Initial flavor	4.6^a	4.4^b	4.7^a	0.07*
Tenderness	5.5	5.6	5.6	0.06
Connective tissue	6.0	6.1	6.0	0.07
Meatiness	5.3	5.2	5.2	0.05
Overall acceptability	4.7	4.7	4.9	0.06
Ether extract[5] (%)	3.88	3.41	2.79	0.50
Total moisture[5] (%)	71.89	73.14	73.62	0.65
Water holding capacity[7]	0.75^b	0.74^c	0.77^a	0.00*
Shear force[8] (kg/1.3cm core)	3.4^a	3.2^b	3.1^b	0.03*
TBA number[5]	0.52	0.74	0.51	0.32

[1]Standard error

[2]Highest possible score, 7 points.

[3]F(1), one-door refrigerator freezer; F(2), two-door 'frostfree' refrigerator freezer; F(3), upright household freezer

[4]Values are the means of 24 determinations.

[5]Values are the means of 8 determinations, two per replicate.

[6]Values are the means of 24 judgments by each of six panelists.

[7]1.0-(expressible liquid index); the larger the value, the greater the amount of liquid expressed. Values are the means of 72 determinations, three per replicate.

[8]Values are the means of 144 determinations, six per replicate.

abc Values without a common letter in their superscript are significantly different (P<0.05).

* Significant at P<0.05. ** Significant at P<0.01.

indicated that there were no significant differences in palatability attributable to freezer type (Table 10). Taste panel scores (Table 11) show that frozen LD steaks stored for 187 days in F(2) and F(3) were softer than comparable frozen steaks stored for 187 days in F(1). Frozen steaks stored 187 days in each of the freezers, were similar in juiciness, tenderness, residual connective tissue, meatiness and overall acceptability. Only the initial flavor scores for LD steaks frozen and stored 187 days in F(2) were significantly lower than the scores for LD steaks frozen and stored the same length of time in either F(1) or F(3).

Data for percent ether extract, total moisture, water holding capacity and TBA number (Table 10) [illegible] to substantiate the taste panel scores which indicate that the eating quality of LD steaks frozen and stored 10 days was similar, regardless of freezer type. However, Warner Bratzler shear force values were lowest (most tender) for LD steaks stored 10 days in F(3) and highest (least tender) for steaks stored 10 days in F(1). Percent ether extract, total moisture and TBA number were similar for LD steaks frozen and stored 187 days in each of the three home freezers (Table 11). Water holding capacity data was lowest for LD steaks frozen and stored 187 days in F(2); highest for frozen LD steaks stored for 187 days in F(3). Warner Bratzler shear values for frozen LD steaks stored 187 days in F(1) were significantly higher than the shear values of comparable steaks frozen and stored 187 days in either F(2) or F(3). The data for the comparisons of fresh steaks and steaks frozen and stored in each of the home freezers are presented in Tables VI, VII and VIII of the Appendix, pages 108, 109 and 110.

The data for freezer burn, total losses and drip in thaw (Tables 10 and 11) tend to agree with reports in the literature which state that high frozen storage temperatures such as that in F(1) (-7°) of the present experiment, have a detrimental effect on the quality of red meat. Ramsbottom (1947) estimated the maximum storage life of fresh meats by averaging data on the color and appearance in the frozen state and the palatability in the cooked state. All test meats (including beef steaks) stored at -3° had reached the margin of unacceptability in less than 30 days, not so much because of deterioration in palatability, but because of discoloration. Although the storage life of the meat samples at -7° was longer than at -3°, the color score dropped more quickly than the palatability score. At lower temperatures (-12°, -18°, -23° and -29°) the color and palatability scores dropped at about the same rate. The maximum storage life suggested for beef steaks frozen and stored at each of the following temperatures was: -7°, less than 90 days; -12°, 120 days; -18°, 240 days; and -23°, more than one year (Ramsbottom, 1947).

A constant low temperature of -18°, similar to that of F(3) of this experiment, is desirable for extended frozen storage (Emerson et al., 1951; Ramsbottom et al., 1950). Fluctuating temperatures such as those observed in the defrost cycle of F(2) result in some minor alterations in quality. Winter et al., (1952) reported that the quality of ground beef stored at a constant temperature (-18°) was consistently superior to the quality of ground beef stored at fluctuating temperatures (-12° to -18°). Similar results for beef steaks were reported by Emerson et al., (1951). However, the sensory characteristics of beef roasts stored at a constant (-18°) or fluctuating (-12° to -18°) temperature were similar. Law et al., (1967) stored beef loin steaks at -18° to -23° for six months without serious loss in quality.

Thawing

Table 12 gives the means and standard error for the objective and subjective measurements for LD steaks thawed by three methods. The average raw weight of all the meat samples was similar. Thawing method had a significant effect on the time required to cook the LD steaks. Cooking time for oven thawed (OT) steaks was significantly longer than the cooking time for comparable steaks thawed at either

Table 12. Means and SE[1] for objective and subjective[2] measurements for frozen beef LD steaks thawed at three temperatures.

Measurements	Thawing Method[3] RF	RT	OT	SE
Raw weight[4] (g)	333.8	338.2	344.4	8.75
Cooking time[4] (min)	23.2^{b}	23.6^{b}	40.6^{a}	0.78**
Total losses[4] (%)	17.43^{b}	17.41^{b}	19.51^{a}	0.23**
Drip in thaw[4] (%)	2.04^{a}	1.82^{a}	0.0^{b}	0.11**
Cooking losses[4] (%)				
Total	15.39^{b}	15.59^{b}	19.51^{a}	0.23**
Volatile	14.39^{b}	14.67^{b}	18.34^{a}	0.19**
Drip	1.00	0.92	1.16	0.07
Taste panel data[5]				
Softness	5.3^{b}	5.5^{a}	5.2^{b}	0.04**
Juiciness	5.1^{a}	5.2^{a}	4.9^{b}	0.04**
Initial flavor	4.8	4.9	4.9	0.04
Tenderness	5.7^{ab}	5.8^{a}	5.6^{b}	0.05**
Connective tissue	6.2	6.2	6.1	0.06
Meatiness	5.3	5.4	5.3	0.03
Overall acceptability	5.0^{c}	5.2^{a}	5.1^{b}	0.03**
Water holding capacity[6]	0.71	0.72	0.73	0.00
Shear force[7] (kg/1.3cm core)	3.2^{b}	3.0^{c}	3.3^{a}	0.02**

[1] Standard error.

[2] Highest possible score, 7 points.

[3] RF, refrigerator temperature; RT, room temperature; OT, oven temperature.

[4] Values are the means of 48 determinations.

[5] Values are the means of 48 judgments by each of six panelists.

[6] 1.0–(expressible liquid index); the larger the value, the greater the amount of liquid expressed. Values are the means of 144 determinations, three per replicate.

[7] Values are the means of 288 determinaitons, six per replicate.

abc Values without a common letter in their superscript are significantly different ($P<0.05$).

** Significant at $P<0.01$.

refrigerator (RF) or room (RT) temperature. Cooking times for RF and RT steaks were similar. Other workers (Vail et al., 1943; Lowe et al., 1952; Brown, 1961; Lind, 1969; Bannister, 1971) have reported similar findings.

Percent total losses and total cooking and volatile losses for OT steaks were higher (P<0.01) than the losses of comparable frozen LD steaks thawed prior to cooking (Table 12). Drip losses for the LD steaks were not affected by thawing method. Total losses, drip in thaw and cooking losses (total, volatile and drip) were similar for LD steaks thawed in either the refrigerator or at room temperature.

Reports in the literature on the effects of methods of thawing on weight losses during thawing and cooking are varied. Brown (1961) observed that total losses and cooking losses for beef steaks refrigerator or room temperature thawed were similar, although refrigerator thawed steaks had a greater drip in thaw volume than did room temperature thawed steaks. Vail et al., (1943) stated that total losses for oven, refrigerator and room temperature thawed steaks were similar. However, cooking losses were highest for oven thawed steaks and lowest for refrigerator thawed steaks. Lowe et al., (1952) reported that the total losses for refrigerator thawed and room temperature thawed steaks were greater than the total losses for oven thawed steaks, but total cooking losses for steaks thawed prior to cooking (refrigerator and room temperature) were lower than the total cooking losses of oven thawed steaks.

The trained panel rated RT steaks softer (P<0.01) and more acceptable (P<0.01) than comparable LD steaks thawed by either RF or OT (Table 12). The juiciness scores of LD steaks thawed prior to cooking were signficantly higher than the score for comparable OT steaks. Panelists indicated that there were no significant differences in initial flavor, residual connective tissue or meatiness of the LD steaks attributable to thawing method. The LD steaks which were thawed at RT were the most tender while the OT steaks were the least tender, as indicated by both taste panel scores and shear force. Water holding capacity data were similar for LD steaks thawed by each of the three methods.

Studies on frozen meat have examined the effects of various methods of thawing on the palatability of the cooked meat. Jakobsson and Bengtsson (1973) observed that oven thawed beef slices were more juicy than slices thawed at room temperature. Vail et al., (1943) obtained more press fluid from oven thawed beef steaks than from beef steaks thawed at room temperature. Steaks thawed in the refrigerator had the greatest amount of press fluid, although the differences were not significant. Lind (1969) found no significant differences in the juiciness of lamb chops thawed in the refrigerator or during cooking. Several researchers have reported that there are no significant differences in the juiciness of meat thawed at room temperature or in the refrigerator (Kalen et al., 1948; Westerman et al., 1949; Brown, 1961).

Reports in the literature have indicated that flavor and desirability are not significantly affected by methods of thawing (Brown, 1961; Lind, 1969). Brown (1961) also noted lower initial tenderness scores for beef steaks thawed at room temperature than for steaks thawed in the refrigerator. Shear force values for the room temperature thawed steaks were greater than values for refrigerator thawed steaks. Vail et al., (1943) also found higher shear values (less tender) for oven thawed steaks than for steaks thawed prior to cooking (refrigerator and room temperature). Steaks thawed at room temperature were the most tender (lowest shear force value) however, the differences were not significant. Smith et al., (1969) found no significant differences in tenderness for beef steaks thawed in the refrigerator or during cooking.

The data (Table 12) indicate that although there are some differences in palatability attributable to thawing method, in general, the palatability of the LD steaks thawed before or during cooking is similar. Several researchers have reported the same results (Vail et al., 1943; Brown, 1961; Lind, 1969).

Data for fresh LD steaks and frozen LD steaks thawed prior to cooking are compared in Tables 13, 14 and 15. The raw weight of both the fresh and thawed steaks was similar. Frozen LD steaks thawed prior to cooking took longer (P<0.01) to reach the 61° endpoint temperature than did comparable fresh steaks. A comparison of fresh and thawed steaks indicated that thawing resulted in a range of initial temperatures (0° to 15.5°). The average initial temperature of the LD steaks was: fresh, 4°; RF, 2°; and RT, 5.5°. Lind (1969) observed that the internal temperature of refrigerator thawed lamb chops ranged from 4° to 12°, and averaged 6°.

In general, the lower the initial internal temperature, the longer the cooking time. Lowe (1955, p. 240) stated that a longer time was required for cooking meat with an internal temperature of 0° to 5° than for cooking meat with an internal temperature of 20°. Brown (1964) was unable to verify this statement.

The percent total losses for LD steaks thawed prior to cooking were significantly higher than the losses of fresh LD steaks, due to the addition of drip in thaw (Tables 13, 14 and 15). Analysis of variance indicated that cooking losses (total, volatile and drip) for comparable fresh and thawed steaks (Table 13) and fresh and RF steaks (Table 14)

Table 13. Means and SED[1] for objective and subjective[2] measurements for fresh LD steaks and frozen LD steaks thawed prior to cooking.

Measurements	Fresh	Thawed[3]	SED
Raw weight[4] (g)	336.1	336.0	10.00
Cooking time[4] (min)	20.0	23.4	1.09**
Total losses[4] (%)	15.00	17.42	0.86**
Drip in thaw[4] (%)	---	1.93	
Cooking losses[4] (%)			
Total	15.00	15.49	0.98
Volatile	13.70	14.56	0.72
Drip	1.30	0.93	0.22
Taste panel data[5]			
Softness	5.2	5.4	0.09*
Juiciness	5.4	5.2	0.07**
Initial flavor	5.0	4.8	0.18
Tenderness	5.4	5.8	0.12**
Connective tissue	5.8	6.2	0.10**
Meatiness	5.2	5.4	0.36
Overall acceptability	5.2	5.1	0.83
Water holding capacity[6]	0.70	0.72	0.02
Shear force[7] (Kg/1.3 cm core)	3.2	3.1	0.03

[1]Standard error of mean difference.

[2]Highest possible score, 7 points.

[3]Refrigerator and room temperature.

[4]Values for fresh steaks are means of 24 determinations; values for thawed steaks are means of 96 determinations.

[5]Values for fresh steaks are means of 24 judgments by each of six panelists; values for thawed steaks are means of 96 judgments by each of six panelists.

[6]1.0-(expressible liquid index); the larger the value the greater the amount of liquid expressed. Values for fresh steaks are means of 72 determination, three per replicate; values for thawed steaks are means of 288 determinations, three per replicate.

[7]Values for fresh steaks are means of 144 determinations, six per replicate; values for thawed steaks are means of 576 determinations, six per replicate.

* Significant at P<0.05. ** Significant at P<0.01.

Table 14. Means and SED[1] for objective and subjective[2] measurements for fresh LD steaks and frozen LD steaks thawed at refrigerator temperature.

Measurements	Fresh	RF[3]	SED
Raw weight[4] (g)	336.1	333.8	10.45
Cooking time[4] (min)	20.0	23.2	1.04**
Total losses[4] (%)	15.00	17.43	0.95*
Drip in thaw (%)	---	2.04	
Cooking losses[4] (%)			
Total	15.00	15.39	1.34
Volatile	13.70	14.39	0.77
Drip	1.30	1.00	0.19
Taste panel data[5]			
Softness	5.2	5.3	0.10
Juiciness	5.4	5.1	0.10**
Initial flavor	5.0	4.8	0.14
Tenderness	5.4	5.7	0.16
Connective tissue	5.8	6.2	0.15**
Meatiness	5.2	5.3	1.43
Overall acceptability	5.2	5.0	0.26
Water holding capacity[6]	0.70	0.71	0.01
Shear force[7] (kg/1.3 cm core)	3.2	3.2	0.00

[1]Standard error of mean difference.

[2]Highest possible score, 7 points.

[3]RF, refrigerator temperature.

[4]Values for fresh steaks are means of 24 determinations; values for thawed steaks are means of 48 determinations.

[5]Values for fresh steaks are means of 24 judgments by each of six panelists; values for thawed steaks are means of 48 judgments by each of six panelists.

[6]1.0-(expressible liquid index); the greater the value the greater the amount of liquid expressed. Values for fresh steaks are means of 72 determinations, three per replicate; values for thawed steaks are means of 144 determinations, three per replicate.

[7]Values for fresh steaks are means of 144 determinations, six per replicate; values for thawed steaks are means of 288 determinations, six per replicate.

* Significant at P<0.05. ** Significant at P<0.01.

Table 15. Means and SED[1] for objective and subjective[2] measurements for fresh LD steaks and frozen LD steaks thawed at room temperature.

Measurements	Fresh	RT[3]	SED
Raw weight[4] (g)	336.1	338.2	11.67
Cooking time[4] (min)	20.0	23.6	1.20**
Total losses[4] (%)	15.00	17.41	0.90**
Drip in thaw[4] (%)	---	1.82	
Cooking losses[4] (%)			
Total	15.00	15.59	0.94
Volatile	13.70	14.66	0.70
Drip	1.30	0.93	0.16*
Taste panel data[5]			
Softness	5.2	5.5	0.10**
Juiciness	5.4	5.2	0.10*
Initial flavor	5.0	4.9	0.15
Tenderness	5.4	5.8	0.10**
Connective tissue	5.8	6.2	0.09**
Meatiness	5.2	5.4	0.19
Overall acceptability	5.2	5.2	0.00
Water holding capacity[6]	0.70	0.72	0.02
Shear force[7] (kg/1.3 cm core)	3.2	3.0	0.04*

[1]Standard error of mean difference.

[2]Highest possible score, 7 points.

[3]RT, room temperature.

[4]Values for fresh steaks are means of 24 determinations; values for thawed steaks are means of 48 determinations.

[5]Values for fresh steaks are means of 24 judgments by each of six panelists; values for thawed steaks are means of 48 judgments by each of six panelists.

[6]1.0-(expressible liquid index); the greater the value the greater the amount of liquid expressed. Values for fresh steaks are means of 72 determinations, three per replicate, values for thawed steaks are means of 144 determinations, three per replicate.

[7]Values for fresh steaks are means of 144 determinations, six per replicate; values for thawed steaks are means of 288 determinations, six per replicate.

* Significant at $P<0.05$. ** Significant at $P<0.01$.

were similar. There were no significant differences in total cooking and volatile losses between fresh and RT steaks (Table 15). However, drip losses for RT steaks were lower ($P<0.05$) than the drip losses for comparable fresh steaks.

Fenton et al., (1956) reported that the total losses and cooking losses of fresh beef roasts and room temperature thawed roasts were similar. Berry et al., (1971) observed fewer losses for fresh chops than for refrigerator thawed chops.

Taste panel data indicate that LD steaks thawed prior to cooking were softer ($P<0.05$) and more tender ($P<0.01$) than comparable fresh steaks (Table 13). However, softness and tenderness scores for both fresh and RF steaks were similar (Table 14). The RT steaks were softer ($P<0.01$) and more tender ($P<0.01$) than comparable fresh LD steaks (Table 15). The fresh LD steaks were more juicy and had more residual connective tissue than the steaks thawed prior to cooking (Tables 13, 14 and 15). Taste panel scores for initial flavor, meatiness and overall acceptability were similar. There was no significant difference in the water holding capacity attributable to thawing prior to cooking. A comparison between fresh steaks and thawed steaks (Table 13) and between fresh steaks and RF steaks (Table 14) showed there were no significant differences in the shear force values. The shear force value for RT steaks was lower ($P<0.05$) than the shear force value of comparable fresh steaks (Table 15).

Fresh LD steaks and LD steaks thawed during cooking (OT) were compared (Table 16). The data indicate that cooking LD steaks from the frozen state resulted in a significantly longer cooking time. Total losses, total cooking and volatile losses of the OT steaks were higher ($P<0.01$) than the losses of comparable fresh steaks. Drip losses for both the fresh and OT steaks were similar. Fresh steaks and OT steaks were similar in each of the eating quality characteristics except juiciness. Taste panel evaluation indicated that fresh LD steaks were juicier than comparable OT steaks. Both the fresh steaks and steaks cooked directly from the frozen state were described as moderately desirable. The water holding capacity of OT steaks was higher than the water holding capacity of comparable fresh steaks. Shear force data for both fresh and OT steaks were similar.

In general, the data (Tables 13, 14, 15 and 16) indicate that there were only slight differences in palatability between fresh LD steaks and LD steaks thawed before or during cooking. Other workers (Fenton et al., 1956; Berry et al., 1971) have reported similar results. The means and standard error for the interaction of thawing method and

Table 16. Means and SED[1] for objective and subjective[2] measurements for fresh LD steaks and frozen LD steaks thawed during cooking.

Measurements	Fresh	OT[3]	SED
Raw weight[4] (g)	336.1	344.4	11.69
Cooking time[4] (min)	20.0	40.6	1.3[illegible]**
Total losses[4] (%)	15.00	19.51	0.71**
Cooking losses[4] (%)			
Total	15.00	19.51	0.71**
Volatile	13.70	18.34	0.57**
Drip	1.30	1.17	0.22
Taste panel data[5]			
Softness	5.2	5.2	0.00
Juiciness	5.4	4.9	0.13**
Initial flavor	5.0	4.9	0.40
Tenderness	5.4	5.6	0.16
Connective tissue	5.8	6.1	0.16
Meatiness	5.2	5.3	0.18
Overall acceptability	5.2	5.1	0.10
Water holding capacity[6]	0.70	0.73	0.01*
Shear force[7] (kg/1.3 cm core)	3.2	3.3	0.04

[1]Standard error of mean difference.

[2]Highest possible score, 7 points.

[3]OT, oven thawed.

[4]Values for fresh steaks are means of 24 determinations; values for thawed steaks are means of 48 determinations.

[5]Values for fresh steaks are means of 24 judgments by each of six panelists; values for thawed steaks are means of 48 judgments by each of six panelists.

[6]1.0-(expressible liquid index); the greater the value the greater the amount of liquid expressed. Values for fresh steaks are means of 72 determinations, three per replicate, values for thawed steaks are means of 144 determinations, three per replicate.

[7]Values for fresh steaks are means of 144 determinations, six per replicate; values for thawed steaks are means of 288 determinations, six per replicate.

* Significant at $P<0.05$. ** Significant at $P<0.01$.

storage time are presented in Tables IX and X of the Appendix, pages 111 and 112.

SUMMARY AND CONCLUSIONS

Beef LD steaks from young bulls were frozen and stored 10 or 187 days in each of three types of household freezers F(1), one-door refrigerator-freezer combination; F(2), two-door 'frostfree' refrigerator-freezer; F(3), upright household freezer. The frozen LD steaks were thawed by three methods, refrigerator temperature (RF); room temperature (RT); and oven thawed (OT) (cooked directly from the frozen state). In order to study the effects of current home freezing, storage and thawing methods, total losses, cooking losses (total, volatile and drip) and eating quality characteristics of the beef LD steaks were evaluated. Fresh LD steaks served as a control.

A comparison of fresh LD steaks and LD steaks frozen and stored 10 days indicated that both types of steaks were similar in appearance and color. The average percent total losses for frozen LD steaks stored 10 days were higher than the total losses of comparable fresh steaks. There were no significant differences in the cooking losses of both the fresh and the frozen steaks stored 10 days. Subjective evaluation of the LD steaks indicated that frozen steaks stored 10 days were softer, more tender, had less residual connective tissue, and were more meaty but less juicy than comparable fresh steaks. Both the fresh steaks and the LD steaks frozen and stored 10 days were similar in initial flavor and overall acceptability. Percentage ether extract, percent total moisture, water holding capacity, shear force value and TBA number were not significantly affected by 10 days of frozen storage. Although these results indicate some differences in quality attributable to a short period of frozen storage, generally, there is little difference in the eating quality of fresh LD steaks and LD steaks frozen and stored for a short (10 days) time.

LD steaks frozen and stored 10 days were superior in appearance and color to comparable steaks frozen and stored 187 days. The average percent total losses, drip in thaw, total cooking, and volatile losses increased significantly between 10 and 187 days frozen storage. However, drip losses for frozen steaks stored either 10 or 187 days were similar. Taste panel data showed that frozen LD steaks stored 10 days rated significantly higher for each of the palatability characteristics evaluated than comparable frozen samples stored 187 days. The findings from the objective measurements tended to show no significant differences attributable to 187 days of frozen storage. However, the data indicate that prolonged frozen storage (187 days) of beef LD steaks in the household freezers results in a loss in eating quality.

The appearance of LD steaks frozen and stored in F(3)

(-17°) was superior to the appearance of steaks frozen and stored in either F(2) (-12°) or F(1) (-7°). Total losses and drip in thaw of LD steaks frozen and stored in F(3) and F(2) were significantly lower than the total losses and drip in thaw for comparable steaks frozen and stored in F(1). The percent cooking losses of steaks frozen and stored in each of the home freezers were similar. LD steaks frozen and stored in F(3) and F(2) were rated softer and had lower shear values (more tender) than comparable LD steaks frozen and stored in F(1). However, LD steaks frozen and stored in each of the three types of home freezers were similar in juiciness, tenderness, residual connective tissue, meatiness and overall acceptability. Initial flavor scores for steaks frozen and stored in F(3) and F(1) were higher than scores for comparable steaks frozen and stored in F(2). Generally, these results indicate that the low frozen storage temperatures (-17° and -12°) in F(3) and F(2) were important in maintaining the quality of the frozen LD steaks. In contrast, the higher frozen storage temperature in F(1) (-7°) appeared to have a less desirable effect on the quality of the meat.

LD steaks purchased fresh can be frozen and stored in each of the three types of household freezers for 10 days without serious loss in eating quality. A constant low temperature, such as that of the upright household freezer, (F(3), -17°) is desirable for extended (187 days) frozen storage. In contrast, a higher temperature (-7°) for long freezer storage (187 days) results in a loss in quality. The low frozen storage temperature (-12°) of the two-door 'frostfree' refrigerator-freezer, F(2) seems to be satisfactory for long periods of frozen storage. However, the flavor of the LD steaks frozen and stored in F(2) decreased with 187 days of frozen storage.

Frozen LD steaks thawed prior to or during cooking took significantly longer ($P<0.01$) to reach the 61° endpoint temperature than did comparable fresh steaks. In addition, the cooking time for OT steaks was significantly longer than the cooking time of comparable RT and RF steaks. Percent total losses for LD steaks thawed before or during cooking were significantly higher than the losses of fresh LD steaks. Generally there were no significant differences in the cooking losses of either fresh and RT steaks or fresh and RF steaks. However, total cooking and volatile losses of the OT steaks were higher than the total cooking and volatile losses of comparable fresh steaks. Comparisons of fresh LD steaks and frozen LD steaks thawed prior to or during cooking showed only slight differences in palatability. Although the eating quality of RT steaks was slightly more desirable than that of RF and OT steaks, in general, the palatability of all steaks thawed before or during cooking was comparable and judged moderately desirable.

Findings from the present study for the combined effects of freezing, storage and thawing indicate the best consumer practice to utilize is frozen storage in the upright household freezer, F(3), followed by thawing at either room (RT) or refrigerator (RF) temperature, regardless of the length of frozen storage (10 or 187 days). A short period of frozen storage in F(2) along with RT thawing, results in a desirable product. However, following prolonged frozen storage (187 days), these same freeze-thaw conditions result in a loss of eating quality. Frozen storage (10 or 187 days) in the freezing compartment of the one-door refrigerator-freezer F(1), combined with cooking directly from the frozen state (OT) is the least desirable household technique for the consumer to use.

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APPENDIX

Table I. Schedule[1] for opening each of the freezer units.

F(1), one-door refrigerator-freezer	
	Refrigerator 1 min 15 sec a.m. 2 min 0 sec noon 2 min 30 sec p.m.
	Freezing Compartment 1 min 30 sec noon
F(2), two-door "frostfree" refrigerator-freezer	
	Freezing Section 1 min 30 sec noon
F(3), upright freezer	
	1 min 30 sec noon

[1]Based on the average freezer usage by ten homemakers for one month.

Table II. Means and SE[1] for obj[illegible] subjective[2] measurements for the freeze-thaw treatment combinations[3] after 10 days of fro[illegible].

Measurements	F(1)RF	F(2)RF	F(3)RF	F(1)RT	F(2)RT	F(3)RT	F(1)OT	F(2)OT	F(3)OT	SE
Raw weigh[illegible] (g)	[illegible]	33[illegible]0	338.5	341.4	351.9	351.5	345.8	341.5	354.5	11.03
Cookin[illegible] (min)	[illegible]	[illegible]	19.4	18.6	20.6	21.7	35.4	35.7	38.8	1.65
Total [illegible] (%)	[illegible]	[illegible].68^{cd}	16.24^{d}	16.68^{cd}	16.97^{bcd}	16.90^{bcd}	19.70^{a}	18.31^{b}	17.90^{bc}	0.47**
Drip in thaw[illegible] (%)	[illegible]	[illegible].54^{b}	1.53^{b}	2.31^{a}	1.51^{b}	1.33^{b}	0.0^{c}	0.0^{c}	0.0^{c}	0.19**
Cooking [illegible]										
[illegible]	[illegible]^{c}	15.13^{c}	14.71^{c}	14.37^{c}	15.46^{bc}	15.57^{bc}	19.70^{a}	18.31^{a}	17.90^{ab}	0.87**
[illegible]	[illegible]1^{c}	14.10^{c}	13.77^{c}	13.54^{c}	14.40^{c}	14.40^{c}	18.71^{a}	17.46^{b}	17.01^{b}	0.18**
D[illegible]	[illegible]	1.02	0.94	0.83	1.05	1.17	0.99	0.85	0.89	0.09
[illegible]										
[illegible]	5.4^{cd}	5.4^{cd}	5.5^{bc}	5.5^{bc}	5.6^{abc}	5.7^{ab}	5.2^{d}	5.8^{a}	5.4^{cd}	0.09**
[illegible]	5.4^{ab}	5.0^{c}	5.1^{bc}	5.3^{abc}	5.3^{abc}	5.5^{a}	5.0^{c}	5.1^{bc}	5.2^{abc}	0.10**
[illegible]	5.4^{a}	5.0^{b}	5.0^{b}	5.2^{ab}	5.4^{a}	5.2^{ab}	5.3^{ab}	5.2^{ab}	5.4^{a}	0.10*
[illegible]	5.8	5.9	5.8	6.0	6.0	6.0	5.7	5.9	5.8	0.07
[illegible] tissue	6.3	6.2	6.3	6.1	6.5	6.3	6.5	6.3	6.0	0.11
[illegible]	5.6	5.3	5.3	5.5	5.4	5.4	5.4	5.5	5.4	0.05
[illegible]tability	5.6^{a}	5.2^{b}	5.2^{b}	5.5^{a}	5.6^{a}	5.6^{a}	5.5^{a}	5.4^{ab}	5.6^{a}	0.09**
[illegible] capacity[6]	0.71	0.65	0.67	0.67	0.70	0.70	0.69	0[illegible]	0.71	0.00
[illegible]ce[7] (kg/1.3 cm core)	3.4^{ab}	3.3^{bcd}	3.0^{e}	3.0^{e}	3.1^{de}	2.7^{f}	3.5^{a}	3.[illegible]^{cd}	3.1^{de}	0.04**

[1]Standard err[illegible]

[2][illegible]ible score, 7 points.

[3]F(1), one-door refrigerator-freezer combination; F(2), two-door 'frostfree' refrigerator-freezer combination; F(3), upright household freezer; RF, refrigerator temperature; RT, room temperature; OT, oven temperature.

[4]Values are the means of 8 determinations.

[5]Values are the means of 8 judgments by each of six panelists.

[6]1.0 − (expressible liquid index); the larger the value the greater the amount of liquid expressed. Values are the means of 24 determinations, three per replicate.

[7]Values are the means of 48 determinations, six per replicate.

abcdef Values without a common letter in their superscript are significantly different (P<0.05).

* Significant at P<0.05. ** Significant at P<0.01.

Table III. Means and SE[1] for objective and subjective[2] measurements for the freeze-thaw treatment combinations[3] after 187 days of frozen storage.

Measurements	F(1)RF	F(2)RF	F(3)RF	F(1)RT	F(2)RT	F(3)RT	F(1)OT	F(2)OT	F(3)OT	SE
Raw weight[4] (g)	319.8	341.1	336.3	327.1	330.8	346.4	333.7	344.9	346.1	11.96
Cooking time[4] (min)	25.5	26.0	25.5	26.4	26.2	28.3	45.1	44.1	44.8	1.58
Total losses[4] (%)	18.42^{cd}	17.36^{d}	18.05^{cd}	18.48^{cd}	17.77^{cd}	17.68^{d}	21.33^{a}	2.053^{ab}	19.30^{bc}	0.49**
Drip in thaw[4] (%)	2.82^{a}	1.90^{b}	1.80^{b}	2.62^{a}	1.78^{b}	1.40^{b}	0.0^{c}	0.0^{c}	0.0^{c}	0.23**
Cooking losses[4] (%)										
Total	15.60^{c}	15.46^{c}	16.25^{c}	15.86^{c}	15.99^{c}	16.28^{c}	21.33^{a}	20.53^{ab}	19.30^{b}	0.51**
Volatile	14.86^{c}	14.41^{c}	15.02^{c}	15.06^{c}	15.10^{c}	15.50^{c}	19.93^{a}	18.91^{ab}	18.09^{b}	0.42**
Drip	0.76^{d}	1.07^{cd}	1.25^{bcd}	0.83^{d}	0.91^{cd}	0.80^{d}	1.42^{bc}	1.64^{a}	1.22^{bcd}	0.18*
Taste panel data[5]										
Softness	5.1^{ab}	5.3^{a}	5.4^{a}	5.2^{a}	5.4^{a}	5.3^{a}	4.8^{b}	5.1^{ab}	5.1^{ab}	0.10**
Juiciness	5.1^{a}	5.0^{a}	5.0^{a}	4.9^{ab}	5.1^{a}	5.1^{a}	4.7^{b}	4.7^{b}	4.9^{ab}	0.09**
Initial flavor	4.6	4.3	4.4	4.5	4.4	4.8	4.5	4.4	4.8	0.08
Tenderness	5.5	5.5	5.7	5.6	5.7	5.6	5.3	5.5	5.4	0.07
Connective tissue	6.1	6.1	6.1	5.9	6.2	6.1	5.9	6.1	5.9	0.09
Meatiness	5.3	5.1	5.0	5.2	5.2	5.4	5.2	5.2	5.3	0.06
Overall acceptability	4.7^{b}	4.7^{b}	4.7^{b}	4.8^{ab}	4.7^{b}	5.1^{a}	4.6^{b}	4.7^{b}	4.8^{ab}	0.11**
Water holding capacity[6]	0.76^{a}	0.73^{c}	0.76^{a}	0.74^{bc}	0.74^{bc}	0.75^{ab}	0.75^{ab}	0.74^{bc}	0.79^{a}	0.01**
Shear force[7] (kg/1.3 cm core)	3.3^{bc}	3.3^{bc}	3.0^{e}	3.2^{cd}	2.8^{f}	3.1^{de}	3.6^{a}	3.4^{b}	3.1^{de}	0.05*

[1]Standard error.

[2]Highest possible score, 7 points.

[3]F(1), one-door refrigerator-freezer combination; F(2), two-door 'frostfree' refrigerator-freezer combination; F(3), upright household freezer: RF, refrigerator temperature; RT, room temperature; OT, oven temperature.

[4]Values are the means of 8 determinations.

[5]Values are the means of 8 judgments by each of six panelists.

[6]1.0 - (expressible liquid index); the larger the value, the greater the amount of liquid expressed. Values are the means of 24 determinations, three per replicate.

[7]Values are the means of 48 determinations, six per replicate.

abcdef Values without a common letter in their superscript are significantly different ($P<0.05$).

* Significant at $P<0.05$. ** Significant at $P<0.01$.

Table IV. Means and SE[1] for objective and subjective[2] measurements for the freeze-thaw treatment combinations[3].

Measurements	F(1)RF	F(2)RF	F(3)RF	F(1)RT	F(2)RT	F(3)RT	F(1)OT	F(2)OT	F(3)OT	SE
Raw weight[4] (g)	324.6	339.5	337.4	324.3	341.2	349.0	339.8	343.2	350.3	5.92
Cooking time[4] (min)	23.1	23.6	22.9	22.5	23.4	25.0	40.2	39.9	41.8	0.89
Total losses[4] (%)	18.13^{cd}	17.02^{d}	17.15^{d}	17.58^{cd}	17.37^{cd}	17.29^{d}	20.51^{a}	19.42^{ab}	18.60^{b}	0.40**
Drip in thaw[4] (%)	2.72^{a}	1.72^{b}	1.67^{b}	2.46^{a}	1.65^{b}	1.36^{b}	0.0^{c}	0.0^{c}	0.0^{c}	0.19**
Cooking losses[4] (%)										
Total	15.40^{c}	15.30^{c}	15.48^{c}	15.12^{c}	15.72^{c}	15.93^{c}	20.51^{a}	19.42^{ab}	18.60^{b}	0.40**
Volatile	14.53^{c}	14.25^{c}	14.39^{c}	14.29^{c}	14.75^{c}	14.96^{c}	19.31^{a}	18.18^{b}	17.54^{b}	0.33**
Drip	0.87	1.04	1.09	0.83	0.97	0.98	1.20	1.24	1.05	0.10
Taste panel data[5]										
Softness	5.2^{bc}	5.4^{ab}	5.4^{ab}	5.4^{ab}	5.5^{a}	5.5^{a}	5.0^{c}	5.4^{ab}	5.2^{bc}	0.07**
Juiciness	5.2^{ab}	5.0^{bc}	5.0^{bc}	5.1^{abc}	5.2^{ab}	5.3^{a}	4.9^{c}	4.9^{c}	5.1^{abc}	0.07**
Initial flavor	5.0^{ab}	4.6^{d}	4.7^{cd}	4.9^{abc}	4.9^{abc}	5.0^{ab}	4.9^{abc}	4.8^{abc}	5.1^{a}	0.07**
Tenderness	5.6	5.7	5.8	5.8	5.9	5.8	5.5	5.6	5.6	0.07
Connective tissue	6.2	6.2	6.2	6.0	6.0	6.4	6.2	6.2	5.9	0.01
Meatiness	5.5^{a}	5.2^{c}	5.2^{c}	5.4^{ab}	5.3^{bc}	5.4^{ab}	5.3^{bc}	5.3^{bc}	5.3^{bc}	0.05*
Overall acceptability	5.2^{ab}	5.0^{c}	5.0^{c}	5.2^{ab}	5.2^{ab}	5.3^{a}	5.1^{bc}	5.1^{bc}	5.2^{ab}	0.06**
Water holding capacity[6]	0.73^{b}	0.69^{d}	0.71^{c}	0.71^{c}	0.72^{bc}	0.73^{b}	0.72^{b}	0.72^{bc}	0.75^{a}	0.01**
Shear force[7] (kg/1.3 cm core)	3.3^{b}	3.3^{b}	3.0^{d}	3.1^{c}	2.9^{d}	2.9^{d}	3.6^{a}	3.3^{b}	3.1^{c}	0.04**

[1]Standard error.

[2]Highest possible score, 7 points.

[3]F(1), one-door refrigerator-freezer combination; F(2), two-door 'frostfree' refrigerator-freezer combination; F(3), upright household freezer: RF, refrigerator thaw; RT, room temperature; OT, oven temperature.

[4]Values are the means of 16 determinations.

[5]Values are the means of 16 judgments by each of six panelists.

[6]1.0 - (expressible liquid index); the larger the value the greater the amount of liquid expressed. Values are the means of 48 determinations, three per replicate.

[7]Values are the means of 96 determinations, six per replicate.

abcd Values without a common letter in their superscript are significantly different (P<0.05).

* Significant at P<0.05. ** Significant at P<0.01.

Table V. Analysis of covariance for time (hours) adjusted for weight of beef LD steaks for three freezing stages of the freezing curves in three household freezers.

Source of variance	DF	Mean Square Freezing Stage[1] 1	2	3
Freezing	2	3.3***	329.7***	248.5***
Error	20	0.1	11.2	6.7

[1] 1 Cooling stage, initial temperature to 0°;
2 freezing stage, 0° to -1.5°;
3 cooling the frozen meat, below -1.5°.

*** Significant at $P<0.001$.

Table VI. Means and SED[1] for objective and subjective[2] measurements for fresh LD steaks and frozen LD steaks stored in a one-door refrigerator freezer (F(1)).

Measurements	Fresh	F(1)	SED
Freezer burn[3]	7.0	5.2	0.45**
Color[4] (raw samples)			
485 nm	12.9	10.0	1.01*
545 nm	8.7	6.9	0.78*
625 nm	28.5	21.4	3.06*
655 nm	32.7	27.8	3.27
Total losses[3] (%)	15.00	18.74	1.10**
Drip in thaw[3] (%)	---	1.73	
Cooking losses[3] (%)			
Total	15.00	17.01	1.30
Volatile	13.70	16.04	1.02
Drip	1.30	0.97	0.14*
Taste panel data[5]			
Softness	5.2	5.2	0.00
Juiciness	5.4	5.1	0.09**
Initial flavor	5.0	4.9	0.10
Tenderness	5.4	5.7	0.15*
Connective tissue	5.8	6.1	0.10**
Meatiness	5.2	5.4	0.24
Overall acceptability	5.2	5.1	0.19
Ether extract[4] (%)	2.68	3.10	0.58
Total moisture[4] (%)	74.30	72.95	0.78
Water holding capacity[6]	0.70	0.72	0.02
Shear force[7] (kg/1.3 cm core)	3.2	3.4	0.30
TBA number[4]	0.56	0.63	0.20

[1] Standard error of mean difference.

[2] Highest possible score, 7 points.

[3] Values for fresh steaks are means of 24 determinations; values for frozen steaks are means of 48 determinations.

[4] Values for fresh steaks are means of 24 determinations, two per replicate; values for frozen steaks are means of 16 determinations, two per replicate.

[5] Values for fresh steaks are means of 24 judgments by each of six panelists; values for frozen steaks are means of 48 judgments by each of six panelists.

[6] 1.0-(expressible liquid index); the larger the value the greater the amount of liquid expressed. Values for fresh steaks are means of 72 determinations, three per replicate; values for frozen steaks are means of 144 determinations, three per replicate.

[7] Values for fresh steaks are means of 144 determinations, six per replicate; values for frozen steaks are means of 288 determinations, six per replicate.

* Significant at $P<0.05$. ** Significant at $P<0.01$.

Table VII. Means and SED[1] for objective and subjective[2] measurements for fresh LD steaks and frozen LD steaks stored in a two-door 'frostfree' refrigerator freezer (F(2)).

Measurements	Fresh	F(2)	SED
Freezer burn[2]	7.0	5.3	0.38**
Color[4] (raw samples)			
485 nm	12.9	10.9	1.16
545 nm	8.7	7.0	0.84
625 nm	28.5	25.2	3.67
655 nm	32.7	30.2	4.10
Total losses[3] (%)	15.00	17.94	0.76**
Drip in thaw[3] (%)	---	1.12	
Cooking losses[3] (%)			
Total	15.00	16.82	0.72*
Volatile	13.70	15.73	0.62**
Drip	1.30	1.08	0.21
Taste panel data[5]			
Softness	5.2	5.4	0.09*
Juiciness	5.4	5.0	0.12**
Initial flavor	5.0	4.8	0.19
Tenderness	5.4	5.7	0.13*
Connective tissue	5.8	6.2	0.12**
Meatiness	5.2	5.3	0.56
Overall acceptability	5.2	5.1	0.48
Ether extract[4] (%)	2.64	3.05	0.58
Total moisture[4] (%)	74.30	73.49	0.75
Water holding capacity[6]	0.70	0.71	0.01
Shear force[7] (kg/1.3 cm core)	3.2	3.2	0.00
TBA number[4]	0.56	1.11	0.54

[1]Standard error of mean difference.

[2]Highest possible score, 7 points.

[3]Values for fresh steaks are means of 24 determinations; values for frozen steaks are means of 48 determinations.

[4]Values for fresh steaks are means of 24 determinations, two per replicate; values for frozen steaks are means of 16 determinations, two per replicate.

[5]Values for fresh steaks are means of 24 judgments by each of six panelist; values for frozen steaks are means of 48 judgments by each of six panelists.

[6]1.0-(expressible liquid index); the larger the value the greater the amount of liquid expressed. Values for fresh steaks are means of 72 determinations, three per replicate; values for frozen steaks are means of 144 determinations, three per replicate.

[7]Values for fresh steaks are means of 144 determinations, six per replicate; values for frozen steaks are means of 288 determinations, six per replicate.

*Significant at P<0.05. ** Significant at P<0.01.

Table VIII. Means and SED[1] for objective and subjective[2] measurements for fresh LD steaks and frozen LD steaks stored in an upright household freezer (F(3)).

Measurements	Fresh	F(3)	SED
Freezer burn[2]	7.0	6.4	0.21**
Color[4] (raw samples)			
485 nm	12.9	10.1	1.20*
545 nm	8.7	6.3	0.88*
625 nm	28.5	25.2	3.51
655 nm	32.7	31.1	4.00
Total losses[3] (%)	15.00	17.68	0.75**
Drip in thaw[3] (%)	---	1.01	
Cooking losses[3] (%)			
Total	15.00	16.67	0.71**
Volatile	13.70	15.63	0.61**
Drip	1.30	1.04	0.22
Taste panel data[5]			
Softness	5.2	5.4	0.13
Juiciness	5.4	5.1	0.15
Initial flavor	5.0	4.9	0.44
Tenderness	5.4	5.7	0.12*
Connective tissue	5.8	6.1	0.12*
Meatiness	5.2	5.3	0.20
Overall acceptability	5.2	5.2	0.00
Ether extract[4] (%)	2.64	3.06	0.58
Total moisture[4] (%)	74.30	73.31	0.74
Water holding capacity[6]	0.70	0.73	0.01*
Shear force[7] (kg/1.3 cm core)	3.2	3.0	0.05
TBA number[4]	0.56	0.72	0.28

[1]Standard error of mean difference.

[2]Highest possible score, 7 points.

[3]Values for fresh steaks are means of 24 determinations; values for frozen steaks are means of 48 determinations.

[4]Values for fresh steaks are means of 24 determinations, two per replicate; values for frozen steaks are means of 16 determinations, two per replicate.

[5]Values for fresh steaks are means of 24 judgments by each of six panelists; values for frozen steaks are means of 48 judgments by each of six panelists.

[6]1.0-(expressible liquid index); the larger the value the greater the amount of liquid expressed. Values for fresh steaks are means of 72 determinations, three per replicate; values for frozen steaks are means of 144 determinations, three per replicate.

[7]Values for fresh steaks are means of 144 determinations, six per replicate; values for frozen steaks are means of 288 determinations, six per replicate.

* Significant at P<0.05. ** Significant at P<0.01.

Table IX. Means and SE[1] for objective and subjective[2] measurements for beef LD steaks thawed at three temperatures after 10 days frozen storage.

Measurements	Thawing Method[3] RF	RT	OT	SE
Raw weight[4] (g)	335.3	341.6	347.3	9.77
Cooking time[4] (min)	20.5^{b}	20.3^{b}	36.6^{a}	0.95**
Total losses[4] (%)	16.92^{b}	16.85^{b}	18.64^{a}	0.27**
Drip in thaw[4] (%)	1.90^{a}	1.72^{a}	0.0^{b}	0.11**
Cooking losses[4] (%)				
Total	15.02^{b}	15.13^{b}	18.64^{a}	0.26**
Volatile	14.03^{b}	14.11^{b}	17.73^{a}	0.22**
Drip	0.99	1.02	0.91	0.10
Taste panel data[5]				
Softness	5.4	5.6	5.5	0.05
Juiciness	5.2^{b}	5.4^{a}	5.1^{b}	0.06*
Initial flavor	5.1	5.3	5.3	0.06
Tenderness	5.8^{b}	6.0^{a}	5.8^{b}	0.06**
Connective tissue	6.3	6.3	6.2	0.09
Meatiness	5.4	5.5	5.4	0.04
Overall acceptability	5.3^{b}	5.6^{a}	5.5^{a}	0.05**
Water holding capacity[6]	0.68	0.69	0.70	0.00
Shear force[7] (kg/1.3cm core)	3.2^{b}	2.9^{c}	3.3^{a}	0.02**

[1]Standard error.

[2]Highest possible score, 7 points.

[3]RF, refrigerator temperature; RT, room temperature; OT, oven temperature.

[4]Values are the means of 24 determinations.

[5]Values are the means of 24 judgments by each of six panelists.

[6]1.0-(expressible liquid index); the larger the value, the greater the amount of liquid expressed. Values are the means of 72 determinations, three per replicate.

[7]Values are the means of 144 determinations, six per replicate.

abc Values without a common letter in their superscript are significantly different ($P<0.05$).

* Significant at $P<0.05$. ** Significant at $P<0.01$.

Table X. Means and SE[1] for objective and subjective[2] measurements for beef LD steaks thawed at three temperatures after 187 days frozen storage.

Measurements	Thawing Method[3] RF	RT	OT	SE
Raw weight[4] (g)	332.4	334.8	341.6	9.00
Cooking time[4] (min)	26.0 b	27.0 b	44.6 a	0.92**
Total losses[4] (%)	17.94 b	17.98 b	20.39 a	0.28**
Drip in thaw[4] (%)	2.17 a	1.93 a	0.0 b	0.10**
Cooking losses[4] (%)				
Total	15.77 b	16.04 b	20.39 a	0.30**
Volatile	14.76 b	15.22 b	18.98 a	0.24**
Drip	1.03 b	0.85 b	1.43 a	0.10**
Taste panel data[5]				
Softness	5.3 a	5.3 a	5.0 b	0.06*
Juiciness	5.0 a	5.1 a	4.8 b	0.05**
Initial flavor	4.5	4.6	4.6	0.07
Tenderness	5.6 a	5.6 a	5.4 b	0.06*
Connective tissue	6.1	6.1	6.0	0.08
Meatiness	5.2	5.3	5.2	0.05
Overall acceptability	4.7	4.8	4.7	0.06
Water holding capacity[6]	0.75	0.74	0.76	0.00
Shear force[7] (kg/1.3cm core)	3.2 b	3.0 c	3.4 a	0.03**

[1]Standard error.

[2]Highest possbile score, 7 points.

[3]RF, refrigerator temperature; RT, room temperature; OT, oven temperature.

[4]Values are the means of 24 determinations.

[5]Values are the means of 24 judgments by each of six panelists.

[6]1.0 -(expressible liquid index); the larger the value, the greater the amount of liquid expressed. Values are the means of 72 determinations, three per replicate.

[7]Values are the means of 144 determinations, six per replicate.

abc Values without a common letter in their superscript are significantly different (P<0.05).

* Significant at P<0.05. ** Significant at P<0.01.

1	2	3	4	5	6	7
extreme		moderate on two sides approximately 1/3 of the steak affected OR one side, more than 1/2 of the steak affected		small patches one side		no visible sign

Figure 1. Scorecard for the sensory evaluation of freezer burn on frozen and stored raw beef LD steaks.

SCORECARD

JUDGE ____________

DATE ____________

SOFTNESS: is the lack of force required to compress a 1.3 cm cube of meat across the grain, between the molar teeth.

JUICINESS: is the amount of moisture in the mouth after 6 chews between the molar teeth.

TENDERNESS: is the number of chews required before a 1.3 cm cube of meat is completely masticated.

MEATINESS: is the intensity of the meaty flavor remaining in the mouth after complete mastication.

SAMPLE NO. ________

	7	6	5	4	3	2	1
Softness		cheddar		swiss			
Juiciness		mushroom		raisin			
Initial Flavor	very full, rich meaty characteristic		good full		slightly weak slightly off		lacking masked or unpleasant
Tenderness No. of chews ____	extremely tender	very tender	tender	slightly tough	tough	very tough	extremely tough
Amount and state residual connective tissue	no CT felt	tiny amount of soft CT	small amount of soft CT	small amount of firm CT	medium amount of firm CT	fairly large amount of firm CT	large amount of firm CT
Meatiness		45 milligrams %		35 milligrams %			
Overall Acceptability	extremely desirable	desirable	moderately desirable	acceptable	slightly undesirable	undesirable	extremely undesirable

COMMENTS:

Figure 2. Scorecard for the sensory evaluation of cooked beef LD steaks.