A COMPARISON OF PALATABILITY AND COOKING CHANGES OF BEEF STEAKS PREPARED BY FOUR METHODS

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Marcille Lamoine Pridgeon

1954

This is to certify that the

thesis entitled

A COMPARISON OF PALATABILITY AND
COOKING CHANGES OF BEEF STEAKS
PREPARED BY FOUR METHODS

presented by

Marcille LaMoine Pridgeon

has been accepted towards fulfillment
of the requirements for

M. S. degree in Foods

Pauline Paul

Date October 5, 1954

A COMPARISON OF PALATABILITY AND COOKING CHANGES OF BEEF STEAKS PREPARED BY FOUR METHODS

By

Marcille Lamoine Pridgeon

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Foods and Nutrition

1954

THESIS

ACKNOWLEDGMENTS

The writer wishes to express her deep appreciation to Dr. Pauline Paul for her interest, guidance and assistance throughout this study. Grateful appreciation is also extended to the food research staff for their assistance with the experimental work, and to each member of the taste panel for her aid in scoring the cooked meat.

A COMPARISON OF PALATABILITY AND COOKING CHANGES OF BEEF STEAKS PREPARED BY FOUR METHODS

By

Marcille Lamoine Pridgeon

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Foods and Nutrition

Year 1954

Approved by Pauline C. Paul

Four meat cookery methods were compared using the adductor and vastus lateralis muscle of the beef round. The methods compared were two braising methods, a dry heat method called "oven-cooking", and deep-fat frying. The muscles were dissected from the left and right rounds of six beef animals, graded U. S. Choice. Each muscle was cut into four 1-inch steaks. The steaks were weighed, wrapped in moisture-vapor proof cellophane, frozen and stored until 24 hours prior to cooking.

Steaks were cooked by all four cooking methods for each scoring period. A panel of five judges scored the steaks for aroma, appearance, tenderness, juiciness, flavor and general acceptability.

The change in moisture and fat content with cooking, the pH of raw and cooked samples and the percent cooking losses were determined. Objective measurements were made of volume and surface area changes with cooking.

The chief source of variation among the palatability scores was cooking method as shown by an analysis of variance made on each palatability factor. The variation in juiciness scores was assigned, however, to both cooking method and difference between muscles. The judges preferred the oven-cooked and deep-fat fried steaks over the braised steaks, as indicated by general acceptability scores.

There was a significant difference in cooking losses as a result of cooking method. The steaks cooked by braise I had the highest percent total cooking loss and the oven-cooked steaks had the lowest. The average weight of drippings plus water was greater for braised II steaks than for braised I steaks.

Results of objective tests were similar to the results of subjective scores. Correlations between shear force and tenderness scores and between juiciness scores and total moisture were highly significant. Volume and surface area changes followed the same general trend as cooking losses. However, a significant difference found between muscles for surface area changes was not present for total cooking losses and volume changes. Highly significant correlations were found between percent total cooking loss and volume change, percent total cooking loss and surface area change, and between volume change and surface area change. The pH values for cooked meat indicated that cooking method had an effect on the degree of change in pH with cooking. The oven-cooked steaks tended to be more acid while the deep-fat fried steaks were generally more alkaline than the braised steaks.

An analysis of covariance on the fat data showed that there was a difference in the fat content of cooked samples due to cooking method. The deep-fat fried steaks showed quite a definite increase in fat content with cooking.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF FIGURES

INTRODUCTION

All laboratory experimental work requires that the investigator follow particular methods of procedure. In meat cookery, roasting is the only method that is well established. Years of experimentation with various roasting procedures have resulted in one generally accepted cooking method. This is not true, however, for other methods of cooking meat. Rather recent investigations in several laboratories have resulted in a number of tentative methods for cooking steaks, particularly those from the round of beef.

It was the purpose of this study to compare four cooking methods, in an effort to contribute some information that might lead to greater standardization of braising, deep-fat frying and dry heat cookery methods for beef steaks.

REVIEW OF LITERATURE

Characteristics of Beef Muscle

Structure

Skeletal muscle is surrounded by fibrous tissue called epimysium, which is continued into the muscle as the perimysium and breaks the muscle into bundles of fibers called fasciculi. Each fiber is surrounded by connective tissue called endomysium and has its own thin, colorless, elastic covering membrane, the sarcolemma (6, 43).

Composition

The two types of protein found in muscle are (a) structural proteins, consisting largely of collagen and elastin and (b) intercellular proteins. The principal intercellular proteins are myosin, actin, myogen and globulin X (6). These proteins coagulate on cooking at a temperature of about 65° C.

According to Cover (23), the toughness of meat can be attributed to two structures, muscle fiber and connective tissue. Lowe (43) states that the toughness of connective tissue depends upon its thickness and density, upon the proportion of collagen to elastin and possibly upon animal age.

Investigators seem to agree that collagen is changed to gelatin by heat in the presence of water. According to Bendall (11) this conversion takes place in three stages: (a) conversion of collagen A to collagen B which occurs at 56-60° C. and results in the shortening of collagen fiber, (b) the uptake of water by collagen B and consequent swelling and softening of the connective tissue and (c) the dissolution of collagen B to form a gelatin sol. The third step occurs only if cooking at 100° C. is abnormally prolonged or in pressure cooking at temperatures above 100° C.

Bogue (12) found that the hydrogen-ion concentration of the hydrolyzing solution, the temperature of heating and the duration of heating affected the hydrolysis of collagen to gelatin. Hydrolysis was slowest at a pH of 4.5 to 6.0. A temperature of 80° C. seemed to be most favorable for conversion of collagen and a heating period of eight hours was needed for complete softening of connective tissue.

Strandine, Koonz and Ramsbottom (62), after a chemical analysis of beef and chicken muscle, concluded that the chief cause of variation in tenderness of muscle was the difference in structure and arrangement of the constituent anatomical elements, the difference in structure within the muscle fibers, or both factors. They felt that these causes had greater effect on tenderness than did pH, fat, total protein or moisture. In a classification of beef muscles on the basis of bundle size and connective tissue pattern, they described the vastus lateralis muscle as being composed of small fasciculi having very thin perimysium, and containing a medium amount of both collagenous and elastic connective tissue. The adductor was found to be a muscle with indistinct fasciculi and very uniform texture, to contain a medium amount of collagenous connective tissue and only small amounts of elastic tissue. In general, muscles with distinct fasciculi and abundant connective tissue were found to be much less tender than those with smooth or homogeneous patterns. The vastus lateralis and adductor muscle of the beef round were chosen for the experimental work in this study.

Factors Affecting Cooking Losses and Palatability

After many years of study and investigation of meat cookery, it has been shown that many factors are responsible for losses from meat on cooking. These, in combination, result in shrinkage of animal fibers and loss of nutritive value. Some of the major contributing factors are freezing, grade of carcass, muscle, aging, temperature of cooking and degree of doneness.

Effect of Freezing

During the freezing of meat, ice crystals are formed which expand the muscle and put the center under pressure.

Ice crystals may rupture the tissue somewhat depending on the freezer temperature and time of storage (15, 43). Since there is some tissue damage, a frozen steak on defrosting has a tendency to drip. Callow (15) found thawed frozen meat to have a more open microstructure than fresh meat, therefore leading to a greater loss of fluid. The percentage of drip and loosely held muscle fluid as reported by Empey (29) was less in muscles having a relatively low concentration of hydrogen ions. Drip was reduced by increasing either the osmotic pressure or the pH or both, prior to freezing.

In a study using the 9-10 and 11-12 rib roast, Paul (52) found that unfrozen beef had a significantly lower total cooking loss than frozen beef, when roasts were cooked to an internal temperature of 58° C, uncovered in a 175° C. oven. Unfrozen beef also had a significantly higher press fluid content than frozen thawed beef. Orr (50), however, using frozen steaks from the longissimus dorsi muscle versus unfrozen steaks, found no appreciable effect in total cooking loss through freezing. Any difference in losses was attributed to difference in total cooking time.

It is generally agreed that freezing makes beef more tender. In comparing frozen and unfrozen beef loin steaks, Hankins and Hiner (36) found increased tenderness with steaks frozen at -10° F. and -40° F. These temperatures had greater tenderizing effect than +20° F.

Effect of Grade

Several investigators have found that the grade or quality of the carcass affects the palatability of cooked meat. This was especially marked when Good or Choice grades were compared with Commercial or Cutter grades (3, 25, 37, 66). After comparing the longissimus dorsi muscle of U. S. Good, U. S. Commercial and U. S. Utility grade beef by roasting, Day (25) reported significant differences in grade for aroma, flavor and tenderness. No consistent pattern was noted for juiciness and no significant difference was found for appearance and texture of the three grades.

Aldrich and Lowe (1) found no significant difference between U. S. Choice and U. S. Good grades, except for a slightly higher percent of press fluid in the choice grade. Six muscles of the beef round were cooked by moist heat for this study.

In a study of beef tenderness, Paul and co-workers (51) concluded that cooking losses were not appreciably affected by grade. Two prime, two good and two commercial animals were used in this study. The meat was cooked by oven roasting and deep-fat frying.

Effect of Muscle

Where muscles from the same animal have been compared by the same cooking method, investigators have concluded that there is a definite difference in palatability factors between muscles and in some cases differences within the same muscle (1, 13, 26, 54, 55, 57, 58, 62).

Satorius and Child (58) reported that coagulation of the protein of meat did not affect the tenderness of the triceps brachii and adductor but the longissimus dorsi became more tender with coagulation. In a second study using the same muscles (59), the adductor required more pounds of force to shear than the other two muscles and was found to contain a smaller number of muscle fibers per bundle when examined histologically. The press fluid did not vary significantly among the cuts but the triceps brachii contained more total moisture than the longissimus dorsi. The adductor had the greatest cooking loss and graded lowest in texture, tenderness, and quality and quantity of juice.

Brady (13) made a histological study of the same three muscles used in the above study and reported no significant difference in the diameter of different muscle fibers but a significant difference in the number of fibers per bundle. The adductor contained 138 fibers per bundle compared to 260 for the longissimus dorsi and 254 for the triceps brachii.

The vastus lateralis muscle of veal is described by Paul and McLean (54) as a muscle containing a large amount of connective tissue, having many collagenous fibers and a medium number of elastic fibers. The fasciculi were not parallel. Fatty tissue was noticeable within the muscle.

Ramsbottom (55) found the vastus lateralis of U. S. Good beef to contain medium amounts of both elastin and collagen. He described the muscle as being "slightly tough".

In comparing the tenderness of representative beef muscles, graded U. S. Good, Ramsbottom (57) reported the following shear force readings using the Warner Bratzler shearing machine: adductor (cooked), 10.6; vastus lateralis (cooked), 11.3; adductor (raw), 5.2; and vastus lateralis (raw), 5.8. Brady (13) found a much higher average shear force reading for the adductor (25.5), but his study included both cows and steers.

Effect of Aging

The primary effect of aging on meat seems to be changes in tenderness and flavor. It is thought that increased tenderness with aging is due to an effect upon muscle fibers. Aging also results in an increase in soluble protein products which when heated play an important part in the flavor of meat (39).

Orr (50) concluded that appearance, aroma and juiciness were little affected by cold storage and that flavor of fat, flavor of lean, texture and tenderness were more noticeably affected.

Studying the histological, physical and organoleptic changes in three grades of beef during aging, Harrison and co-workers (37) found the aroma and flavor scores reached their maximum within 10 days of aging and decreased after 30 days of aging. Aging of roasts increased tenderness as indicated by shear force and judges' score. Griswold (34) was able to find only small differences in flavor and tenderness of meat aged 9 and 37 days at 34° F. Deatherage (28) reported increased tenderness of U. S. Good and U. S. Choice loins until 17 days, with no improvement or a decrease in tenderness at 24 days, and some improvement at 31 days over 17 days.

Work that has been carried on concerning the tenderness of beef carcasses immediately after slaughter has shown varying results. Ramsbottom and Strandine (56) stated that beef was more tender two hours after storage than at any time after from two to six days. By the 9th to the 12th day after slaughter the beef had improved in tenderness so that it was more tender than two hours following slaughter. Paul and co-workers (52), however, found that roasts cut from the semitendinosus and biceps femoris muscle of beef were less tender immediately after slaughter, and that tenderness increased with storage. Beef steaks, they found, were tender immediately after slaughter, became less tender with cold storage up to 24 hours, and returned to approximately their original tenderness with storage of 144 to 149 hours.

Alexander (3), roasting lamb at various stages of aging, reported that increasing the ripening period after slaughter decreased the cooking shrinkage and shortened the time required to roast leg of lamb. Cooking losses tended to increase with storage through 24 hours and then remain constant, according to Paul and co-workers (51) from their study on the aging of beef.

<u>Effect of Temperature of Cooking and Degree of Doneness</u>

It is well known that cooking of any type causes meat to shrink. Shrinkage may be due to some change in the fibrous tissue or to coagulation of the muscle fiber. According to Andross (6) this shrinkage takes place during the first 15 to 20 minutes of heating, owing to expulsion of water, the process being greatest in boiling and stewing. Roasting and grilling he states also cause a loss of water by evaporation and some shrinkage.

McCance and Shipp (46) stated that muscle tissue shortens without change in volume or loss of weight when heated to 40° C. At 60° C., however, there is loss of weight caused by increased shrinkage of the meat proteins, resulting in expression of juices.

It is quite well accepted by most investigators that a low oven temperature, especially for roasts, results in smaller cooking losses and juicier meat (3, 4, 19).

The internal temperature to which the meat is cooked has also been shown to have a marked effect on cooking loss and palatability (16, 23, 53). In general, with dry heat cookery, juiciness and tenderness decrease with increasing internal temperature. Lowe and co-workers (44) found little difference in juiciness scores or percent of press fluid of beef roasts cooked at oven temperatures of 120° C., 150° C. or 175° C., provided the roasts were cooked to the same internal temperature.

The Effect of Method of Cooking on Palatability and Cooking Losses

Roasting

After many years of study, roasting in the oven by dry heat is quite standardized. This method for roasting has resulted in a palatable meat with a minimum of cooking losses, maximum retention of nutritive value and a minimum cost per serving.

Numerous studies have been made on meat since Grindley and co-workers (37) first studied the losses involved in meat cookery in 1898 at the University of Illinois. Their initial study involved the nature and extent of cooking losses, nutritive value of meats, changes taking place in various cooking methods and the influence of cooking upon the flavor and palatability.

These workers concluded that the chief loss in weight during the boiling, sauteeing and the pan-broiling of meat is due to loss of water and fat. They also reported that the longer the time and the higher the temperature of cooking, other factors being the same, the greater the losses resulting (33).

Aroma, appearance and flavor. One of the characteristic changes produced by cooking meat is a change in color (43). This change is due to an alteration in myoglobin; the myoglobin becoming denatured, changing from red to pink, and then to brownish grey (6).

Variation in aroma in roasting studies has been attributed to grade (25) and to length of frozen storage (44); the longer storage meat having lower aroma scores.

Latzke (41) reported that high roasting temperatures of 150° C. to 175° C. resulted in a browner, more pleasing color but palatability was sacrificed.

The cooking of animal muscle results in a "meaty" flavor apparently owing to chemical changes taking place in the fiber rather than in the juice. This "meaty" flavor according to Crocker (24) is due to volatile substances detected by the sense of smell, even though chewing is needed to release them. He states that beef flavor is complicated chemically and consists more of odor than taste. It is thought that the flavor of meat created by low temperatures is due to the cracking of amino acid units of protein, particularly those of the fiber. Meat cooked at low temperatures retains all of the salts and sugars noted in the raw meat and therefore is more flavorful.

Andross (6) stated the flavor of meat was the summation of three factors: (a) odor affecting olfactory organs, (b) taste, affecting the taste buds of the tongue and buccal surfaces, and (c) texture.

<u>Tenderness</u>. Many studies of the roasting of meat have shown that a low oven temperature for all or a majority of the roasting period results in greater tenderness (3, 4, 19, 22).

Using constant oven temperatures of 125° C. and 225° C. for roasting various cuts of beef, Cover (23) reported greater tenderness for roundbone chuck and rump cooked at the lower temperature as judged by a scoring panel. Rib roasted at the lower temperature was preferred by 69 percent of the judges. No significant majority was in favor of the low temperature for lamb. The author felt that the difference in tenderness results might be due to the longer time of cooking and not just the oven temperature.

Satorius and Child (58) compared the tenderness of individual beef muscles. With increasing internal temperature the semitendinosus was found to be more tender until 75° C. was reached, when it was found less tender than that cooked to 67° C. The authors stated that from 58° to 67° C. collagen was being hydrolyzed with some coagulation of protein but from 67° C. to 75° C. muscle protein increased in density and decreased in tenderness. The diameter of the muscle fibers decreased with increasing temperature to 67° C. No difference was noted in diameter of fibers at 75° C.

Noble and workers (49) reported that toughening of beef muscle took place during heating from 61° C. to 75° C., as shown by penetrometer readings.

Juiciness. Lowe (44) reported juiciness scores were influenced by the kind of roast, whether boned or not, the stage of cookery and the oven temperature. That is, the lower the internal temperature and oven temperature, the juicier the cooked meat. A greater amount of fat in a roast has also been found to increase juiciness (7, 30, 60, 66). Barbella (7) concluded that the juice of beef rib roasts increased quite rapidly with increase in fatness to 22.5% fat and more slowly to 42.5%, after which there was no apparent effect.

Cooking losses. Cooking losses during roasting are affected primarily by cooking temperature, degree of doneness, and composition of meat (33, 41, 44, 64). The higher the internal temperature and the higher the oven temperature the greater the cooking loss. Thille (63) reported that the greater the degree of surface fat, the larger the cooking loss. Satorius and Child (59) found the opposite true, however. It appears that a layer of fat not in excess may help hold in juices and not contribute greatly to drippings, while a large layer of fat on melting will increase cooking losses considerably. Grindley and Mojonnier (53) stated that in the roasting of meat the chief loss was due to the removal of both fat and water.

The semitendinosus muscle was found by Child (17) to have a 24% to 37% cooking loss when cooked to an internal temperature of 75° C., while an internal temperature of 58° C. yielded a loss of only 9% to 15%. An average loss of 27% for well-done lamb roasts was reported by Alexander (3). The adductor muscle averaged a cooking loss of 18.24% when cooked by roasting to an internal temperature of 58° C. (59).

Braising

Braising is browning meat and cooking slowly in a covered utensil in a small amount of liquid (5).

Aroma, appearance and flavor. Using temperatures of 90° C., 90° C. + 40 minutes, 90° C. + 50 minutes and 90° C. + 120 minutes for beef pot roasts, Lowe and workers (44) found aroma and flavor scores varied only slightly. Cline (18) reported little change in flavor in heel of round pot roasts, braised with or without water. Tests made on 88 pairs of less tender cuts from U. S. Medium grade beef cattle showed the flavor of the lean to be more desirable when braised to internal temperatures of 75°-85° C. than when oven roasted (18).

Aldrich (1) found an internal temperature of 90° C. + one hour for pot roasts resulted in the development of undesirable sulphury flavors, undesirable odors and a loss of attractive appearance. The meat braised to an internal temperature of 90° C. was found to be more acceptable.

<u>Tenderness</u>. The few braising studies that have been conducted have shown that long cooking periods have a slight tenderizing effect on meat (1, 18, 44). This was thought to be due to greater conversion of collagen to gelatin. As braising studies were generally performed on cuts containing considerable amounts of connective tissue, this reason seems probable.

Cline (18) reported heel of round cuts braised with water, to be slightly less tender than cuts braised without water. The cooking period, however, was shortened when water was added. Pork chops braised without added water scored higher in all palatability factors including tenderness when compared to chops braised with added water (47).

<u>Juiciness</u>. In general, braising methods resulted in greater cooking losses than other cooking methods described in several studies. Therefore, braised meat was found to be less juicy (18, 48, 60, 67). Cline's (18) results on less tender cuts of U. S. Medium beef braised to varying

internal temperatures from 75-85° C. were not in agreement. She found decreased cooking losses, decreased cooking time per pound and a slightly more juicy meat when the cuts were braised rather than oven roasted. Most investigators cooked their meat to higher internal temperatures, however.

Low juiciness scores and high weight losses for all braised meat were reported by Lowe and workers (44). Long holding periods after pot roasts had reached 90° C. resulted in drier meat than roasts cooked to just 90° C. (1, 44).

Cooking losses. As was mentioned earlier, the cooking losses of braised meat are large. Experiments on braising that have been reported in the literature showed a cooking loss of 33-40% (1, 44, 65).

The longer the meat was braised the higher the internal temperature up to the maximum, and the greater the cooking losses (1, 44, 60). The reason for higher internal temperatures and longer cooking periods than for other cooking methods was the need for the softening of larger amounts of connective tissue.

Broiling

Broiling is to cook by direct heat (5).

Aroma, appearance and flavor. Lowe (44) stated broiler temperatures of 150° C. and 175° C. produced attractive looking steaks while a 200° C. temperature resulted in considerable charring. The higher temperature also produced steaks of poorer flavor. Hayes (38), however found the 200° C. oven to give more attractive steaks than either a 175° C. or 250° C. oven. She worked with 1-inch steaks, broiled to an internal temperature of 58° C., three inches from the heat, while Lowe broiled 1-inch steaks two inches from the heat and 2-inch steaks four inches from the broiler unit, to internal temperatures of 58° C. and 75° C.

McLachlan (47) reported a 225° C. oven produced steaks which were rated higher for aroma and appearance but lower for flavor than steaks cooked in a 175° C. oven.

Tenderness. Cline (21) found the porterhouse and rib steaks to be more tender than sirloin or round. The range of the judges' tenderness scores was 2.8 to 6.8 with 2.8 being the score for the center muscle of the bottom round. Averages for the tenderness of the round were 4.0 or "slightly tough" as indicated by the score sheet. In a second study Cline (20) found the rib and round less tender than the porterhouse and sirloin. The muscle of the bottom round graded low in tenderness even in the steer and heifer.

McLachlan (47) reported broiling temperature had an effect on the tenderness of steaks from the beef loin. Steaks broiled at an oven temperature of 175° C. required fewer pounds to shear than steaks broiled at 225° C.

Porterhouse steak was reported the most tender in this study. Cline's (20) "modified roasting method" which consisted of searing the steak with one turning in a closed gas broiler, pre-heated to 500° F. and transferring to a gas broiler set at 275° F., produced a more tender steak than the constant oven broil of 350° F.

Lowe and workers (44) felt there might be a trend for well-done steaks to be scored less tender than those cooked to a lower internal temperature.

Juiciness. Steaks broiled at an oven temperature of 225° C. were juicier than steaks broiled at 175° C., according to McLachlan who cooked steaks from the beef loin to an internal temperature of 58° C. Lowe and workers (44) compared medium-done loin steaks to well-done steaks and reported the well-done steaks were always scored less juicy. They recommended broiler temperatures of 135° C., 150° C. and 175° C. for all palatability factors. Lower temperatures did not improve palatability and required a longer time for cooking. The 200° C. temperature was considered acceptable for 2-inch steaks.

Cooking losses. The cooking losses of broiled beef steaks seem to be dependent, in general, on the final internal temperature and the broiler temperature (38, 44, 47, 65).

Lowe and workers (44) found, as did Tucker (65), that well-done steaks always lost more weight in cooking than less well-done steaks. Lowe reported a 35% greater weight loss in well-done steaks, than medium-done steaks, while Tucker reported an average weight loss of 28% for well-done loin steaks and 20% for the same steaks cooked rare to medium-done.

McLachlan's (47) results for her work on porterhouse, club and sirloin steaks showed a 225° C. oven temperature gave greater cooking losses than a 175° C. temperature. The range for the percent total loss for the higher temperature was 25.36% to 28.24%, and 20.14% to 25.36% for the lower temperature. Hayes (38) agreed that a 250° C. oven resulted in greater cooking losses than a 175° C. oven.

Cline (21) compared the percent cooking loss of rib, porterhouse, sirloin and round steak with results showing that cooking time and thickness of the steak influenced losses. Her data showed a loss of 17.93% for the round as compared to 21.24% for rib, 21.42% for porterhouse and 23.95% for the sirloin. The round steak was not as thick as the other steaks compared, therefore a shorter cooking time and a smaller cooking loss resulted.

Deep-fat Frying

Deep-fat frying is cooking in a deep layer of fat (5). Little has been reported in the literature on cooking losses and palatability of meat as affected by a deep-fat frying method.

Temperature of fat. Temperatures that investigators have used for fat in which meat has been cooked are quite varied. Ramsbottom, Strandine, and Koonz (57) cooked beef in lard at 121.1° C. Harrison and workers (37) used a temperature of 96-98° C. for the lard in which they cooked beef roasts. Orr (50) fried beef steaks in vegetable shortening at 150° C. According to Lowe and workers (44) 135° C. and 150° C. were found to be the best temperatures for deep-fat frying beef patties.

Palatability. Lowe and workers (44) reported that beef patties fried in deep-fat had a browner, crisper crust than patties fried in shallow fat. They also found considerable variation in the palatability scores of shallow and deep-fat fried meat.

Cooking changes. McCance and Shipp (46) thought that in deep-fat frying the evaporation of moisture from the meat must be intense since the flesh is surrounded by a liquid immiscible with water at a very high temperature. They reported the loss of salts quite small, however. Orr (50) reported cooking losses of 17.96% to 23.53% for unfrozen longissimus dorsi steaks aged from 0 to 167 hours and cooked in deep-fat to an internal temperature of 63° C.

Shallow-fat Frying

A few investigators have been interested in shallow-fat cookery for meat. A very early study on the sauteeing of meat resulted in the conclusion that meat lost 2.15% of its nitrogenous matter and 3.07% of its ash in the fat in which it was cooked, while cooked meat contained 2.3 times more fat than before cooking (33). Tucker (65) determined the total cooking loss of round steaks fried in shallow fat to be 15%, 14% being volatile loss.

Methods of Evaluating the Palatability of Meat

Subjective Methods

Although investigators have recognized the limitations of a taste panel for judging the palatability of food, there are still factors which cannot be judged objectively. In the case of meat, color, aroma and appearance are better scored by a taste panel and are important factors in determining flavor (6, 24). Juiciness and tenderness are usually analyzed both subjectively and objectively and a highly significant correlation is often found between the two methods of testing (13, 19, 25, 27).

Objective Methods

Several tests have been developed for measuring physical characteristics and determining the chemical composition of meat. Some of the primary objective tests used for meat investigations are shear force, pH readings, volume and surface area changes, fat determinations and moisture determinations.

Shear force. Mechanical methods for testing the tenderness of meats have been used for a number of years (42). Bratzler (14) developed in 1930 a shearing device which he tested on roast rib of beef and concluded there was a definite correlation between the shearing values and the judges' scores.

In 1934 Lowe (42) compared the differences in the Standard New York testing laboratory type penetrometer and the dynamometer designed by Bratzler. The correlation coefficient calculated for the two devices was not significant for raw, rare and well-done meat. The author felt a shearing device held greater promise than the penetrometer for measuring the tenderness of meat.

Recent studies have made considerable use of the Warner-Bratzler shearing device as a tenderness measure (1, 25, 45, 55, 57). This device, which measures the number of pounds of force required to cut through a core of meat of specified diameter, has proved satisfactory in many experiments. Several investigators have reported high correlations between shear force results and tenderness scores. Deatherage and Garnatz (27), however, were not in agreement

with these results. They found the differences in shear force in pounds were not as great as differences in taste panel scores. Correlation coefficients were not significant. These authors felt that tenderness scores and shear strength did not measure the same property of meat and that shears may be only related to tenderness.

pH. According to Bate-Smith (10) the pH reached by meat at the completion of rigor mortis depends on three factors (1) the initial pH, (2) the glycogen content of the muscle at the moment of death, and (3) the buffering power of the muscles. The normal initial pH of raw beef muscle has been found to range from 5.42 to 5.80 (66). Meat, on cooking, becomes more alkaline (8, 11, 15, 31, 50). Bendall (11) reported a rise of .30 on the heating of chuck steak. The same rise was noted 10 minutes after heating at 100° C., after one hour at 100° C. and after 3 hours of pressure cooking at 126° C. Bard and Tischer (8), in their study, found the pH value of raw beef to range from 5.52 to 5.61 and to increase from 5.95 to 6.05 after 40 to 120 minutes of processing.

It has been shown that shrink in cooked meat is less when the pH is high than when it is low (15). A high pH also decreases the tendency for thawed muscle to drip (9, 29).

Winkler (68) concluded that toughness in pork was at a maximum at 5.0 to 6.0 and that with either a higher or lower pH the meat was progressively more tender. Results from beef studies were similar but the authors felt that maximum toughness range was at a lower pH.

Volume and surface area. Changes in volume have been determined for roasts by measuring their length, width and depth before and after cooking, and by water displacement tests (1, 25, 37). Harrison (37) found that all roasts decreased in width and all but one increased in thickness. Aldrich's (1) results for pot-roasts were very similar. According to McCance and Shipp (46) muscle tissue shortens without change in volume or loss of weight when heated to 40° C. At 60° C., however, there is loss of weight caused by increased shrinkage of the meat proteins causing expression of juices. Aldrich (1) found volume losses followed the pattern of total cooking losses. Marked decreases in volume and dimensions of all cuts were noted at 90° C. Braising roasts to an internal temperature of 90° C. plus one hour resulted in volume losses of 25.3%, while braising to an internal temperature of 90° C. resulted in a 19.6% volume loss.

In cooking small cuts such as steaks, the change in surface area is used as an indication of change in muscle fiber diameter. Fluid is lost from muscle fibers as the weight and volume decrease (43). Satorius and Child (58) found the diameter of muscle fiber to decrease with increasing temperature to 67° C. No decrease in the diameter of muscle was observed from 67° C. to 75° C. It could be concluded that this shrinkage was complete at 67° C. for that particular cooking method.

Moisture. Grindley and Emmett (31), as early as 1905, obtained about 34% of the juice from raw meat by grinding and then pressing the meat in a compound screw press. The first mechanical device, however, for the determination of the moisture in cooked meat was developed by Child and Baldelli (17) in 1934. This instrument, called a pressometer, was used to extract muscle fluid from meat by subjecting small samples to a pressure of 250 pounds. Child and co-workers used the pressometer in several cooking studies.

Tanner and co-workers (63) described a method of determining juiciness of cooked meat by means of a hydraulic laboratory press. Correlation coefficients calculated between committee scores and percent of expressible juice were relatively low when the hydraulic press was used to extract juice from beef muscle cooked to 58° C. internal temperature. Their study showed that the type of meat scored by the judges made a difference. When beef, pork, and lamb containing the same percentages of press fluid were rated by the judges, beef samples received the highest scores for juiciness.

Several investigators have been interested in the total moisture content of raw and cooked meat, rather than, or in addition to, press fluid (55, 58, 59). Most of the workers reporting a method of determining moisture have dried samples in an air oven plus additional drying in a vacuum oven, or completely dried samples in a vacuum oven. The percent moisture was calculated by difference in weight of the original and dried sample. In several studies at Michigan State College, meat samples have been dried in a forced air apparatus*, as a method of determining total moisture.

Grindley (33) reported the average percent moisture of beef round as being 75.53%. Satorius and Child (58) found the adductor to contain 73.57% moisture, which decreased during roasting to 70.46%. The roasts were cooked to 58° C. The vastus lateralis muscle contained 73.9% moisture according to Ramsbottom (55). Other muscles of the round have been reported to be 74.4% and 73.3% moisture (55, 60).

<u>Fat</u>. In general two types of chemical methods are used for the determination of fat in meat. In the first, dried material is extracted with a suitable solvent, usually ether, in a continuous extraction apparatus, the solvent then evaporated, the residue weighed and reported as fat.

---

* Brabender semi-automatic moisture tester

In the second method the material is saponified and the fatty acids which are set free are estimated by suitable means (46).

The ether extract method was used by the majority of the investigators reporting in the literature since they were interested in the total fat content of meat rather than the fatty acids only.

Barbella and workers (7) found the fat content of beef rib roasts varied from 7.5% to 57.5%. The whole beef carcass averaged 10.95% fat according to Grindley and Emmett (31). Andross (6) found fat to vary from muscle to muscle, the sirloin having 27% fat, the fillet 22%.

Fat determined on the wet basis showed a range of 2.47% to 3.49% for muscles of the round of beef (57, 58, 59).

EXPERIMENTAL PROCEDURE

Description of Experiment

Four cooking methods were compared using the adductor and vastus lateralis muscle of the beef round. The methods used were a dry heat method called "oven cooking", two braising method, and deep-fat frying.

The rounds of six beef animals were secured from a local meat packer after aging from 10 to 14 days. The two muscles to be used in this study were dissected from the left and right round of each animal. All animals were graded U. S. Choice.

The muscles were cut into 1-inch steaks. Steaks were compared both objectively and subjectively. One muscle was cooked for each scoring period using all four cooking methods. The cooking treatments were assigned to the muscles so that each two treatments would appear together twice on paired steaks (Figure 1).

Preparation of Samples

Both muscles of each animal yielded four pairs of 1-inch steaks. Two adjacent steaks were used for each cooking treatment. All steaks were wrapped with a drugstore

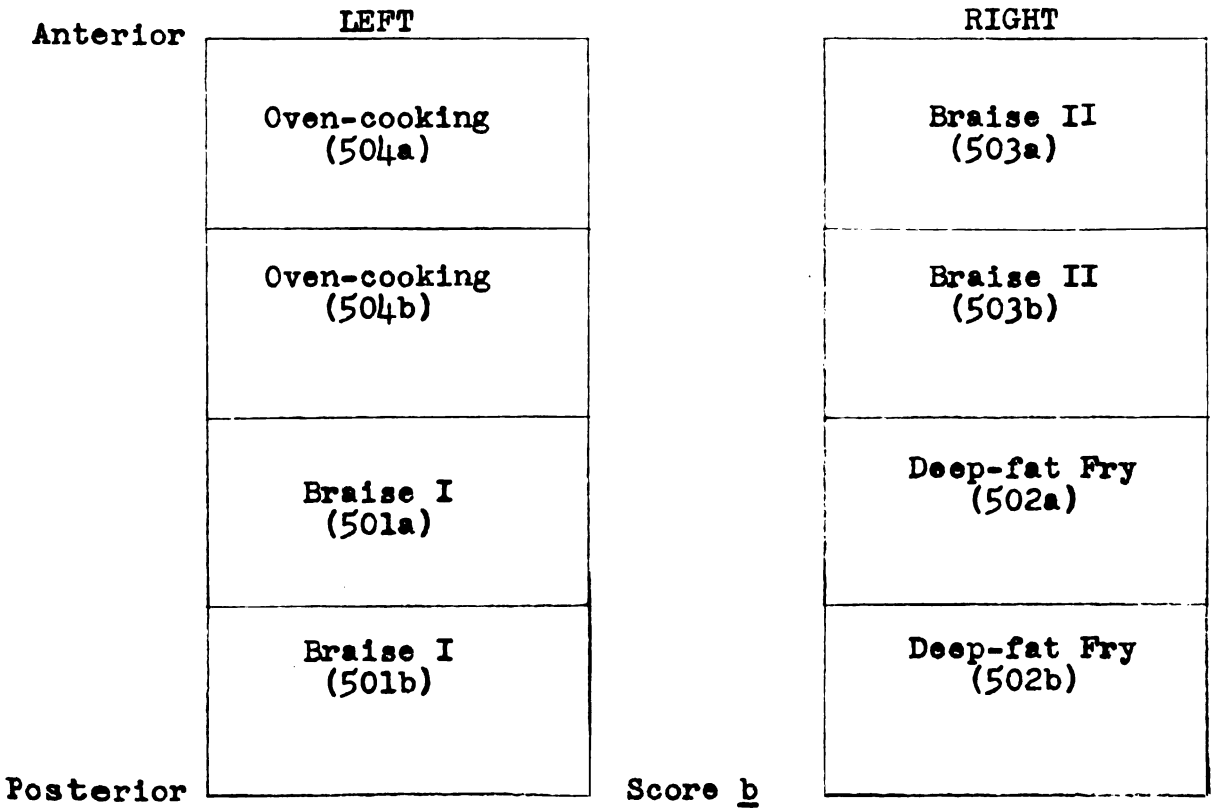


Fig. 1. Paired rounds cut into 1-inch steaks. Cooking methods assigned in pairs.

wrap in cellophane, sealed with scotch tape, labeled and frozen. Each steak was weighed before and after wrapping.

The storage period for the steaks ranged from 33 to 110 days, the vastus lateralis muscle having the longest storage.

Each steak was allowed to thaw 24 hours in the laboratory refrigerator before cooking. The weight of each frozen wrapped steak was recorded, in order to check on any weight losses during frozen storage.

General Procedure

It was necessary to use two steaks for each cooking method, since one steak did not yield enough material for both subjective and objective tests on raw and cooked samples.

After recording the weight of each thawed steak, one of the two steaks used for each cooking method was halved. The steak to be halved was chosen at random (Figure 1). The half steak was wrapped securely in cellophane, sealed with scotch tape and returned to the refrigerator to be used later for moisture and fat determinations, and pH readings. The remaining one and one-half steaks were weighed as one steak and the weight recorded for determination of total cooking loss. The one-half steak, which was cooked, was used for determination of volume and surface area loss in cooking, part of the shear values and pH. The center of the whole cooked steak was sliced for judging, and the remainder reserved for moisture and fat determinations (Table 1).

The volume and surface area of each half steak was determined before cooking by methods described later in this section.

Thermometers were inserted into the thickest portion of the lean tissue to record initial internal temperature, temperature rise during cooking and maximum temperature reached.

The following data were recorded for each set of steaks: weight before and after cooking, size and thickness, cooking time, temperature during cooking, maximum internal temperature, cooking loss in grams and percent cooking loss.

TABLE 1

USE OF TWO ADJACENT STEAKS COOKED BY EACH METHOD

One steak (cooked)	One-half steak (cooked)	One-half steak (raw)
Subjective scoring	Surface area	Total moisture
Total moisture	Volume	Fat content
Fat content	pH	pH
Shear	Shear	

The internal temperature when placed in the oven, volume of water added and weight of water plus drippings were recorded for the braised steaks.

Methods of Cooking

Two methods of dry heat cookery and two methods of moist heat cookery were used in this study. Steaks were cooked to the internal temperature found most satisfactory in previous studies for the particular method. The internal temperature to which steaks were cooked differed for each cooking method. Since investigators have found that the internal temperature of meat continues to increase after removal from the oven, maximum temperature rise was recorded. A time-temperature curve was made for each cooking method.

<u>Braise I</u>

This method was developed by the Michigan State College food research laboratory and found to be preferable to other braising methods tested on particular muscles of the beef round.

The steaks were browned one minute on each side in a heavy Dutch oven, preheated to 246° C. on an electric range. A griddle thermometer was used to determine the temperature of the Dutch oven. A rack with 1/2-inch legs was placed under the steaks. Fifty ml. of water was added, the pan covered and transferred to a gas oven set at 121° C. The steaks were cooked to an internal temperature of 98° C.

plus one-half hour beyond the time of reaching 98° C. The final temperature reached was 99.5° C.

Braise II*

The steaks were browned three minutes on each side in a heavy Dutch oven, which had been preheated to 232° C. on a thermostatically controlled electric grill. A griddle thermometer was used to regulate the temperature of the Dutch oven. A rack with 1/2-inch legs was placed under each steak, 50 ml. of water added, the pan covered, and transferred to a gas oven set at 121° C. The steaks were cooked to an internal temperature of 80° C. The maximum temperature reached was 84-85° C.

Oven-cooking

A rack having 4-inch legs was preheated 15 to 20 minutes at 232° C. in a gas oven, over a pan 1-inch deep. The steaks were placed on the preheated racks and cooked to an internal temperature of 71° C. Maximum temperature reached was 72° C.

Deep-fat Frying

Fifteen pounds of fat** was heated to 150° C in an electric deep-fat fryer. The steaks were placed on edge

* Method used at MSC for work under BHNHE contract A1S-31905.
** Vegetable shortening without added emulsifier

in the fat, against the side of the frying basket, so that the thermometer was out of the fat. All steaks were cooked to an internal temperature of 65° C., then drained one minute per side on brown paper toweling to remove excess fat. The maximum temperature reached was 72° C.

Palatability Scores

A panel of five judges from the Foods and Nutrition Department scored the steaks for appearance, aroma, flavor of lean, juiciness, tenderness and general conclusion. The highest possible score was ten and the lowest one, for each factor. A sample score sheet is shown on page 94 of the Appendix.

Five 1/8-inch slices were cut from the center of each warm steak. The slices were cut across the width of each steak with the grain. Each slice was divided into three parts, the center piece being as nearly uniform in size as possible and used for recording the number of chews. Each judge was given one slice for scoring, with the whole steak being available for rating aroma and appearance. Four steaks cooked by the four cooking methods were scored each time, the order of judging being randomized for each scoring period.

Objective Tests

Shears

Five to seven half-inch cylindrical cores were taken from steak cooked by each method. Cores were sheared on a Warner-Bratzler shear stress apparatus. The readings from each steak were averaged.

Volume

The average weight of a quart saucepan of water was calculated after many preliminary weighings. A string was tied around each steak and the steak lowered into the filled pan of water, causing the water to overflow. The exterior of the pan was wiped free from water, the pan weighed and the weight recorded. This weight was subtracted from the initial weight, thus giving the weight in grams of water displaced. This test was used before and after cooking, the difference in water weight recorded and the percent change in volume by cooking calculated.

Surface Area

The shapes of the raw and cooked steaks were drawn on brown paper, traced on onion skin paper and measured with a planimeter. The percent change in surface area by cooking was calculated.

pH

A pH reading was made for both raw and cooked steaks. A five gram sample of meat was minced with a sharp knife, added to 45 ml. of distilled water and allowed to stand 20 minutes. The liquid portion was decanted and the pH of the liquid determined with a Beckman pH meter. Duplicate readings were made on each steak.

Total Moisture

The samples reserved for moisture content were tightly sealed in moisture-vapor proof cellophane and placed in a refrigerator. The maximum time any sample was held was 27 hours.

Preliminary work showed that a more homogeneous sample resulted if the meat was blended with distilled water in a Waring blendor. The amount of water needed for a smooth slurry depended on the method of cooking and whether the meat was raw or cooked. The raw meat required less water for blending than the cooked meat. With most raw samples equal weights of water and meat resulted in a smooth blend. Braise I required 100 to 120 grams of water for a 50 gram sample of meat, while the other three cooking methods needed only 75 to 100 grams of water for a satisfactory mixture. The time necessary for blending was approximately two minutes.

Ten gram samples were dried at 120° C. in a Brabender semi-automatic moisture tester until the weight changed less than 0.05% during a half hour interval. This required two to two and one-half hours. As the ratio of water to meat varied in each sample, the percent moisture was calculated accordingly from the Brabender reading.

Fat

Samples for fat determinations of the raw and cooked meat were taken from the same blended mixture as was used for moisture readings. Ten gram samples were weighed into fat-free filter paper and dried in aluminum drying pans at a temperature of 120° C. The samples were held in a dessicator until time for fat extraction.

Fat was extracted with ether*. The fat extraction process was carried on for three hours in a closed apparatus. A preliminary analysis showed the three hour period to be satisfactory for complete extraction of fat from the dried samples. The percentage of fat was calculated on the basis of dry weight.

Statistical Methods

Analysis of variance was made and correlation coefficients were calculated according to methods recommended by

---

* Goldfisch fat extraction apparatus.

Snedecor (61). Correlations were calculated between the following pairs of items: change in surface area and total cooking loss, surface area and volume change, volume change and total cooking loss, judges' juiciness scores and moisture content, judges' juiciness scores and fat content, shear force and judges' tenderness scores.

DISCUSSION OF RESULTS

Freezing and Thawing Losses

The adductor freezing losses were negligible. A few steaks lost as little as 0.5 of a gram during storage. All but ten of the 48 steaks of the vastus lateralis lost weight during frozen storage. This loss generally ranged from 0.5 of a gram to 1 gram except for two steaks which lost 1.5 and 2 grams. The vastus lateralis muscle, however, was stored one to six weeks longer than the adductor.

An analysis of variance made on the percent thawing losses showed the difference in animals highly significant. A highly significant interaction was also present. It was noted, for example, that the adductor of animal I showed the highest average thawing loss, 2.1%, while the vastus lateralis of the same animal had one of the lowest thawing losses for that muscle, 0.88%. For animal II the vastus lateralis muscle had the highest average thawing losses, 1.28%, and the adductor had next to the lowest thawing loss for all adductor muscles, 0.59% (Table 2).

Looking at the animals, rather than the individual muscles, animal I had the highest thawing loss and animal VI the lowest, with average percentages of 1.49% and 0.69%.

The muscles and animals having the highest thawing loss did not necessarily have the highest cooking and moisture losses except for the adductor of animal I, which showed both the highest thawing loss and the greatest per-cent decrease in moisture of all adductor muscles. The greater thawing losses for particular animals did not appreciably affect the judges' juiciness scores.

TABLE 2

AVERAGE PERCENTAGE THAWING LOSSES

Animal	Adductor	Vastus Lateralis	Both Muscles
I	2.10	.88	1.49
II	.74	1.28	1.01
III	.59	.95	.77
IV	1.20	.95	1.07
V	.71	1.15	.93
VI	.76	.63	.69

Palatability Factors

The average daily judging scores for each steak are shown in the Appendix, page 95-101. The highest possible score a steak could receive for any particular palatability factor was ten, the lowest, one.

<u>Appearance</u>

Average scores and analysis of variance for appearance (Table 3) indicate that the chief source of variation among the scores can be attributed to the difference in cooking method. The deep-fat fried and oven-cooked steaks scored higher in appearance than the braised steaks. The braised I steaks, which were browned at a higher temperature and cooked a longer time than the braised II steaks, also received higher average scores for appearance. The braised II steaks were greyish in color rather than brown. Some of the judges disliked the appearance of the oven-cooked steaks. During the fast cooking of these steaks, the juices were pushed out on top of the meat and partially coagulated. During braising and deep-fat frying this same expression of juices was no doubt present but the juices were lost in the deep-fat or pan drippings. The material which was left on the surface of the oven-cooked steaks was reddish-brown in color and of soft consistency. The surface of the meat under the coagulated material was also a bronze-red color. This condition seemed to improve as the steak cooled. The deep-fat fried steaks were quite dark brown in color and crisp on the exterior.

The difference between muscles was not statistically significant, although the vastus lateralis muscle received slightly higher scores for the oven-cooking and deep-fat

TABLE 3

AVERAGE SCORES AND ANALYSIS OF VARIANCE
FOR APPEARANCE SCORES

Method of Cooking	Muscle	
	Adductor	Vastus Lateralis
Braise I	6.1	5.9
Braise II	5.5	5.1
Oven-cooking	7.7	8.0
Deep-fat Fry	8.0	8.3

Analysis of Variance

Source	Degrees of Freedom	Mean Square	F
Total	47		
Cooking Method	3	22.6080	79.55**
Muscle	1	.0002	<1
Animal	5	.1722	<1
Error	38	.2842	

**Significant at 1% level

frying methods and slightly lower scores for the braising methods.

Aroma

The average scores and analysis of variance for aroma are shown in Table 4. The main variation as shown by the analysis was due to cooking method, and was significant at the 1% level.

The braise I and deep-fat frying methods were given the highest scores for aroma by the scoring panel. Both methods resulted in browner steaks, especially the deep-fat fry. This greater browning probably was the chief factor in development of aroma.

Flavor

The main source of variation in flavor among the steaks was cooking method as noted from average scores and analysis of variance (Table 5).

The judges preferred the flavor of the deep-fat fried and oven-cooked steaks, with a slight preference for the oven-cooked. The steaks cooked by either braising method were scored almost identically and more than one full scoring point lower than the other two methods, on the one to ten scale used for scoring in this study.

TABLE 4

AVERAGE SCORES AND ANALYSIS OF VARIANCE
FOR AROMA SCORES

Method of Cooking	Muscle Adductor	Muscle Vastus Lateralis
Braise I	7.4	7.4
Braise II	6.3	6.1
Oven-cooking	6.9	6.8
Deep-fat Fry	7.4	7.2

Analysis of Variance

Source	Degrees of Freedom	Mean Square	F
Total	47		
Cooking Method	3	3.6991	10.07**
Muscle	1	.2002	<1
Animal	5	.3310	<1
Error	38	.3673	

**Significant at 1% level

TABLE 5

AVERAGE SCORES AND ANALYSIS OF VARIANCE
FOR FLAVOR SCORES

Method of Cooking	Muscle	
	Adductor	Vastus Lateralis
Braise I	5.8	5.7
Braise II	5.9	5.6
Oven-cooking	7.3	7.5
Deep-fat Fry	7.1	7.3

Analysis of Variance

Source	Degrees of Freedom	Mean Square	F
Total	47		
Cooking Method	3	9.9502	26.06**
Muscle	1	.0052	<1
Animal	5	.3159	<1
Error	38	.3818	

**Significant at 1% level

The oven-cooked and deep-fat fried steaks reached the same maximum internal temperature of 72° C. as compared to 85° C. and 99.5° C. for the braised steaks. This fact may account somewhat, for the better flavor, since studies have shown that lower internal temperatures and dry heat generally result in a more flavorful meat, through retention of salts and nitrogenous bases. McCance and Shipp (46) reported very small losses of salts in deep-fat frying. Andross (6) stated that moist heat cookery, such as boiling or stewing, leached out extractives and resulted in loss of flavor.

Another factor which may have contributed to a better flavor for the oven-cooking and frying methods is the relatively high heat used in their cookery which resulted in a quick browning of the outside of the meat and a shorter cooking period, therefore, flavor was improved and extractives retained.

Tenderness

Cooking method accounted for the greatest part of the variation in tenderness between steaks as shown by average scores and analysis of variance for tenderness (Table 6). There was a significant difference in cooking methods at the 1% level.

Steaks cooked by oven-cooking and deep-fat frying received the highest tenderness rating, with the oven-cooking

TABLE 6

AVERAGE SCORES AND ANALYSIS OF VARIANCE FOR TENDERNESS SCORES

Method of Cooking	Muscle Adductor	Muscle Vastus Lateralis
Braise I	6.2	6.6
Braise II	5.5	5.5
Oven-cooking	7.6	7.1
Deep-fat Fry	7.4	6.7

Analysis of Variance

Source	Degrees of Freedom	Mean Square	F
Total	47		
Cooking Method	3	7.8836	10.36**
Muscle	1	.3675	<1
Animal	5	.8108	1.07
Error	38	.7607	

**Significant at the 1% level

method being given a slight preference. The braised II steaks were scored lowest in tenderness by the scoring panel.

From the results that have been published for tenderness studies, it would appear that the protein of oven-broiled and deep-fat fried steaks had not coagulated at 72° C., to the point that it had toughened and become dense. Yet there evidently was some change in collagen as both muscles have been reported to contain medium amounts of collagen.

The steaks braised to an internal temperature of 98° C. + 1/2 hour, however, were scored more tender than the steaks braised to an internal temperature of 80° C. It would appear from these results that there is considerable more softening of collagen with the longer braising period, which would counteract somewhat the toughening of intercellular protein as far as final tenderness scores are concerned. At a temperature of 80° C., evidently both forces are working together to oppose tenderness, that is, the temperature is high enough to coagulate the protein considerably, yet not high enough or the cooking period long enough to convert large amounts of collagen to gelatin. Dean (26) reported that connective tissue was little affected by braising at internal temperatures of 85° C. and when an interior temperature which decomposes the connective tissue is held constant, the tissues eventually break entirely and the fibers of meat separate.

No significant difference was found in tenderness between muscles.

Juiciness

Variation in juiciness scores can be attributed to both cooking method and muscle as seen in Table 7, where average scores and analysis of variance for juiciness are shown.

Both braising methods were scored as "dry" with the braise I being the driest, averaging 3.3 for both muscles. One judge described the meat as being "strawy".

The oven-cooked steaks were considered to be the juiciest with the deep-fat fried steaks not quite a scoring point lower.

Several investigators have concluded that braising results in large cooking losses and rather dry meat. This study agrees with the findings that the longer the meat is braised the less juicy the meat.

Since the oven-cooked and deep-fat fried steaks were cooked to a lower internal temperature, cooked a shorter time and were cooked by dry heat methods, juicier steaks would be the expected result.

The slightly higher juiciness scores for the vastus lateralis muscle when cooked by each method were statistically significant at the 1% level. Aldrich (1) also found

TABLE 7

AVERAGE SCORES AND ANALYSIS OF VARIANCE
FOR JUICINESS SCORES

Method of Cooking	Muscle	
	Adductor	Vastus Lateralis
Braise I	3.0	3.6
Braise II	4.6	5.1
Oven-cooking	8.1	8.4
Deep-fat Fry	7.3	7.8

Analysis of Variance

Source	Degrees of Freedom	Mean Square	F
Total	47		
Cooking Method	3	63.5736	20.19**
Muscle	1	2.5209	8.01**
Animal	5	.0983	<1
Error	38	.3149	

**Significant at 1% level

vastus lateralis muscle slightly more juicy than the adductor. Satorius and Child (58) reported the adductor scored lower than the triceps brachii and the longissimus dorsi in quantity of juice.

General Acceptability

The scores for general acceptability followed the trend for tenderness scores, with cooking method again being the chief factor in variation of scores (Table 8).

The oven-cooking and deep-fat frying methods were equally acceptable with average scores for both muscles being 7.2 and 7.1 respectively. The braising methods were scored practically two scoring points lower and both methods were equally acceptable to the judges. The braise I method received an average score of 5.5 and the braise II an average score of 5.3 for both muscles. Even though the scores were very much alike, the impression should not be left that the braising methods gave the same results. The braised I steaks were scored higher in aroma, appearance and tenderness but were rated very dry, while the braised II steaks were juicier and just as flavorful, so consequently, general acceptability scores were much the same for each method.

The oven-cooked and deep-fat fried steaks, however, paralleled one another on practically all palatability factors.

TABLE 8

AVERAGE SCORES AND ANALYSIS OF VARIANCE FOR GENERAL ACCEPTABILITY SCORES

Method of Cooking	Muscle Adductor	Muscle Vastus Lateralis
Braise I	5.4	5.5
Braise II	5.3	5.2
Oven-cooking	7.2	7.1
Deep-fat Fry	7.1	7.0

Analysis of Variance

Source	Degrees of Freedom	Mean Square	F
Total	47		
Cooking Method	3	11.7235	43.92**
Muscle	1	.0352	<1
Animal	5	.2632	<1
Error	38	.2669	

**Significant at 1% level

Cooking Changes and Time-Temperature Relationships

The original percentages for total cooking losses and decrease in surface area are found on page 101 and 102 of the Appendix.

Total Cooking Losses

The total cooking losses were greatest for the braised I steaks with an average of 45.04% for both muscles, and least for the oven-cooked with an average loss of 23.49% for both muscles (Table 9). The braise II and deep-fat frying losses were similar in the vastus lateralis, but with the adductor the deep-fat fry resulted in almost a 4% smaller loss than braise II. The analysis of variance showed the variance in total cooking loss attributable to cooking method significant at the 1% level (Table 10).

It appeared that the two muscles might have reacted differently to the cooking methods, but interactions calculated between the various sources were not statistically significant. The 2% greater cooking loss in the vastus lateralis by braising II and deep-fat frying was not significant. The greater loss by deep-fat frying might be partially accounted for by a longer average cooking time for the vastus lateralis. This longer period for cooking was due to a nine-minute cooking period for the deep-fat fried

TABLE 9

AVERAGE TOTAL, DRIPPING AND VOLATILE LOSSES

Cooking Method	Muscle	Percent Total Cooking Loss	Percent Volatile Loss	Percent Dripping Loss	Drippings[1] Plus Water (gms)
Braise I	Adductor	44.76			106.6
	Vastus Lateralis	45.31			108.8
Braise II	Adductor	35.09			118.3
	Vastus Lateralis	33.40			113.6
Oven-cooking	Adductor	23.59	21.60	1.99	
	Vastus Lateralis	23.38	21.10	2.28	
Deep-fat Fry	Adductor	31.44			
	Vastus Lateralis	33.96			

1 Includes 50 grams of water added

TABLE 10

ANALYSIS OF VARIANCE FOR PERCENT TOTAL COOKING LOSS

Source	Degrees of Freedom	Mean Square	F
Total	47		
Cooking Method	3	936.4086	110.97**
Muscle	1	1.0150	<1
Animal	5	5.3825	<1
Cooking x Muscle	3	9.1598	1.09
Cooking x Animal	15	9.8162	1.16
Muscle x Animal	5	9.7166	1.15
C x M x A	15	8.4381	

**Significant at 1% level

steaks from animal IV. The average cooking time was about six minutes. This steak measured one-quarter to one-half inch thicker than the other steaks. Aldrich (1) found cuts from the adductor to have higher cooking losses than the vastus lateralis. The adductor consistently averaged over a 35% cooking loss and the vastus lateralis from 30-35% cooking loss in her study. In this study there was a trend toward these results for braise II but not for braise I where total cooking losses were much the same for each muscle.

Drip and Volatile Losses

The percent drip and volatile losses were not determined as such for any method but oven-cooking. The weight of the added water plus drippings was recorded for the braising methods.

The primary loss of weight in the oven-cooked steaks can be accounted for as volatile loss. Only an average of 1.99% was found to be drip loss, while an average of 21.6% was volatile loss (Table 9). As was mentioned earlier in discussion of appearance, the juices tended to be pushed out on top of the steak during the fast cooking at 232° C. and settled back into the meat on cooling, therefore the juices were not actually lost. There was very little fat covering the meat to contribute to dripping loss.

The braise II resulted in a greater average weight of water plus drippings than the braise I. However, there were four cooking periods out of the total of twelve where the opposite was true (Table 9). Two opposing forces were undoubtedly responsible for these results; drippings lost from the meat and the loss of liquid through evaporation. Objective and subjective tests showed that braise I was less juicy and contained less moisture than braise II, so even though the drip loss was probably greater from braise I the greater evaporation from the pan left smaller amounts of drippings. The juices from the braised I steaks appeared to be slightly more concentrated than the juices from the braised II steaks.

Change in Surface Area

It has been shown many times by investigators that cuts of meat on cooking become smaller or shrink. A shrink in surface area is one of the factors contributing to this total change in size. This study found all steaks to decrease in surface area with cooking (Table 11).

Since the steaks were cut across the grain and were placed cut side down for tracing their size, it would seem that a decrease in surface area indicated a shrinkage in the diameter of muscle fibers or a change in connective tissue resulting in greater compactness of the fibers.

TABLE 11

SURFACE AREA OF RAW AND COOKED STEAKS
(in square centimeters)

	Braise I		Braise II		Oven-cooking		Deep-fat Fry	
	Raw	Cooked	Raw	Cooked	Raw	Cooked	Raw	Cooked
Adductor I	40.2	28.2	50.9	34.5	38.4	37.1	49.0	39.6
II	44.3	32.5	48.8	33.5	54.8	41.7	52.0	39.6
III	37.7	21.2	38.9	28.9	43.9	34.5	52.5	36.6
IV	45.4	28.7	46.9	29.7	37.9	32.5	50.3	40.0
V	51.4	31.7	60.6	43.1	46.5	33.5	50.3	39.7
VI	58.2	38.1	57.2	38.9	49.0	39.2	37.4	26.3
Vastus Lateralis I	43.3	30.4	46.1	36.7	29.2	25.0	55.0	46.6
II	42.4	25.9	53.8	44.9	33.0	29.9	51.8	39.2
III	48.9	40.3	52.8	44.0	46.1	42.2	50.3	41.6
IV	42.1	35.0	43.8	35.4	48.0	42.7	48.2	40.0
V	49.9	35.4	49.7	40.8	47.9	40.7	58.5	40.4
VI	46.2	30.8	47.3	42.2	51.4	49.5	47.8	32.2

The analysis of variance and average readings for surface area showed that both muscle and cooking method were largely responsible for variation between readings (Tables 11, 12).

The adductor had from 1.11% to 14.23% greater surface area decrease than the vastus lateralis muscle. The greatest difference between muscles was noted in the oven-cooking and the least difference in the deep-fat frying method. The fibers of the vastus lateralis evidently were less affected by the braising method and the high temperature of the oven-cooking than the fibers of the adductor. The greater amount of elastin in the vastus lateralis undoubtedly affected this shrinkage (62).

Steaks cooked by braise I had the greatest decrease in surface area and steaks cooked by oven-cooking the least. For both muscles the greatest decrease in surface area with cooking was 34.99% and the smallest decrease was 10.33%.

Correlations calculated between total cooking loss and surface area were statistically significant at the 1% level (Table 13). This verifies results of other investigators that shrinkage of fibers is accompanied by loss of water and fat.

Change in Volume

Along with a change in surface area, cooking results also in a change in volume. The water displacement test used

TABLE 12

AVERAGE PERCENTAGES AND ANALYSIS OF VARIANCE FOR DECREASE IN SURFACE AREA

Method of Cooking	Muscle Adductor	Muscle Vastus Lateralis
Braise I	34.99	27.59
Braise II	31.14	16.91
Oven-cooking	18.49	10.33
Deep-fat Fry	24.09	22.98

Analysis of Variance

Source	Degrees of Freedom	Mean Square	F
Total	47		
Cooking Method	3	573.6946	13.30**
Muscle	1	715.5669	16.59**
Animal	5	34.7061	<1
Error	38	43.1299	

*Significant at 1% level

TABLE 13

CORRELATION BETWEEN VARIOUS SCORING MEASURES

Percent change in volume and total cooking loss	0.7641**
Percent change in surface area and total cooking loss	0.6482**
Percent change in surface area and percent change in volume	0.5996**
Shear force readings and tenderness scores	-0.5599**
Percent decrease in moisture and juiciness scores	0.7152**
Adjusted[1] fat percentages and juiciness scores	0.1098
Adjusted[1] fat percentages and juiciness scores (without oven-cooking method)	0.1610

**Significant at 1% level

[1] Adjusted for variations in fat content of raw samples

in this study showed that all steaks decreased in volume during cooking, the percent change depending upon the cooking method (Table 14). This change during cooking would indicate not only a decrease in fiber diameter but a shortening of muscle fibers, since both width and length of fibers are concerned in volume changes. The amount of elastin connective tissue and the change in collagen connective tissue no doubt also contribute to the degree of volume change.

The decrease in volume with cooking followed, in general, the same pattern as total cooking loss. The difference between muscles found for surface area was not noted in volume changes (Table 15). The chief variation in volume readings was attributed to cooking method, significant at the 1% level, and animals, significant at the 5% level. Both braising methods and the deep-fat fry had large losses in volume as compared to the oven-cooking method. There was not as great a difference in the first three methods for volume as was found in total cooking losses and surface area. The deep-fat fry more nearly paralleled the oven-cooking method in cooking losses and surface area decrease. These findings would seem to indicate that the frying and braising methods resulted in the same degree of shrinkage in fiber length but the braising methods had greater effect on shrinkage of the fiber diameter and loss of fluid.

TABLE 14

PERCENT DECREASE IN VOLUME WITH COOKING

Muscle	Braise I	Braise II	Oven-cooking	Deep-fat
Adductor I	39.34	30.28	13.73	36.69
II	29.51	33.34	18.47	22.26
III	37.70	34.29	28.41	36.76
IV	37.29	36.82	22.91	36.26
V	50.29	43.07	41.51	33.34
VI	43.90	34.81	20.92	43.01
Average	39.67	35.44	24.33	34.72
Vastus Lateralis I	47.57	29.20	17.65	32.83
II	43.52	35.36	30.68	37.67
III	37.78	28.06	28.78	37.59
IV	36.09	38.20	25.00	36.55
V	51.18	37.80	27.27	39.68
VI	42.19	37.88	26.81	43.12
Average	43.06	34.42	26.03	37.91

TABLE 15

ANALYSIS OF VARIANCE FOR DECREASE IN VOLUME WITH COOKING

Source	Degrees of Freedom	Mean Square	F
Total	47		
Cooking Method	3	549.8253	21.00**
Muscle	1	39.5125	1.51
Animal	5	103.5822	3.96*
Error	38	26.1784	

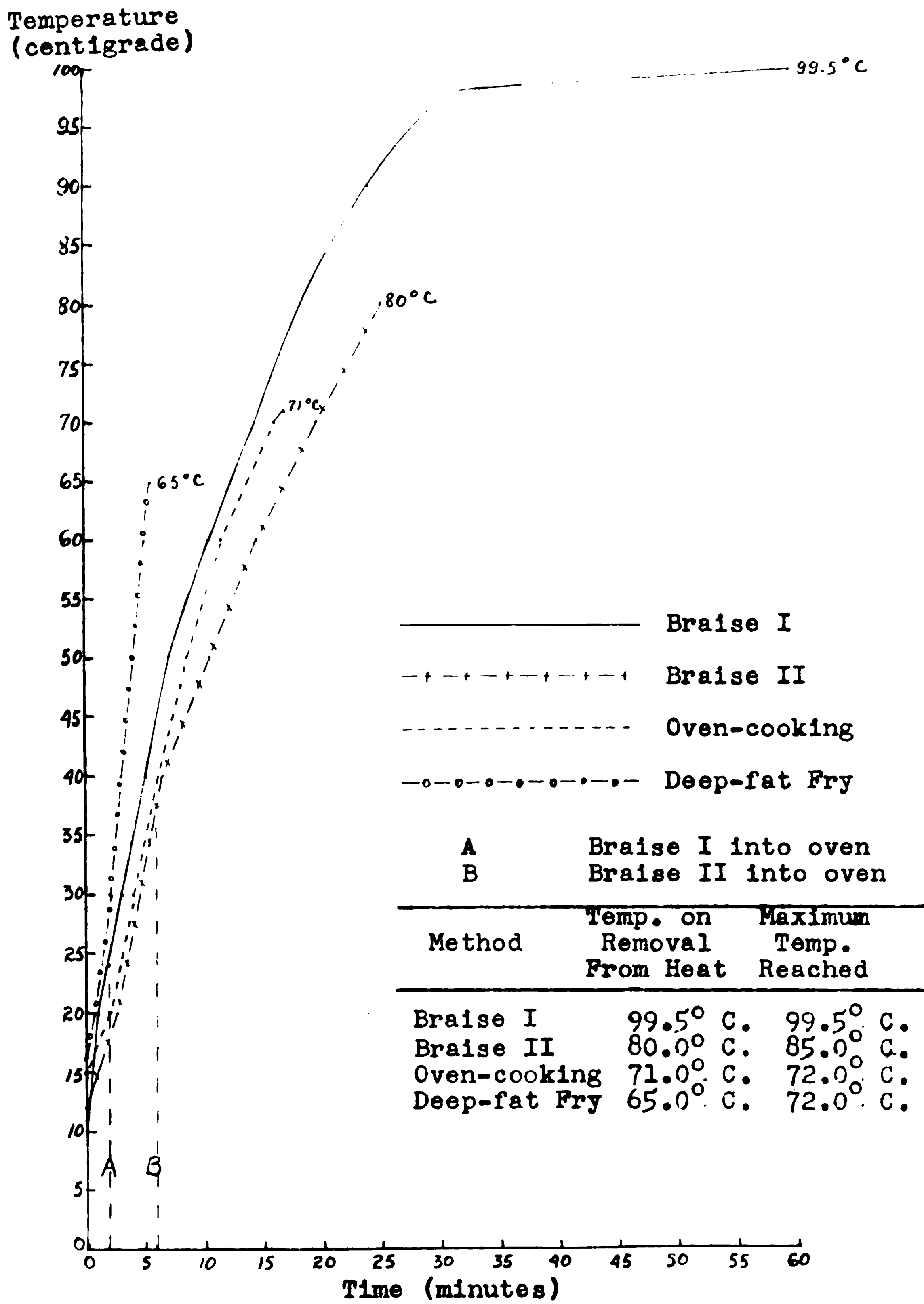
**Significant at 1% level
*Significant at 5% level

A highly significant positive correlation existed between volume and total cooking losses and also between surface area and volume, the first showing the greater correlation (Table 13).

The main animal difference seemed to be in animal V. This animal showed a greater overall volume decrease than the other animals, as well as greater surface area decrease and slightly greater total cooking losses (Tables 11, 14, 30).

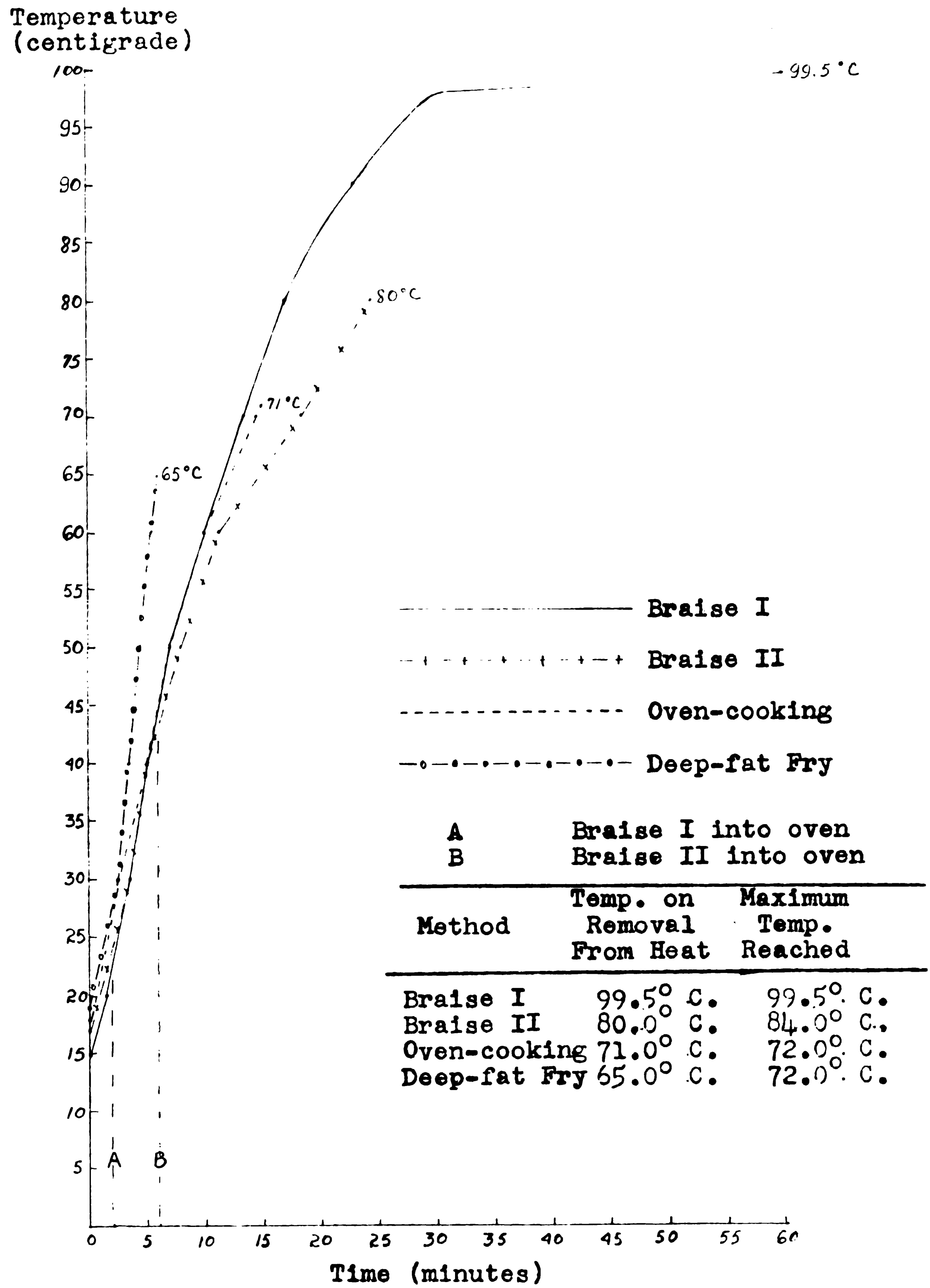
Time-Temperature Curves

The time-temperature curves for the four cooking methods are shown in Figures 2 and 3. The two muscles had slightly different time-temperature curves, chiefly due to the differences in initial internal temperature. The steaks of the vastus lateralis muscle showed temperatures 3-5° C. higher at the beginning of the cooking period. This difference was undoubtedly due to the higher room temperature during the spring months when the vastus lateralis muscle was cooked. The steaks with the higher initial internal temperatures within each group had been left at room temperature a longer period before cooking. Several tests had to be made on steaks before cooking, thereby necessitating longer holding periods for the steaks cooked by deep-fat frying and oven-cooking methods.



Method	Temp. on Removal From Heat	Maximum Temp. Reached
Braise I	99.5° C.	99.5° C.
Braise II	80.0° C.	85.0° C.
Oven-cooking	71.0° C.	72.0° C.
Deep-fat Fry	65.0° C.	72.0° C.

Fig. 2. Average time-temperature curves for beef steaks from the adductor muscle.



Method	Temp. on Removal From Heat	Maximum Temp. Reached
Braise I	99.5° C.	99.5° C.
Braise II	80.0° C.	84.0° C.
Oven-cooking	71.0° C.	72.0° C.
Deep-fat Fry	65.0° C.	72.0° C.

Fig. 3. Average time-temperature curves for beef steaks from the vastus lateralis muscle.

Each cooking method had a different end-point for temperature but the oven-cooking and deep-fat methods resulted in the same maximum temperature after removal from their cooking medium. The deep-fat fried steaks showed an average internal temperature rise of 7° C. after removal from the deep-fat, while the oven-cooked steaks showed only an average internal temperature rise of 1° C. These results indicate that the rate of heat penetration through a fat medium at 150° C. was much faster than heat penetration through air at 232° C. The steaks cooked in deep-fat reached 65° C. in an average of 5.5 to 6 minutes, while it took the oven-cooked steaks 15 to 16.5 minutes to reach 71° C. The braised II steaks showed an average internal temperature rise of 4.5° C. after removal from the oven while the braised I steaks reached a maximum temperature of 99.5° C. in the oven and did not show a rise after removal.

Comparing all methods of cooking, braise II had the slowest rate of heat penetration and the deep-fat fry the fastest rate. The temperature of the oven-cooked and braised I steaks moved at relatively the same rate to 71° C., when the oven-cooked steaks were removed from the oven. However, this comparison is made on different cooking temperatures, the oven-cooked steaks being in a 232° C. oven and the braised I steaks in a 122° C. oven. This would indicate that water conducts heat more rapidly than air, even though the braised II steaks in this study showed the slowest heat penetration. It must be noted that the braised steaks were cooked at a very low oven temperature. Lowe (43) stated that meat reached a definite interior temperature very much faster in water than in air of the same temperature.

The difference in the rate of heat penetration for the two braising methods, cooked at the same oven temperature, can probably be accounted for by the varied browning periods. Evidently the fast two-minute browning at 246° C., used for braise I, accelerated the penetration of heat, as compared to the slower six-minute browning period at 232° C. for braise II. The difference in time, for steaks cooked by the two methods, to reach 40° C. was only 1/2 to 1 1/2 minutes but the difference at 70° C. had increased to five minutes. No plateau was noticed for any cooking method except at 98° C. for the braise I method, but cooking was generally slower for all methods, except deep-fat frying, after 50° C. was reached.

Objective and Chemical Tests

Shear Force

The original shear force values are shown on page 103 of the Appendix. Each reading is an average value for five to seven cores.

The analysis of variance for average shear force readings showed no significant difference due to cooking method (Table 16). This is not in agreement with judges' scores for tenderness but a highly significant correlation was found to exist between judges' scores for tenderness and shear force (Table 13). This would seem to indicate that the two devices were testing the same factor but the judges' scores indicated that there were greater differences in tenderness than was found with the shearing machines.

The shear values were highest for the braised II steaks for both muscles, and the deep-fat fry for the vastus lateralis muscle, showing them to be the least tender of the steaks compared. There was little difference in shear values for the other three cooking methods using the adductor. The braise I method was found to yield the most tender steaks from the vastus lateralis muscle. Interaction between the various sources were not significant (Table 16).

Difference between muscles was significant at the 5% level for shear values (Table 16). The adductor was sheared with fewer pounds of force for all cooking methods except braise I. This method of cookery had greater tenderizing effect on the vastus lateralis than any of the other cooking methods. Studies have shown that the vastus lateralis has more distinct fasciculi and a larger amount of elastin connective tissue than the adductor (62). This fact would account for the difference in tenderness.

TABLE 16

AVERAGE READINGS AND ANALYSIS OF VARIANCE FOR SHEAR FORCE IN POUNDS

Method of Cooking	Muscle	
	Adductor	Vastus Lateralis
Braise I	8.60	8.30
Braise II	9.42	10.29
Oven-cooking	8.01	9.11
Deep-fat Fry	8.02	10.43

Analysis of Variance

Source	Degrees of Freedom	Mean Square	F
Total	47		
Cooking Method	3	5.0990	2.03
Muscle	1	12.5256	5.00*
Animal	5	2.6704	1.07
Cooking x Muscle	3	3.6939	1.47
Cooking x Animal	15	2.4240	<1
Muscle x Animal	5	4.6249	1.84
C x M x A	15	2.5071	

*Significant at 5% level

pH

Cooking increased the alkalinity of all samples as indicated in Table 17. The average pH of the raw steaks ranged from 5.48 to 5.51, while the average pH of the cooked steaks ranged from 5.67 to 5.79. The pH averages showing the most marked effect of cooking method were the averages for oven-cooking. These steaks were slightly more acidic than the steaks cooked by the other methods. The vastus lateralis muscle was more alkaline when deep-fat fried and braised by method I than the adductor cooked by these methods. Otherwise, the braising methods resulted in identical pH average readings for both muscles. The oven-cooking method also showed similar pH readings for both muscles.

The lower internal temperature of the oven-cooked steaks does not seem to account for the lower pH values, since the deep-fat fried steaks reached the same maximum internal temperature, yet were much more alkaline.

Total Moisture

The raw steaks in this study were found to contain from 71.81% to 74.74% moisture, with the adductor averaging 72.71% and the vastus lateralis 73.79% (Table 18). All steaks decreased in moisture content with cooking, the method of cooking determining the amount. The oven-cooking

TABLE 17

AVERAGE pH READINGS FOR RAW AND COOKED STEAKS

Method of Cooking	Adductor		Vastus Lateralis	
	Raw	Cooked	Raw	Cooked
Braise I	5.48	5.71	5.50	5.76
Braise II	5.49	5.71	5.50	5.71
Oven-cooking	5.48	5.68	5.49	5.67
Deep-fat Fry	5.49	5.71	5.51	5.79

TABLE 18

PERCENT MOISTURE IN RAW AND COOKED SAMPLES

Muscle		Average of Raw*	Braise I	Braise II	Oven-Cooking	Deep-fat
Adductor	I	72.86	54.22	58.32	68.19	57.73
	II	71.81	53.77	66.10	64.57	67.74
	III	72.70	57.15	61.95	65.19	60.50
	IV	71.89	57.75	62.85	66.80	61.01
	V	73.61	56.93	61.63	64.23	66.76
	VI	73.38	57.75	60.50	67.57	64.43
Average		72.71	56.26	61.89	66.09	63.03
Vastus Lateralis	I	73.30	57.15	63.75	69.38	64.19
	II	73.15	55.35	61.73	65.64	64.80
	III	72.90	54.44	62.48	61.82	60.42
	IV	74.74	56.13	63.98	69.51	58.73
	V	74.51	56.75	60.75	68.26	61.58
	VI	74.14	55.03	64.87	66.69	62.45
Average		73.79	55.81	62.93	66.88	62.03

*Duplicate samples from four steaks

method resulted in the smallest decrease in moisture, approximately 9%, and braise I the largest decrease, approximately 23% for both muscles (Table 19). Braise I averaged about a 7% greater decrease in moisture than braise II. The deep-fat fried steaks which reached the same internal temperature as the oven-broiled steaks contained at least 3% less moisture on the average after cooking. Original percentages for decrease in moisture with cooking are found on page 104 of the Appendix.

The difference in muscles was not statistically significant even though the vastus lateralis muscle showed a greater decrease in moisture with cooking than the adductor for all methods except braise II.

The correlation coefficient calculated between judges' scores for juiciness and percent decrease in moisture was highly significant (Table 13). The correlation was positive since the greater the decrease in moisture the lower the judges' scores for juiciness.

Fat

Table 20 indicates that the fat content of the individual raw samples was quite different. Realizing that the fat content of the original sample would affect the percent of fat in the cooked sample, it was decided to use analysis of covariance on these data. The analysis indicated that

TABLE 19

AVERAGE PERCENTAGES AND ANALYSIS OF VARIANCE FOR DECREASE IN MOISTURE CONTENT WITH COOKING

Method of Cooking	Muscle Adductor	Vastus Lateralis
Braise I	22.67	24.23
Braise II	15.09	14.73
Oven-cooking	8.89	9.31
Deep-fat Fry	13.17	16.08

Analysis of Variance

Source	Degrees of Freedom	Mean Square	F
Total	47		
Cooking Method	3	417.1272	38.43**
Muscle	1	16.7797	1.56
Animal	5	8.4919	<1
Error	38	10.8545	

**Significant at the 1% level

TABLE 20

PERCENT FAT IN RAW AND COOKED STEAKS
(Dry basis)

	Braise I		Braise II		Oven-cooking		Deep-fat	
	Raw	Cooked	Raw	Cooked	Raw	Cooked	Raw	Cooked
Adductor I	11.18	15.35	13.04	23.40	20.36	16.82	9.48	17.99
II	25.53	16.29	24.26	10.04	25.19	16.74	21.41	11.19
III	14.39	16.95	9.41	14.21	20.34	25.43	19.92	26.07
IV	27.97	19.84	21.93	18.09	25.75	11.79	20.68	21.97
V	11.30	13.45	14.36	14.02	7.50	15.87	23.43	15.36
VI	12.65	10.75	10.94	14.15	9.67	9.51	4.12	8.76
Vastus Lateralis I	11.20	13.64	17.44	13.72	23.19	12.90	11.45	14.19
II	27.27	16.56	16.08	15.83	20.55	14.90	17.35	18.22
III	21.37	18.03	15.24	16.21	20.16	28.26	19.49	24.04
IV	21.97	27.62	14.87	17.54	15.27	13.88	16.21	25.71
V	14.67	13.90	15.27	24.75	14.63	14.15	18.07	22.42
VI	14.70	14.10	11.60	18.69	11.16	11.30	12.06	14.85

the difference in cooking method was not due just to the fat content of the raw meat. Variation in fat content as affected by cooking method was statistically significant at the 1% level (Table 21).

The average percent fat for all steaks cooked by each method showed the deep-fat fried steaks to contain the highest percentage of fat and the oven-cooked steaks the lowest. When the average percent fat in the cooked samples was adjusted to correct for difference in the raw samples the cooking methods ranked in the same order as far as fat content but the values were somewhat changed (Table 22).

It would appear from these analyses that the deep-fat fried steaks absorbed some of the fat in which they were cooked. Grindley and Mojonnier (33) reported similar results in an early study of frying. They found that meat fried in shallow fat contained 2.3 times more fat than before cooking. The deep-fat fried steaks were the only steaks showing quite a consistent trend toward increased fat with cooking. Table 20 indicates, however, that within each cooking method there were many instances of increased fat content. Satorius and Child (58) reported that cooked roasts from the longissimus dorsi muscle showed a 35-40% increase in fat over the raw roast. Thille (64) studied both fat and lean roasts and reported that the center of the cooked roasts had greater fat content than the raw meat.

TABLE 21

ANALYSIS OF COVARIANCE FOR FAT CONTENT OF RAW AND COOKED STEAKS

Source	Degrees of Freedom	Mean Square	F
Error	37	9.2899	
Cooking Method plus Error	40		
Difference due to Cooking	3	54.0144	5.81**

**Significant at 1% level

TABLE 22

AVERAGE ORIGINAL AND ADJUSTED[1] FAT PERCENTAGES FOR COOKED STEAKS

Cooking Method	Average Percent Fat	Adjusted Percentages
Braise I	16.37	15.86
Braise II	16.72	17.40
Oven-cooking	15.96	15.47
Deep-fat Frying	18.40	18.71

1 Adjusted for variation in fat content of raw samples

An explanation suggested by Lowe (43) for this increase in fat during cooking is that the phospholipins combined with the proteins may be released by coagulation and more readily extracted by ether from cooked than raw meat.

A factor that must be considered in comparing the effect of cooking method on fat content is the relationship of moisture to fat content. The samples from cooked steaks with a lower moisture content would undoubtedly have a higher concentration of fat, gram for gram, than steaks containing more moisture. However, the loss of fat in drippings from the steak cooked a longer time, would counteract somewhat this concentration of fat. Looking at the adjusted averages in Table 22, it would appear that the second factor was more responsible for the fat content of braise II since it had the second highest average percent fat and was cooked a shorter time than Braise I. In the case of the oven-cooking method, the greater moisture content could have accounted for the reduced amount of fat in the sample. Since the percent fat in braise I and the oven-cooked steaks was much the same, it might be presumed that these two opposite forces produced the same results.

An analysis of variance of the percent fat in the cooked meat showed the difference between animals to be significant at the 1% level (Table 23). The chief variation in fat content between raw samples was also attributed to a difference

TABLE 23

ANALYSIS OF VARIANCE FOR FAT IN COOKED STEAKS

Source	Degrees of Freedom	Mean Square	F
Animal	5	74.8412	4.18**
Muscle	1	35.6282	1.99
Method of Cooking	3	13.6815	<1
Error	38	17.9237	

**Significant at 1% level

in animals, as found from an analysis of variance of percent fat in the original samples.

Realizing that the fat content of both raw and cooked meat might have an effect on the judges' juiciness scores, the percent fat content for each steak was adjusted to remove the effect of variation in the raw samples. These adjusted percentages were then used to calculate a correlation coefficient between fat content and juiciness scores. A significant correlation, however, was not present. A slightly better correlation was obtained when the oven-cooking method was omitted from the analysis, yet not statistically significant (Table 13). The moisture content of the steaks evidently had much more influence on the judges' juiciness scores than the fat content.

SUMMARY AND CONCLUSIONS

Four meat cookery methods were compared using the adductor and vastus lateralis muscle of the beef round. The methods compared were two braising methods, a dry heat method called "oven-cooking", and deep-fat frying. The muscles were dissected from the left and right rounds of six beef animals, graded U. S. Choice. Each muscle was cut into four 1-inch steaks. The steaks were weighed, wrapped in moisture-vapor proof cellophane, frozen and stored until 24 hours prior to cooking.

Steaks were cooked by all four cooking methods for each scoring period. A panel of five judges scored the steaks for aroma, appearance, tenderness, juiciness, flavor and general acceptability.

The change in moisture and fat content with cooking, the pH of raw and cooked samples and the percent cooking losses were determined. Objective measurements were made of volume and surface area changes with cooking.

The chief source of variation among the palatability scores was cooking method as shown by an analysis of variance made on each palatability factor. The variation in juiciness scores was assigned, however, to both cooking method and difference between muscles. The judges preferred the oven-cooked and deep-fat fried steaks over the braised steaks, as indicated by general acceptability scores.

There was a significant difference in cooking losses as a result of cooking method. The steaks cooked by braise I had the highest percent total cooking loss and the oven-cooked steaks had the lowest. The average weight of drippings plus water was greater for braised II steaks than for braised I steaks.

Results of objective tests were similar to the results of subjective scores. Correlations between shear force and tenderness scores and between juiciness scores and total moisture were highly significant. Volume and surface area changes followed the same general trend as cooking losses. However, a significant difference found between muscles for surface area changes was not present for total cooking losses and volume changes. Highly significant correlations were found between percent total cooking loss and volume change, percent total cooking loss and surface area change, and between volume change and surface area change. The pH values for cooked meat indicated that cooking method had an effect on the degree of change in pH with cooking. This was particularly noted with the oven-cooking and deep-fat frying methods. The oven-cooked steaks tended to be more acid while the deep-fat fried steaks were generally more alkaline than the braised steaks.

An analysis of covariance on the fat data showed that there was a difference in the fat content of cooked samples due to cooking method. The deep-fat fried steaks showed quite a definite increase in fat content with cooking.

On the basis of these findings it appears that:

1. Oven-cooking and deep-fat frying resulted in more palatable steaks from the adductor and vastus lateralis than the braising methods compared in this study.

2. Steaks braised to an internal temperature of 80° C. were juicier than steaks cooked to 99.5° C. plus 1/2 hour but were less palatable as far as aroma, appearance and tenderness were concerned.

3. Oven-cooked steaks had the lowest total cooking losses and highest moisture content, while the braised I steaks had the highest total cooking losses and the lowest moisture content.

4. Deep-fat fried steaks increased in fat content during cooking.

LIST OF REFERENCES

1. Aldrich, P. J. and Lowe, B. Comparison of grades of beef rounds: Effect of cooking times on palatability and cost. J.A.D.A. 30:39-43. 1954.

2. Alexander, L. M. Report on the Cooking of meat. Proc. Am. Soc. Animal Prod. 21:117-118 1928.

3. ______________. Shrinkage and heat penetration during the roasting of lamb and mutton as influenced by carcass grade, ripening period and cooking method. U. S. Dept. Agr. Tech. Bul. 440:23-25. 1934.

4. ______________. Shrinkage of roast beef in relation to fat content and cooking temperature. J. Home Econ. 22:915-922. 1930.

5. American Home Economics Association. Handbook of Food Preparation. Rev. ed. Washington, D. C. 1947.

6. Andross, M. Effect of cooking on meat. Brit. J. Nutr. 3-4:396-406. 1949-50.

7. Barbella, N. G., Tannor, B. and Johnson, T. G. Relationships of flavor and juiciness of beef to fatness and other factors. Proc. Am. Soc. Animal Prod. 32:320-325. 1939.

8. Bard, J. C. and Tischer, R. G. Objective measurement of changes in beef during heat processing. Food Tech. 5: 296-300. 1951.

9. Bate-Smith, E. C. Muscle and meat. Food Sci. Abstr. 23:209-210. 1951.

10. ______________. Observations on the pH and related properties of meat. J. Soc. Chem. Ind. 67:83-90. 1948.

11. Bendall, J. R. Effect of cooking on the creatine-creatinine, phosphorus, nitrogen and pH values of raw, lean beef. J. Soc. Chem. Ind. 65:226-230. 1946.

12. Bogue, R. H. Conditions affecting the hydrolysis of collagen to gelatin. Ind. Eng. Chem. 15:1154-1159. 1923.

13. Brady, D. E. A study of the factors influencing tenderness and texture of beef. Proc. Am. Soc. Animal Prod. 30:246-249. 1937.

14. Bratzler, L. J. Measuring the tenderness of meat by means of a mechanical shear. Unpublished M. S. thesis. University of Illinois. 1930.

15. Callow, E. H. Brief review of the science of meat. Brit. J. Nutr. 3: 375-380. 1949.

16. Child, A. M. Effect of interior temperatures of beef muscle upon the press fluid and cooking losses. J. Agr. Res. 51:655-662. 1935.

17. __________ and Baldelli, M. Press fluid from heated beef muscle. J. Agr. Res. 48:1127-1134. 1936.

18. Cline, J. A. and Dizmang, V. Methods of cooking less tender cuts of U. S. medium grade beef. Mo. Agr. Expt. Sta. Bul. 358:78-79. 1935.

19. __________ and Godfrey, R. S. A study of temperature and time of cooking on the quality and palatability of meat. Mo. Agr. Expt. Sta. Bul. 256:74-75. 1927.

20. __________, Loughead, M. E. and Schwartz, B. C. Methods of cooking steaks from different classes of beef animals. Mo. Agr. Expt. Sta. Bull. 310:39. 1932.

21. __________, Trowbridge, E. A., Foster, M. T. and Fry, H. E. How certain methods of cooking affect the quality and palatability of beef. Mo. Agr. Exp. Sta. Bul. 293:40 pp. 1930.

22. Cover, Sylvia. Effect of extremely low rates of heat penetration on tendering of beef. Food Res. 8:388-394. 1943.

23. __________. The effect of time and temperature of cooking on the tenderness of roasts. Texas Agr. Expt. Sta. Bul. 542:5-33. 1937.

24. Crocker, E. C. Flavor of meat. (Editorial) Food Res. 13:179-183. 1948.

25. Day, J. C. Longissimus dorsi of three grades of beef: Comparison of cooking weight losses, palatability and edible portion. Unpublished Master's thesis. Michigan State College. 1953.

26. Dean, J. B. The effect of cooking on the tenderness of meat. I. A comparison of two cooking temperatures on paired tough cuts cooked by moist heat in the oven. Unpublished Master's thesis. Iowa State College. 1933.

27. Deatherage, F. E. and Garnatz, G. A comparative study of tenderness determination by sensory panel and shear strength measurements. Food Tech. 6:260-262. 1952.

28. ______________ and Harsham, A. Relation of tenderness of beef to aging time at 33° - 35° F. Food Res. 12: 164-171. 1947.

29. Empey, W. A. Studies on the refrigeration of meat. Conditions determining the amount of drip from frozen and thawed muscle. J. Soc. Chem. Ind. 52:230T. 1933.

30. Gaddis, A. M., Hankins, A. G. and Hiner, R. L. Relationships between the amount of composition of press fluid, palatability and other factors of meat. Food Tech. 4: 498-503. 1950.

31. Grindley, H. S. and Emmett, A. M. Studies on the influence of cooking upon the nutritive value of meats. U. S. Dept. Agr. Expt. Sta. Bul. 162:230 pp. 1905.

32. ______________ and McCormack, P. Losses in cooking meat. U. S. Dept. Agr. Expt. Sta. Bul. 102: 1901.

33. ______________ and Mojonnier, M. S. Experiments on losses in cooking meat. U. S. Dept. Agr. Expt. Sta. Bul. 141: 1904.

34. Griswold, R. M. and Wharton, M. A. Effect of storage conditions on palatability of beef. Food Res. 6: 517-527. 1941.

35. Hammond, J. Some factors affecting the quality and composition of meat. Chem. and Ind. 18:521-525. 1940.

36. Hankins, O. G. and Hiner, L. L. Freezing makes beef tenderer. Food Ind. 12:49-51. 1948.

37. Harrison, D. L., Lowe, B., McClurg, B. and Shearer, P. S. Physical, organoleptic and histological changes in three grades of beef during aging. Food Tech. 3:284-288. 1949.

38. Hayes, M. C. A study of the relation of U. S. grades of beef to the palatability of porterhouse steaks. Unpublished Master's thesis. University of Missouri. 1939.

39. Howe, P. E. and Barbella, N. G. The flavor of meat and meat products. Food Res. 2:197-202. 1937.

40. Husaini, S. A., Deatherage, F. E., Kunkle, L. E. and Draudt, H. N. Studies on meat. I. The biochemistry of beef as related to tenderness. Food Tech. 4:313-316. 1950.

41. Latzke, Esther. Standardizing methods of roasting beef in experimental cookery. No. Dak. Agri. Expt. Sta. Bul. 242:2-18. 1930.

42. Lowe, B. Mechanical measurement of the tenderness of raw and cooked meat. Unpublished Master's thesis. University of Chicago. 1934.

43. _________. Experimental Cookery. Second Edition, New York, John Wiley and Sons. 1943.

44. _________, Crain, E., Amick, G., Riedesel, M., Peet, L. J., Smith, F. B., McClurg, B. R. and Shearer, P. S. Defrosting and cooking frozen meat. Agr. Expt. Sta. Iowa State College Res. Bul. 385: 1952.

45. Mackintosh, D. L., Hall, J., Lowe, B., and Vail, G. E. Some observations pertaining to the tenderness of meat. Proc. Am. Soc. Animal Prod. 29:285-289.

46. McCance, R. H. and Shipp, H. L. The chemistry of flesh foods and their losses on cooking. Spec. Rpt. Series No. 187. Medical Research Council, London.

47. McLachlan, Helen. Standardizing methods of broiling beef steaks and methods of cooking pork chops. Unpublished Master's thesis. University of Missouri. 1937.

48. Morgan, A. F. and Nelson, M. P. Study of certain factors affecting shrinkage and speed in the roasting of meat. J. Home Econ. 20: 371-378; 444-448. 1926.

49. Noble, I. T., Halliday, E. G. and Klaas, H. K. Studies on the tenderness and juiciness of cooked meat. J. Home Econ. 26:238-242. 1934.

50. Orr, K. J. Effect of cold storage and frozen storage on the palatability and histological appearance of the longissimus dorsi of beef. Unpublished Master's thesis. Michigan State College. 1949.

51. Paul, P., Bratzler, L. J., Farwell, E. D., and Knight, K. Studies on the tenderness of beef. I. Rate of heat penetration. Food Res. 17:504-510. 1952.

52. _______ and Child, A. M. Effect of freezing and thawing muscle upon press fluid, losses and tenderness. Food Res. 2:339-345. 1937.

53. _______ and McLean, B. B. Studies on veal. I. Effect of different internal temperature on veal roasts from calves of three different weights. Food Res. 11:107-115. 1946.

54. _______________. Studies on veal. II. Variations between some muscles of the hind quarter. Food Res. 11:116-120. 1946.

55. Ramsbottom, J. M. and Strandine, E. J. Comparative tenderness and identification of muscles in wholesale beef cuts. Food Res. 13:315-328. 1948.

56. _______________. Initial physical and chemical changes in beef as related to tenderness. Proc. Am. Soc. Animal Prod. J. Animal Sci. 7:(abstract) 519. 1948.

57. _______________ and Koonz, C. H. Comparative tenderness of representative beef muscles. Food Res. 10:497-509. 1945.

58. Satorius, M. J. and Child, A. M. Effect of coagulation on press fluid, shear force, muscle cell diameter and composition of beef muscle. Food Res. 3:619-626. 1938.

59. _______________. Effect of cut, grade and class upon palatability and composition of beef roasts. Minn. Agr. Expt. Sta. Tech. Bul. 131: 1938.

60. Seimers, L. and Hanning, F. A study of certain factors influencing the juiciness of meat. Food Res. 18:113-130. 1953.

61. Snedecor, G. W. Statistical methods. 4th ed. Iowa State College Press., Ames, Iowa. 1950.

62. Strandine, E. J., Koonz, C. H. and Ramsbottom, J. M. A study of variations in muscles of beef and chicken. J. Animal Sci. 8:483-494. 1949.

63. Tanner, B., Clark, N. G. and Hankins, A. G. Mechanical determination of juiciness of meat. J. Agr. Res. 66: 403-412. 1943.

64. Thille, M., Williamson, L. J. and Morgan, A. F. The effect of fat on the shrinkage and speed in the roasting of beef. J. Home Econ. 24:720-732. 1932.

65. Tucker, R. E., Hinman, W. F. and Halliday, E. G. The retention of thiamine and riboflavin in beef cuts during braising, frying and broiling. J. A.D.A. 22: 877-881. 1946.

66. Wanderstock, J. J. and Miller, J. I. Quality and palatability of beef as affected by method of feeding and carcass grade. Food Res. 13:291-303. 1948.

67. Wilmeth, M. C. The effect of braising and pressure saucepan cookery on the cooking losses, palatability and nutritive value of the proteins of round steak. Unpublished Ph. D. thesis, Kansas State College. 1953.

68. Winkler, C. A. Tenderness of meat. I. A recording apparatus for its estimation and relation between pH and tenderness. Can. J. Res. 17D:8-14. 1939.

APPENDIX

TABLE 24

SCORE SHEET FOR STEAKS

FACTOR	10	9	8	7	6	5	4	3	2	1
Aroma	Extremely good	Very good	Good	Plus	Medium	Minus	Fair	Poor	Very Poor	Extremely poor
Appearance	Extremely good	Very good	Good	Plus	Medium	Minus	Fair	Poor	Very Poor	Extremely poor
Flavor of Lean	Extremely good	Very good	Good	Plus	Medium	Minus	Fair	Poor	Very poor	Extremely poor
Tenderness	Extremely tender	Very tender	Good	Plus	Medium	Minus	Fair	Poor	Very tough	Extremely tough
Juiciness	Extremely juicy	Very juicy	Good	Plus	Medium	Minus	Fair	Poor	Very dry	Extremely dry
Flavor of fat	Extremely good	Very good	Good	Plus	Medium	Minus	Fair	Poor	Very poor	Extremely poor
General conclusions	Extremely good	Very good	Good	Plus	Medium	Minus	Fair	Poor	Very poor	Extremely poor

Number of steak: ______ Number of chews: ______

TABLE 25

AVERAGE DAILY SCORES FOR APPEARANCE

Muscle	Braise I	Braise II	Oven-Cooking	Deep-Fat
Adductor I	6.6	6.4	6.8	8.0
II	6.8	5.0	7.2	7.8
III	5.8	6.2	7.6	8.0
IV	5.8	5.8	8.2	8.2
V	6.0	4.8	8.2	7.8
VI	5.8	4.8	8.2	8.0
Vastus Lateralis I	5.6	5.2	7.8	8.4
II	5.8	5.0	7.3	8.8
III	6.6	4.8	7.6	7.8
IV	6.4	4.8	8.8	8.8
V	5.8	5.4	7.4	8.2
VI	5.3	5.5	8.8	7.8

TABLE 26

AVERAGE DAILY SCORES FOR AROMA

Muscle	Braise I	Braise II	Oven-Cooking	Deep-fat
Adductor I	7.6	6.2	5.0	7.6
II	7.0	6.4	6.6	7.4
III	7.0	6.6	7.6	7.2
IV	8.0	7.0	7.2	8.0
V	7.4	5.4	8.0	6.8
VI	7.2	6.4	6.8	7.6
Vastus Lateralis I	7.2	7.0	6.0	6.6
II	7.3	5.5	7.3	7.5
III	8.0	5.0	7.2	6.8
IV	7.4	5.8	6.8	7.2
V	7.2	6.0	6.0	7.8
VI	7.5	7.0	7.5	7.3

TABLE 27

AVERAGE DAILY SCORES FOR FLAVOR

Muscle	Braise I	Braise II	Oven-cooking	Deep-fat
Adductor I	6.8	6.8	7.2	6.8
II	5.8	5.0	6.6	6.4
III	5.8	5.2	8.2	7.2
IV	6.0	6.0	6.8	8.4
V	5.0	6.2	7.4	6.8
VI	5.6	6.2	7.6	7.2
Vastus Lateralis I	5.6	5.8	7.6	6.6
II	5.3	5.5	8.0	8.3
III	6.0	6.2	8.4	7.6
IV	6.2	5.2	7.4	7.0
V	4.6	5.8	7.0	7.8
VI	6.3	5.0	6.8	6.5

TABLE 28

AVERAGE DAILY SCORES FOR TENDERNESS

Muscle	Braise I	Braise II	Oven-cooking	Deep-Fat
Adductor I	5.0	6.4	8.2	6.0
II	7.6	3.6	6.8	7.4
III	5.4	4.6	8.6	7.8
IV	7.6	5.4	7.0	8.2
V	5.2	6.2	7.0	8.0
VI	6.6	6.6	7.8	6.8
Vastus Lateralis I	6.0	4.6	6.8	6.4
II	7.0	5.0	7.8	7.8
III	6.6	7.0	7.8	7.0
IV	7.2	6.0	7.0	7.0
V	6.8	4.8	6.0	5.6
VI	6.0	5.8	7.3	6.3

TABLE 29

AVERAGE DAILY SCORES FOR JUICINESS

Muscle	Braise I	Braise II	Oven-cooking	Deep-fat
Adductor I	3.0	5.2	8.6	6.6
II	2.8	3.8	7.2	7.2
III	2.6	3.8	8.4	7.0
IV	3.6	4.8	8.4	7.6
V	2.8	5.0	7.2	8.0
VI	3.2	5.2	8.6	7.2
Vastus Lateralis I	3.4	4.6	7.6	8.4
II	3.8	5.3	8.5	8.3
III	3.6	6.0	8.2	7.8
IV	4.2	4.4	9.0	7.4
V	3.0	5.8	8.6	7.0
VI	3.5	4.3	8.3	7.8

TABLE 30

AVERAGE DAILY SCORES FOR GENERAL ACCEPTABILITY

Muscle	Braise I	Braise II	Oven-cooking	Deep-fat
Adductor I	5.8	6.4	7.0	6.6
II	5.8	4.6	6.2	6.2
III	5.2	5.2	8.0	7.2
IV	5.4	5.4	7.4	8.2
V	4.6	5.0	7.0	7.2
VI	5.8	5.4	7.4	7.0
Vastus Lateralis I	5.4	4.8	6.8	6.4
II	5.3	5.5	7.5	8.0
III	5.4	5.6	7.6	7.4
IV	6.2	5.0	7.0	6.4
V	5.0	5.0	6.6	7.2
VI	5.8	5.3	7.0	7.0

TABLE 31

PERCENTAGE TOTAL COOKING LOSSES

	Braise I	Braise II	Oven-cooking	Deep-fat
Adductor I	45.29	35.56	18.36	34.84
II	43.59	35.63	27.66	29.80
III	44.14	35.68	24.15	33.86
IV	44.41	32.47	24.05	32.33
V	47.34	36.26	29.19	25.89
VI	43.80	34.91	18.11	31.94
Vastus Lateralis I	43.79	33.33	20.47	29.97
II	46.90	30.82	24.08	27.94
III	44.98	28.71	25.51	34.02
IV	45.04	34.52	25.20	39.88
V	46.48	35.44	21.87	36.11
VI	44.67	37.57	23.13	35.81

TABLE 32

PERCENTAGE DECREASE IN SURFACE AREA WITH COOKING

	Braise I	Braise II	Oven-cooking	Deep-fat
Adductor I	29.85	32.22	3.39	19.18
II	26.64	31.35	23.91	23.85
III	43.77	25.71	21.41	30.29
IV	36.78	36.67	14.25	20.48
V	38.33	28.88	27.96	21.07
VI	34.54	31.99	20.00	29.68
Vastus Lateralis I	29.79	20.39	14.38	15.64
II	38.92	16.54	9.39	24.32
III	17.59	16.67	8.46	17.30
IV	16.86	19.18	11.04	17.01
V	29.06	17.91	15.03	30.94
VI	33.33	10.78	3.70	32.64

TABLE 33

SHEAR FORCE VALUES FOR COOKED STEAKS IN POUNDS

		Braise I	Braise II	Oven-cooking	Deep-fat
Adductor	I	10.20	6.54	5.29	8.67
	II	5.05	10.18	9.50	7.32
	III	10.96	10.95	7.04	8.39
	IV	6.33	11.93	9.11	8.82
	V	9.11	7.25	9.21	7.64
	VI	9.96	9.66	7.89	7.29
Vastus Lateralis	I	9.82	13.07	9.11	11.07
	II	7.42	10.04	8.33	10.50
	III	7.25	9.64	10.04	10.43
	IV	6.89	9.43	8.00	9.04
	V	6.36	9.43	9.32	9.68
	VI	12.08	10.93	9.86	11.86

TABLE 34

PERCENTAGE DECREASE IN MOISTURE WITH COOKING

	Braise I	Braise II	Oven-cooking	Deep-fat
Adductor I	25.58	19.96	6.41	20.77
II	25.12	7.95	10.08	5.67
III	21.39	14.79	10.33	16.78
IV	19.67	12.57	7.08	15.13
V	22.66	16.27	12.74	9.31
VI	21.30	17.55	7.92	12.20
Vastus Lateralis I	22.03	13.03	5.35	12.43
II	24.33	15.61	10.27	11.41
III	25.32	14.29	15.20	17.12
IV	24.90	14.40	7.00	21.42
V	23.84	18.47	8.39	17.35
VI	25.78	13.85	10.05	15.77