1976

Low temperature cooking in crockery pots or ovens as related to chemical characteristics and to survival of Clostridium perfringens in inoculated beef loaves and roasts

Alice Dittmer Sundberg
Iowa State University

Low temperature cooking in crockery pots or ovens as related to chemical characteristics and to survival of *Clostridium perfringens* in inoculated beef loaves and roasts

by

Alice Dittmer Sundberg

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Department: Food and Nutrition
Major: Food Science

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1976

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The electric crockery pot, an appliance designed for long hours of unattended cooking, has become popular because it is suitable for the life-style of contemporary Americans, especially working women. In addition to being convenient, the appliance is economical in energy consumption and practical for cooking less expensive beef cuts. In 1975, more than 20 models of slow-cookers were on the market; some were continuous-heat units[1], others were thermostatically controlled[2] (Anonymous, 1975).

Many people are questioning the safety of cooking in an electric crockery pot for 8-10 hours. In the past, similar questions were raised about cooking in an oven at low temperatures for a long time. The bacteria on raw beef cuts or ground beef are primarily psychrotrophic spoilage organisms that may produce objectionable odors from the proteolysis or lipolysis of meat stored in the refrigerator. Common genera are Pseudomonas, Achromobacter, Flavobacterium, Micrococcus and Microbacterium (Ayres, 1960). Although carefully excised muscle tissue from freshly slaughtered animals contains few organisms, after chilling, aging and transport to the retail store, counts may reach $>10^5/in.^2$ on the exposed surfaces of the carcasses (Stringer et al., 1969). Cutting and grinding further increase the exposed surfaces and distribute the bacteria throughout the meat so that counts of $>10^6/g$ in ground beef at the time of purchase are common (Haziak, 1973). Although psychrotrophic bacteria grow

---

[1]Draw 60-250 watts continuously throughout the cooking period.

[2]Draw 800-1600 watts intermittently.

on meat held at refrigeration temperatures, most genera have accelerated growth rates and enzyme activity at higher temperatures. Thus, in a crockery pot or slow oven, aerobic organisms on roasts or ground meat may multiply and produce off-odors during the 3-4 hr interval before the temperature of the meat reaches 120°F.

The anaerobic, spore forming bacterium Clostridium perfringens is frequently isolated from beef. Hall and Angelotti (1965) isolated the organism from 70% of the beef cuts and 100% of the ground beef sampled. Ingestion of a sufficiently large number of vegetative cells of C. perfringens causes gastroenteritis. The organism was implicated in 9.4% of the cases of confirmed foodborne disease in 1974 (Center for Disease Control, 1976). At refrigeration temperatures, C. perfringens does not grow and compete with spoilage organisms on beef. But during cooking the situation changes; competing organisms are killed, oxygen is driven out of the food and spores of C. perfringens are heat-activated, increasing the percentage that germinates. Thus, vegetative cells or outgrown spores of C. perfringens might multiply in meat cooked at low temperatures for a long period in a crockery pot or in an oven.

If the safety of slow cooking in an oven or crockery pot to a specified end-point temperature is established, prediction of the cooking time required to reach that temperature becomes important. Removing the meat before the recommended temperature or time could result in survival of bacteria that were present initially or that grew in the 2-4 hr interval before the temperature was 120°F.

The cooking method used on a piece of meat affects the yield of cooked meat. Some advertising for electric crockery pots claims that more juice is retained and less shrinkage occurs in meat cooked in slow-cookers than in meat cooked conventionally. Specific information is needed about the effect of long slow cooking on losses from beef roasts or meat loaves.

Some American consumers, responding to inflation or to nutrition education, are looking for value and quality in food. Although meat is an important source of B-vitamins, during cooking substantial portions of the vitamins are lost in the drippings. Researchers are concerned about vitamin B_6 in the diet because of possible interrelations of the vitamin with synthetic hormone drugs (Rose, 1966; Price et al., 1967). No information about the effect of low-temperature, long-time cooking on vitamin B_6 retention was found in the literature.

Thus, in my research, the most important objective was to determine the safety of slow-cooked beef. Inoculated rump roasts or beef loaves were used to study the survival of aerobic organisms and of C. perfringens vegetative cells and spores in beef cooked either in a crockery pot on low or in a slow oven. Cooking time, rate of temperature increase and cooking losses of top round roasts, rump roasts and meat loaves cooked at low temperatures were determined. Vitamin B_6, fat and moisture content of rump roasts cooked at low or moderate temperatures were compared.

REVIEW OF LITERATURE

A main objective of this thesis was to determine the effect of long slow cooking on microbial populations in beef. Also in my research several physical and chemical characteristics of slow-cooked beef were measured. Thus, the review will focus first on cooking time, cooking losses, and vitamin B_6 retention of slow-cooked beef. Then research related to the bacterial populations in slow-cooked meat will be reviewed with emphasis on the survival of vegetative cells and spores of C. perfringens, a food-poisoning organism used in this study to measure the safety of long slow cooking.

Cooking Time

The time required to cook meat will be influenced by a number of factors including cooking method; cooking temperature and final internal temperature; size, shape and composition of the cut; and any changes induced by previous heating (Paul, 1972).

Cooking temperature

Three studies compared cooking time in min/lb at low and moderate oven temperatures. Time required for paired rump roasts (4 lb) to cook to 160°F was 123 min/lb at 225°F, 2.6 times as long as the 47 min/lb required at 325°F (Nielsen and Hall, 1965). A similar relation between low and moderate oven temperatures was observed for 1-lb ground chuck cylinders by Funk and Boyle (1972). The cooking time to 80°C (176°F) of 234 min/lb in an oven at 121°C (250°F) was about 2.2 times longer than the 105 min/lb at 177°C (350°F). More data from the latter study will be reviewed in the

discussion of the effect of composition on cooking time. In the third study, the time required for paired rib roasts (3.9 lb) to cook to 158°F at 225°F was 98 min/lb, 2.5 times as long as the 39 min/lb at 325°F (Bayne et al., 1973a).

Cooking times for meat have been compared in ovens that differed in temperature by only 50°F. The cooking time to 185°F for round roasts weighing 1-3 lb was 268 min/lb at 250°F compared with 60 min/lb at 300°F (Griswold, 1955). To compare two very low oven temperatures, paired semimembranosus muscles (3.6 lb) wrapped in foil were cooked to 149°F, and the cooking time was 321 min/lb at 155°F and 104 min/lb at 200°F (Bramblett and Vail, 1964).

Final internal temperature

Two studies have reported on the relation between cooking time and final temperature at a low oven temperature. Institutional size (10 lb) top round roasts cooked at 200°F required an average cooking time in min/lb of 49 to 140°F, 106 to 158°F and 180 to 176°F (Marshall et al., 1960). The authors noted that variability in rate of heat penetration among roasts cooked to the same end-point made estimation of cooking time difficult. For 3.9-lb rib roasts cooked at 225°F, the cooking time in min/lb averaged 61 to 140°F, 98 to 158°F and 134 to 170°F (Bayne et al., 1973a).

Some studies have varied both oven and end-point temperature. Cover (1943) reported that bottom round roasts (3.7 lb) required 480 min/lb if cooked at 80°C (176°F) to 70°C (158°F) but 100 min/lb if cooked at 125°C (257°F) to 80°C (176°F). She stated that although the final temperature was 10°C lower in roasts cooked in the 80°C oven than in those cooked in

the 125°C oven, all roasts were "well-done." In another study that consisted of only two replications, ground chuck loaves (2 lb) required 137 min/lb if cooked at 200°F to 164°F, but only 24 min/lb if cooked at 450°F to 180°F (Baity et al., 1969).

Cooking method

When meat is cooked in a covered container, steam is formed from the meat juices. The rate of heat penetration into the meat then increases because steam conducts heat more rapidly than air (Paul, 1972). In a study of the cooking time required for frozen top round roasts (3 lb) to reach 60° or 70°C (140° or 158°F), Vollmar et al. (1976) stated that cooking in a slow-cooker required less time than cooking in a rotary hearth oven at 94°C (200°F).

Composition

The effect of the amount of fat in meat on the cooking time at low and moderate temperatures was studied by Funk and Boyle (1972). Three batches of lean ground beef with enough added fat to give mixtures containing 3, 14 or 30% fat were molded into 1-lb cylinders and cooked at 121°, 149° or 177°C (250°, 300° or 350°F). Total cooking time at each oven temperature required to reach 80°C (176°F) decreased as the fat level increased. But the following data indicate that the effect of fat level on total cooking time was greater at the low than at the moderate temperatures:

Percent fat	Oven temperature (°F)		
	250	300	350
	min	min	min
3	290	178	109
14	234	161	105
30	204	144	106

Cooking Losses

Factors affecting cooking losses from meat include cooking temperature, final internal temperature, cooking time, method of cooking and composition of the cut (Paul, 1972).

Cooking temperature

Variability in the effect of oven temperature on cooking losses in the several studies that compared low and moderate oven temperatures may be attributed to the differences in the cuts and in the final internal temperatures used by the investigators. Nielsen and Hall (1965) found that total cooking losses did not differ significantly (31.9 or 32.9%) in paired rump roasts (4 lb) cooked at 225° or at 325°F to 160°F. But in a study of paired rib roasts (3.9 lb) cooked to 158°F, Bayne et al. (1973a) reported that losses at 225°F were about 3 percentage points lower than losses at 325°F (17.9 vs. 20.6%). In contrast, in a study by Griswold (1955), total cooking losses were about 9 percentage points higher at 250°F than at 300°F for top round roasts cooked to 185°F (36.9 vs. 28.1%). Also Funk and Boyle (1972) reported that 1-lb ground chuck cylinders (14% fat) cooked to 80°C (176°F) in an oven at 121°C (250°F) had total losses of 37.0%,

about 5 percentage points higher than the losses of 32.2% for cylinders cooked in an oven at 177°C (350°F).

Final internal temperature

The effect of final internal temperature on cooking losses of meat cooked at low oven temperatures has been reported by Marshall et al. (1960) for 10-lb top round roasts cooked at 200°F. Total cooking losses increased from 10% at 140°F to 25% at 158°F and 37% at 176°F. A similar relation of end-point temperature and total cooking losses was reported for 3.9-lb rib roasts cooked at 225°F (Bayne et al., 1973a). Total cooking losses increased from 10.0% at 140°F to 17.9% at 158°F and 24.4% at 170°F.

Some investigators have varied both final internal temperature and oven temperature. In one such study, paired roasts (3.7 lb) cooked at 80°C (176°F) to 70°C (158°F) or at 125°C (257°F) to 80°C (176°F) had the same total losses of 32.6% (Cover, 1943). The author noted that the similarity in losses was remarkable in view of the large difference in cooking time, 29.8 hr at 176°F and 6.3 hr at 257°F. In another study, in which each variable was replicated only twice, ground beef loaves (2 lb) cooked at 200°F to 164°F or at 450°F to 180°F had similar total losses of 36% (Baity et al., 1969).

In summary, total cooking losses were increased with higher final internal temperatures if the oven temperature was held constant (Marshall et al., 1960; Bayne et al., 1973a), but cooking losses were not increased with higher final internal temperatures if oven temperature was increased (Cover, 1943; Baity et al., 1969).

Cooking method

Moist heat methods of cooking usually increase losses from meat compared with dry roasting, but specific conditions in the study affect the outcome (Paul, 1972). Vollmar et al. (1976) compared two methods of long slow cooking to 60° or 70°C (140° or 158°F) for frozen top round roasts (3 lb). They stated that total losses from roasts cooked in a slow-cooker at 85°C (185°F) or in a rotary hearth oven at 94°C (200°F) did not differ significantly.

Composition

In one investigation of the effect of composition of the meat on cooking losses, ground beef containing 3, 14 or 30% fat was molded into 1-lb cylinders and cooked to 80°C (176°F) at three oven temperatures (Funk and Boyle, 1972). Results indicated that total cooking losses were higher at the 3% fat level than at the 14 or 30% levels. Volatile losses decreased as the fat content increased, but there was a dramatic increase in drip losses at the 30% fat level. Average total, volatile and drip losses for each oven temperature at each fat level were:

Percent fat	Oven temperature (°F)		
	250	300	350
	total cooking losses (%)		
3	43.7	39.2	36.1
14	37.0	35.4	32.2
30	38.1	37.2	35.7
	volatile losses (%)		
3	41.7	37.2	33.4
14	33.6	32.1	29.1
30	25.5	25.5	24.9
	drip losses (%)		
3	2.0	2.1	2.6
14	3.4	3.6	3.1
30	12.6	11.9	10.8

Vitamin B_6 Retention

Vitamin B_6 is a collective term for pyridoxine, pyridoxal and pyridoxamine, three naturally occurring pyridines that function as coenzymes in amino acid metabolism. The synthetic form of the vitamin, pyridoxine hydrochloride, is readily soluble in water, stable to heat and light in acid solutions and unstable to light in neutral or alkaline solutions (Pike and Brown, 1975). The predominant forms of vitamin B_6 in animal products are pyridoxal and pyridoxamine (Polansky and Toepfer, 1969). Reports on the stability of vitamin B_6 during cooking of beef are limited in the literature.

Most studies of the vitamin B_6 content of food have used the yeast growth assay method developed by Atkin et al. (1943). All three forms of

vitamin B_6 have nearly the same activity as growth factors for Saccharomyces carlsbergensis, the organism used in this test (Brubacher and Wiss, 1968).

In the study by Lushbough et al. (1959), vitamin B_6 values for one pair of beef rib roasts and for one pair of Boston cuts were determined. One roast in each pair was tested raw and the other was tested after cooking at 325°F to 170°F. Microbiological analysis revealed that the average vitamin B_6 content per 100 g of meat was 0.32 mg in the raw and 0.28 mg in the cooked for the rib roasts and was 0.38 mg in the raw and 0.25 mg in the cooked for Boston cuts. The retention of vitamin B_6 was calculated as the ratio of the B_6 content of the cooked meat, corrected for cooking losses, to the B_6 content of the raw. Standing rib roasts retained 56% and Boston cuts retained 43% of the vitamin B_6. Assays of the drip from the roasts indicated that less than 20% of the observed loss of vitamin B_6 could be accounted for in the drip.

A study by Meyer et al. (1969) reported the vitamin B_6 content in 12 paired beef loin roasts. One roast from each pair was tested raw and the other was tested after cooking at 300°F to 158°F. Results indicated that raw meat had 0.44 mg and cooked meat had 0.43 mg of vitamin B_6/100 g of meat. Calculated on a fat-free, dry-weight basis, the retention of the vitamin in the meat was 72%. Additional analyses indicated that 16% of the vitamin B_6 was recovered in the drip.

The effect of braising on the vitamin B_6 content of 12 paired top round roasts also was reported in the study by Meyer et al. (1969). One roast of each pair was tested raw and the other roast was seared, cooked in a covered skillet in an oven at 300°F to 210°F and then tested. The

average vitamin B_6 content of the raw meat was 0.50 mg/100 g and of the cooked meat was 0.45 mg/100 g. Retention of vitamin B_6 in the meat averaged 49% and in the drip averaged 34%.

No studies were found that investigated the effect of long slow cooking on the vitamin B_6 retention of beef.

Bacterial Populations

Aerobic organisms

Most raw meat contains a variety of bacterial contaminants, including psychrotrophic, mesophilic and thermophilic organisms. Aerobic populations on surfaces of wholesale cuts might average 10^4 to $10^5/cm^2$ (Ayres, 1955). Although the flora on chilled meat is heterogeneous, the majority of the genera are transient or adventitious. But after the meat has been stored, members of the genera Pseudomonas and Achromobacter, which are psychrotrophic, spoilage organisms, are present in the largest numbers (Ayres, 1955).

During long slow cooking, the temperature of meat rises very gradually and passes through optimum growth zones for various contaminants. The optimum growth zones, according to Frazier (1967), are between 20° and 45°C (68°-113°F) for most psychrotrophic and mesophilic organisms. Although some thermophilic organisms have optimum temperatures around 55°C (131°F), the ability of most bacteria to multiply declines rapidly above 45°C (113°F) and most nonsporing bacteria are killed at temperatures above 60°C (140°F), the length of time required depending on the type of organism (Hobbs, 1968).

Conventional cooking methods kill most of the aerobic organisms in meat, especially psychrotrophic bacteria. Counts of 10^6/g in raw meat loaves were reduced to insignificant numbers when loaves were cooked in an oven at 325°F to 165°F (Ziprin, 1975).

Only two studies were found on the effect of long slow cooking on populations of aerobic bacteria in meat. In one recent study on meat loaves cooked in an electric slow-cooker, aerobic plate counts at the end of the cooking period showed "drastic" reductions compared with the initial counts in the raw loaves (Peters, 1974). In the other study, the aerobic plate counts were monitored throughout the cooking period for ground beef (2-lb lots) cooked in electric Crock-Pots[1] (Wells and Kennedy, 1972). Counts were reduced from more than 10^7/g at the start (80°F) to 10^3/g at 130°F for the 3 1/2 and 4 1/2-qt models and at 140°F for the 2-qt model. The temperatures at which no bacteria were recovered ranged from 140°-150°F.

Clostridium perfringens

One ubiquitous organism associated with foodborne disease and frequently isolated from raw meat is C. perfringens (Bryan and Kilpatrick, 1971; Haziak, 1973; Ladiges et al., 1974). Bacteria of this species of anaerobic spore formers cause gastroenteritis if a large number of vegetative cells are ingested (Hauschild and Thatcher, 1967).

Temperature is one of several factors that affect growth and survival of C. perfringens in food; available nutrients, pH, oxidation-reduction

[1]Models 3100 (3 1/2 qt), 3300 (4 1/2 qt) and 3103 (2 qt), Rival Manufacturing Co.

potential, water activity, curing agents and other bacteria also have an effect (Walker, 1975). In considering the effect of temperature on C. perfringens one has to consider not only vegetative cell growth and destruction but also spore activation and destruction.

Specific information was obtained by Barnes et al. (1963) and by Brown and Twedt (1972) about temperatures permitting growth of vegetative cells of C. perfringens in beef. In their studies, raw or cooked beef cubes inoculated with vegetative cells were held at various temperatures. Although the method of inoculation and temperatures studied varied, the experiments indicated that in beef, growth of C. perfringens occurred over a temperature range of 20°-51°C (68°-124°F).

Spores of C. perfringens are more resistant than vegetative cells to temperatures encountered during cooking. But the heat resistance of the spores varies among strains; some survive boiling for more than an hour, whereas others are killed at 95°C (203°F) within a few minutes (Hall et al., 1963; Rey et al., 1975). Strains associated with foodborne disease outbreaks may produce either the heat-resistant or the heat-sensitive type of spores (Hall et al., 1963). Temperatures in the range 60°-80°C (140°-176°F) activate the less-resistant type of spores, i.e., increase the percentage that germinate in a favorable environment (Ahmed and Walker, 1971). Thus, cooking meat to temperatures above 140°F may activate any C. perfringens spores present. But because germinated spores lose their heat resistance, additional exposure to heat may kill them. For instance, in the study by Barnes et al. (1963), 25-g beef cubes were inoculated with Cl. welchii, cooked in a water bath at 70°C (158°F) for 30 min and then

held at 37°C (99°F) for 2 days. As indicated by low counts for heated portions of sample homogenates, almost all the spores germinated and lost their resistance to heat.

The effect of a conventional cooking method on C. perfringens in beef loaves was reported by Ziprin (1975). In meat loaves inoculated with a mixture of vegetative cells (10^5/g) and spores (10^3/g), cell counts were reduced by 2.5 log cycles and spore counts, determined by heating sample homogenates at 80°C for 15 min, were reduced by 1.3 log cycles when the loaves were cooked in an oven at 325°F to 165°F. Outgrown spores may have contributed to the vegetative cell counts since the final internal temperature of the loaves was sufficient to activate the spores.

In a study of a moist heat method of cooking, Sutton et al. (1972) inoculated two 2.7-kg (6 lb) beef roasts with Cl. welchii vegetative cells of one serotype and spores of another, cooked one roast in a moist air oven at 82°C (180°F) and 95% relative humidity and one in a conventional oven at 213°C (415°F) to 71°C (160°F) and then cooled the roasts overnight at room temperature (13°-15°C). Large numbers of cells (>10^5/g) were recovered after cooling of the inoculated cooked roasts. But since no cells were isolated corresponding to the serotypes of the vegetative cells in the inoculum, all cells apparently multiplied from heat-activated spores.

Only one study of the effect of long slow cooking on Cl. welchii in beef was found. Roasts (4 lb) inoculated with a mixture of vegetative cells and spores and then cooked at 200°F for 16 hr to approximately 150°F gave a higher recovery of Cl. welchii than inoculated roasts cooked at

400°-450°F to a final temperature of 155°-160°F (Sylvester and Green, 1961).

PROCEDURE

Cooking in a crockery pot[1] was compared with roasting in a low or moderate oven[2] in relation to the effects on cooking time, cooking losses, microbial flora, physical characteristics, chemical composition and nutritive value of beef. Three experiments were conducted, two to determine the safety of slow-cooked meat and one to determine the efficiency of the crockery pot for slow cooking.

One primary concern about long slow cooking is its safety. Thus, in Experiment I the destruction of aerobic bacteria and of added C. perfringens vegetative cells and spores was measured as an indication of the safety of long slow cooking of rump roasts. Inoculated rump roasts were cooked at low temperatures in a crockery pot for 10 hr or in an oven at 225°F (107°C) for 9 hr or roasted in an oven at 350°F (177°C) to 170°F (77°C). In Experiment II, meat loaves inoculated with C. perfringens were cooked in a crockery pot set on low or in an oven set at 325°F (163°C) to different temperatures, 120°, 135°, 150° or 165°F (49°, 57°, 66° or 74°C).

The effects on cooking time and cooking losses of top round roasts cooked to 150°F (66°C) in a crockery pot set on low, in an oven set at 200°F (94°C) or in an oven set at 350°F (177°C) were compared in Experiment III.

---

[1]Model 3100 (capacity, 3 1/2 qt; wattage on low setting, 70 w) or Model 3300 (capacity, 4 1/2 qt; wattage on low setting, 95 w), Rival Manufacturing Co.

[2]Model J349001DC (wattage on "bake" setting, 4.6 kw) or Model J390003HT (wattage on "bake" setting, 3.4 kw), General Electric Co.

The variables studied and parameters evaluated are summarized for each experiment in Table 1.

Table 1. Variables and parameters studied in Experiments I, II and III

Experiment[a]	I	II	III
Variables			
Meat:	Inoculated rump roasts	Inoculated meat loaves	Top round roasts
Crockery pot model:	Rival 3100	Rival 3100	Rival 3300
Cooking method:	CP[b] (200°F) LO (225°F) MO (350°F)	CP (200°F) -- MO (325°F)	CP (200°F) LO (200°F) MO (350°F)
End point: temperature	170°F (MO)	120°, 135°, 150°, 165°F	150°F
or time	10 hr (CP) 9 hr (LO)		
Parameters			
Cooking time	x	x	x
Cooking losses	x	x	x
Aerobic plate count	x	x	-[c]
Clostridium perfringens			
Vegetative cells	x	x	-
Spores	x	x	-
Chemical composition			
Moisture and fat	x	-	-
Vitamin B_6	x	-	-

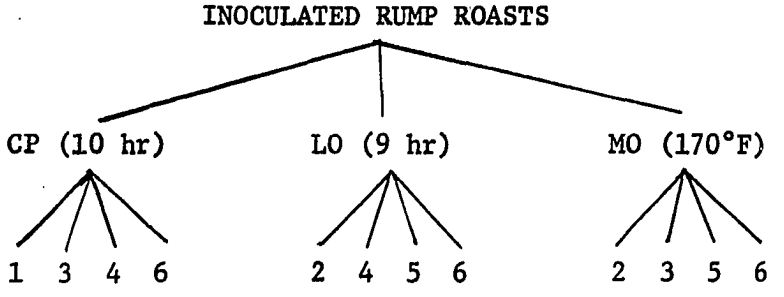
[a] I: May and June 1974; II: March and April 1975; III: Study A, May 1973; Study B, February 1975.

[b] CP: electric crockery pot, low; LO: low oven, 200° or 225°F; MO: moderate oven, 325° or 350°F.

[c] - = parameter not tested.

Experiment I - Inoculated Rump Roasts

In Experiment I, the effect of three methods of cooking on the survival of aerobic bacteria and of C. perfringens vegetative cells and spores was determined. Twelve boneless rolled rump roasts were inoculated with C. perfringens S-45 and cooked in a crockery pot set on low (CP) for 10 hr, in an oven set at 225°F (LO) for 9 hr or in an oven set at 350°F (MO) to a final internal temperature of 170°F. Data were obtained on cooking time and cooking losses, and time-temperature relations were calculated. Moisture and fat content of the raw and cooked meat were analyzed. A microbiological assay was used to determine the vitamin B_6 retention in the cooked meat. The three cooking methods (twc each week) were replicated four times over a period of 6 weeks in May and June 1974. The cooking methods tested each week were:



Preliminary work indicated that, although a 10-hr cooking period was satisfactory for a roast cooked in the CP, a roast cooked 10 hr in the LO at 225°F was overdone. Thus a 9-hr cooking period was chosen for roasts cooked in the LO.

Each week of Experiment I, the following schedule was used: (1) a

series of subcultures was begun 3 days before the test day to prepare the sporulated inoculum; (2) 1 day before the test day, two roasts were purchased, inoculated and refrigerated; (3) on the test day, roasts were cooked, samples for chemical analysis were frozen, and samples for bacterial enumeration were plated; and (4) on the 2 days succeeding the test day, bacterial colonies were counted.

Roasts, inoculation and sampling

The rump roasts were purchased from a local grocery store. Roasts, cut from the same location, i.e., the "big end," of larger rump roasts, ranged in weight from 3.1 to 4.2 lb and averaged 3.5 lb.

Just before inoculation, the elastic webbing around each roast was removed. Samples (50 g) for moisture and fat determination and for vitamin B_6 assay were obtained by cutting a slice from the flat outside surface of the roast. The samples were wrapped in polyethylene and aluminum foil and placed in glass jars for storage at 0°F (-18°C) until assayed.

C. perfringens S-45 was obtained from the Department of Food Technology, Iowa State University. An inoculum suspension containing vegetative cells and spores was prepared as described in Figure 9, Appendix. The suspension was used immediately after preparation.

Two 2 x 3 1/2-in. areas were marked with thread on the inner surface of each roast. One ml of the inoculum suspension was spread over each marked area by moving a pipet back and forth five times above the surface and releasing the suspension dropwise. After the roast was rolled so that the inoculated surface was inside, it was inserted into fresh webbing,

wrapped in polyethylene film and held in a household refrigerator at 42°F for 16 hr.

The concentration of vegetative cells in the suspension was checked by plating appropriate dilutions in SPS agar (Difco), and of spores, by heating a 3-ml portion of the suspension at 80° ± 1°C for 15 min and then plating. Log counts of cells in the inoculum for each of the replications ranged from 8.80 to 9.09 and averaged 8.80/ml; spore counts ranged from 5.08 to 5.57 and averaged 5.32/ml.

The next day, samples were taken from each roast for enumeration of aerobic bacteria and of C. perfringens vegetative cells and spores in the raw roast. The webbing was removed and forceps and a sterile scalpel were used to cut out one of the two inner inoculated surface areas as a thin (1/4 - 3/8 in.) slice that averaged 28 g. Raw slices were held in sterile petri dishes at 42°F until plated not more than 6 hr later. The roast was rolled and inserted into fresh webbing.

Cooking

Each roast to be cooked in the CP was placed in the 3 1/2-qt pot equipped with a circular rack 1/2 in. high. The pot and roast were weighed and an iron-constantan thermocouple welded into a stainless steel hypodermic needle was inserted into the roast at the geometric center. To measure air temperature, another thermocouple was placed so that the tip was approximately 1/2 in. from the side of the CP and 1/2 in. from the roast. Temperatures were monitored on a recording potentiometer (Honeywell Electronik 16, Model 70735-01-1). A flat stainless steel lid, 8 5/8 in. in diameter, which contained two holes for the thermocouple wires, was

used to replace the glass lid on the CP, see Figures 1 and 2. Split corks held the thermocouples in place and sealed the holes. The control on the CP was turned to the low setting (200°F) for 10 hr.

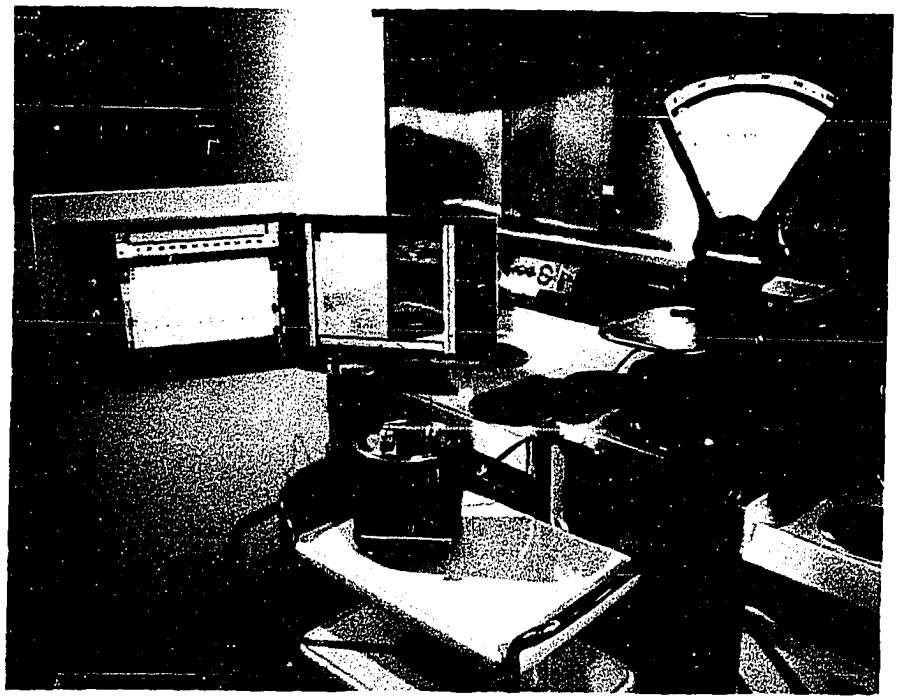
Each roast to be cooked by the LO or MO method was placed on a rack in a 9 x 13 x 2 in. aluminum pan and weighed. A thermocouple was inserted into the geometric center of the roast. A thermocouple for oven air-temperature measurements was placed to the left of the center of the oven cavity and approximately 3 in. from the roast. The oven was turned on after the roast was placed on a shelf 6 in. from the bottom of the oven. For the LO treatment, the oven thermostat setting was 225°F, and the roast was removed after 9 hr. For the MO treatment, the oven thermostat setting was 350°F and the roast was removed when the final internal temperature was 170°F.

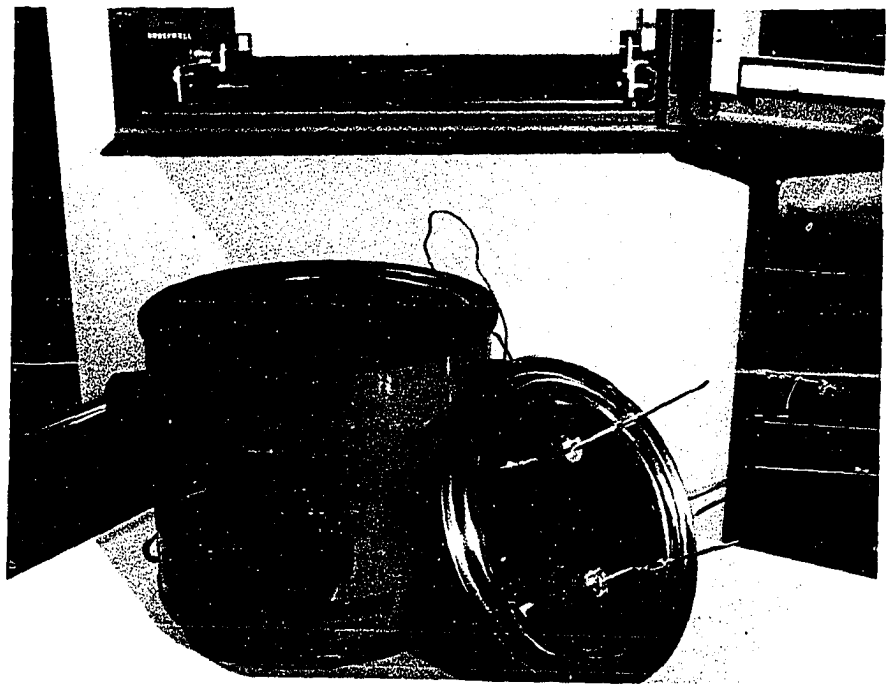
When the designated end-point for the cooking period was reached, weights of the roast and drippings were obtained for calculation of cooking losses. The aroma of the roast and the appearance of the fat and lean were noted.

Ten minutes after cooking ended, each roast was unrolled. The surface area that was inoculated before cooking was removed in the manner described for cutting the raw sample. Weight of the cooked samples averaged 22 g and the surface area averaged 34 cm^2. Samples were held at 42°F until plated not more than 6 hr later. The remainder of the roast was cubed and used for assays of chemical composition. The cubes were mixed, divided into two 150-200 g samples, wrapped in polyethylene and foil and stored at 0°F in a household freezer until assayed.

Figure 1. Crockery pot, recording potentiometer used to monitor air and meat temperatures and Toledo scales

Figure 2. Thermocouples for measurement of air and meat temperatures inserted through holes in metal lid of the crockery pot





Bacterial enumeration

Enumeration of aerobic bacteria and of C. perfringens vegetative cells and spores was done on the thin slices cut (1) just before cooking and (2) 10 min after cooking from the inoculated inner surfaces of the rump roasts. Each sample was aseptically cut into small pieces, diluted 1:5 (w/w) with 0.1% peptone solution and homogenized 3 min in an Oster blender (Model 10). Then decimal dilutions were prepared.

To enumerate aerobic bacteria, aliquots of the appropriate dilutions were mixed with Plate Count agar (Difco) by the pour plate method. Incubation was at 30°C for 2 days.

Pouches used in enumeration of C. perfringens were prepared by the method of Bladel and Greenberg (1965) from a laminated film [75 Maraflex (30), American Can Co.] consisting of an outer layer of Mylar (polyester), a middle layer of Saran (polyvinylidine chloride) and an inner layer of polyethylene. For C. perfringens vegetative cell counts, 1.0 or 0.1 ml of the selected dilutions and 16 ml of Sulfite-polymixin-sulfadiazine (SPS) agar (Difco) were mixed in each plastic pouch. For counts of C. perfringens spores, 10 ml portions of the 1:5 homogenates were equilibrated to 80°C in a water bath (about 4 min) and then held at 80° ± 1°C for 15 min in 15 x 150 mm test tubes. After heating, the tubes were cooled in tap water and portions of the heated homogenates were diluted and plated as described for the vegetative cell counts. All pouches (for enumeration of vegetative cells or spores) were incubated at 37°C for 24 hr. Black colonies were counted with the aid of a dissecting microscope (AO Stereostar).

Composition analysis

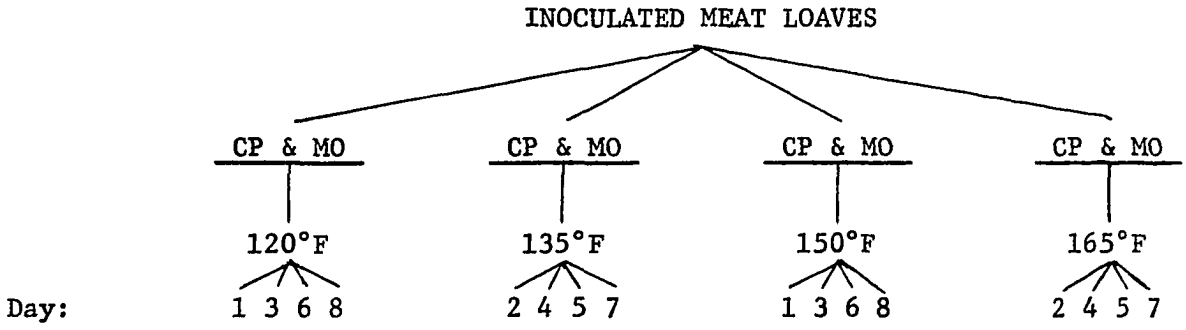
Moisture and fat analysis Samples for moisture and fat analysis were stored 3 mo at 0°F. Raw and cooked samples from each roast were assayed on the same day. After each sample was thawed for approximately 16 hr at 38°F, it was ground twice through the 3/16-in. plate of the grinder attachment of a KitchenAid mixer (Model K45 or K5A). For moisture determination, 5 g of ground sample were weighed into Teflon pans and dried in the convection oven of a Brabender Semi-Automatic Moisture Tester set at 102°C. Then each dried sample was refluxed for 6 hr with petroleum ether (boiling point range, 30° - 60°C) in a Goldfisch extraction apparatus to determine ether-extractible material (fat content).

Vitamin B_6 assay *Saccharomyces uvarum* Y-1089, the assay organism, was obtained from Northern Regional Research Laboratory, U.S. Department of Agriculture, and the pyridoxine hydrochloride standard from Sigma Chemical Co. The assay medium was Pyridoxine Y medium (Difco). Meat samples for vitamin B_6 assay were stored 6 mo at 0°F, thawed at 38°F for approximately 16 hr and then ground twice. The 20 g of ground sample were diluted 1:10 with distilled water and homogenized 2 min in an Oster blender. A 20 ml portion of the homogenate was diluted with 1 ml 10 N HCl and 161 ml distilled water. The vitamin B_6 was extracted, filtered and assayed by the procedures recommended by The Association of Vitamin Chemists, Inc. (1966) except that the standard solution and the inoculum were prepared as suggested by Difco Laboratories (1972). The filtrate was diluted 1:10 with distilled water, making a final dilution of 1:1000. Each test solution was assayed at three levels in duplicate test tubes on two

succeeding days. All steps in the assay were done in a darkened room. Yeast growth was determined turbidimetrically.

Experiment II - Inoculated Meat Loaves

The survival of aerobic bacteria and of C. perfringens vegetative cells and spores was compared in inoculated meat loaves cooked to 120°, 135°, 150° or 165°F in a crockery pot (CP) set on low or in a moderate oven (MO) set at 325°F. Rates of heat penetration and cooking losses also were determined. Four replications were made in March and April 1975. On each test day, four loaves made the previous day were used to compare two cooking methods and two end-point temperatures. Thus, two test days were required to complete one replication. End-point temperatures tested the same day differed by 30°F, i.e., 120° vs. 150°F and 135° vs. 165°F. The cooking methods, final temperatures and test days for Experiment II were:



The day before each test day, ground chuck for four meat loaves was purchased from a retail grocery store and sampled for information about populations of aerobic bacteria and of C. perfringens. Then the meat was inoculated and made into loaves. The next day the loaves were sampled

raw, cooked and sampled again. Plating of all samples was done that same day.

Meat loaves

For bacterial enumeration of the uninoculated ground chuck for four meat loaves (6.4 lb), a 60-g sample was taken and held in a covered sterile beaker at 45°F for 24 hr. After sampling, the ground chuck was inoculated with C. perfringens S-45, originally obtained for Experiment I and maintained on Cooked Meat medium (Difco). Inoculum for four meat loaves was prepared as described in Figure 9, Appendix. Log counts of cells in the inoculum for each of the test days ranged from 8.18 to 8.94 and averaged 8.67/ml; spore counts ranged from 5.40 to 5.95 and averaged 5.67/ml. The amount of ground chuck (1368 g) for two meat loaves (2000 g of meat loaf mixture) was combined with 20 ml of the inoculum suspension. The inoculum was dispensed from a disposable syringe in units of 2 ml. The meat was cut and turned 3 times after each addition of the inoculum.

After the meat was inoculated, meat loaves were prepared. The meat loaf recipe contained ingredients in the proportion specified by the U.S. Department of Agriculture School Lunch Program recipe D-36 except that all seasonings were omitted except salt. Ingredients and their source and the mixing procedure for the inoculated meat loaves are presented in Figure 10, Appendix. Each 2000 g of meat loaf mixture was formed into loaves by placing approximately 500 g in each of two sterile cans (5 in. in diameter) and pressing the mixture with 10 pats of a rubber spatula. Then the remaining mixture was divided between the two cans. A waxed paper circle was placed on top of each loaf and the cans were covered with foil and

plastic lids. The loaves were refrigerated and then two more loaves were prepared. All four loaves were stored at 45°F until cooked the following day.

Cooking

The next day, each loaf was removed from the refrigerator and assigned to one of the two cooking methods (CP or MO) and to one of the two end-point temperatures to be tested that day. The two loaves assigned to the same final temperature but to the different methods were cooked at approximately the same time of day.

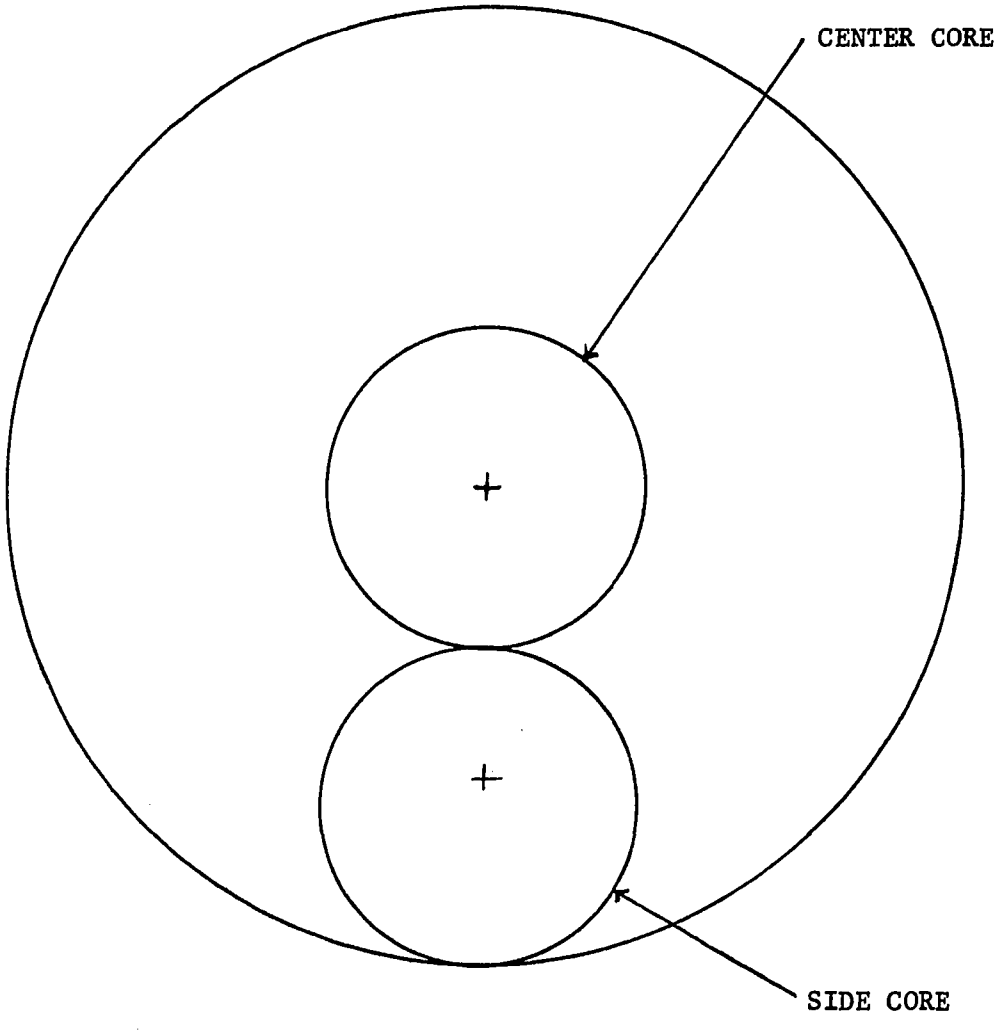
Each loaf to be cooked in the 3 1/2-qt CP was unmolded into the pot. A 60-g sample, half from the top and half from the bottom of the circular meat loaf, was taken for bacterial enumeration. The sample was covered and refrigerated at 45°F for approximately 4 hr until plated. Then the meat loaf and CP were weighed. The raw weight of the 3-in. tall circular loaves ranged from 908 to 925 g and averaged 916 g.

After each loaf was weighed, one thermocouple was inserted at the geometric center and another was inserted 1 1/2 in. deep and 1 in. from the side, see Figure 3. The temperature of the air in the CP was measured with a thermocouple suspended approximately 1 in. above the meat loaf and 1 in. from the wall of the CP. Thermocouples were held in place by the split corks that stoppered the holes in the stainless steel lid, see Figures 1 and 2. The control on the CP was turned to the low setting (200°F) and temperatures were monitored throughout the cooking period. In addition, the exact time that the temperature at the center of each meat loaf reached 60° and 90°F was recorded.

Figure 3. Locations of thermocouples used to monitor meat loaf temperatures and of samples for bacterial enumeration of cooked loaves, Experiment III. Actual size of meat loaf

MEAT LOAF - TOP VIEW

X = THERMOCOUPLE LOCATION



Each meat loaf cooked in the MO was unmolded into a 2-qt circular Pyrex casserole, sampled and weighed. Thermocouples were inserted as described for meat loaves cooked in the CP. The thermocouple for air-temperature measurement in the oven was placed near the center of the upper half of the cavity. The meat loaf was placed in the preheated MO (325°F). Loaf and air temperatures were monitored.

When the designated final temperature was reached, each meat loaf was removed from the CP or MO, and weights of the loaf and drippings were obtained for calculation of cooking losses. After the loaf was weighed, cylindrical samples weighing 70-100 g and approximately 1 3/4 in. in diameter were taken at the center and at the side, see Figure 3. The samples from each location contained meat from the top, center and bottom of the loaf. Samples were placed in sterile beakers, covered and refrigerated at 45°F for 6 ± 3 hr until plated. The aroma and color of the outside and of the interior of the loaf were noted.

Bacterial enumeration

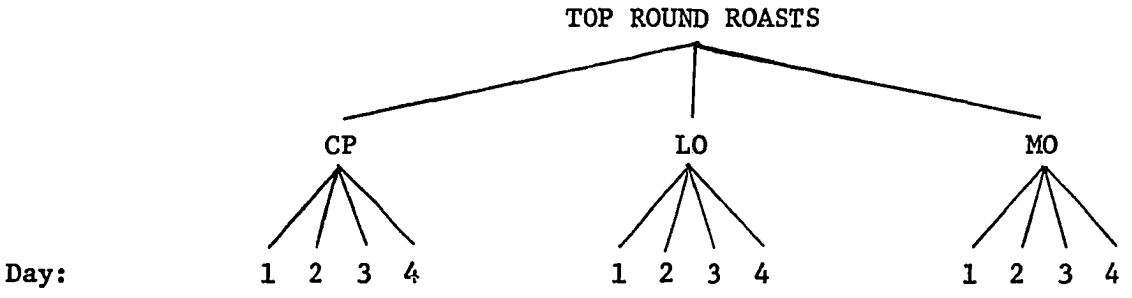
Each day that the four meat loaves were cooked, aerobic bacteria were enumerated in samples of the following: (1) raw ground chuck, (2) one of the raw loaves, (3) center core of each of the cooked loaves and (4) side core of each of the cooked loaves. C. perfringens vegetative cells and spores were enumerated in the same samples as for the aerobic plate counts except that counts were obtained for each of the raw meat loaves.

Each sample was subdivided with a sterile spatula, and a representative subsample (50 g) was weighed. The subsample was homogenized for 3 min with 200 ml of 0.1% peptone and then serially diluted. The same

plating procedures described for bacterial enumeration of rump roast samples in Experiment I were used for obtaining counts of aerobic bacteria and of C. perfringens vegetative cells and spores in the ground chuck or meat loaf samples in Experiment II. The heat-shock procedure, incubation conditions and counting method were also the same in the two experiments.

Experiment III - Top Round Roasts

Experiment III was conducted as two studies, designated A and B. Study A was performed in May 1973 and Study B in February 1975. In each study the time required to reach 150°F and the cooking losses were determined for 4.4-lb top round roasts cooked by three methods, 4 1/2-qt crockery pot on low (CP), oven at 200°F (LO) and oven at 350°F (MO). The studies were identical with one exception; in Study A the model of the ranges used for the LO and MO treatments was General Electric model J349001DC, whereas in Study B the model was General Electric J390003HT. Each study consisted of four replications done on consecutive days; all three cooking methods were tested the same day. Thus the cooking methods and test days were:



Roasts

For each replication, three top round roasts, graded U.S. Choice, were purchased from a local grocery store. The 2 1/2-in. thick roasts, cut from the wholesale round perpendicular to the main muscle fiber direction, contained portions of the semimembranosus, adductor and gracilis muscles. Roasts were 8 1/2 to 10 1/2 in. in length and 3 3/4 to 5 in. in width. After the meat was brought to the laboratory, it was held in a household refrigerator at 38°F for 12 to 16 hr until prepared for cooking.

Cooking

A 4 1/2-qt electric crockery pot and two 30-in. electric range ovens were used for cooking the beef roasts. Before cooking, each roast was circled with string to make it more compact. Each roast to be cooked in the CP was placed in the 4 1/2-qt pot equipped with a circular rack 1/2 in. in height. The roast and CP were weighed and thermocouples were inserted into the roast (1) at the geometric center and (2) 1/2 in. deep, 2 in. from one end and 2 in. from the side. For air-temperature measurements, a thermocouple was placed approximately 1 in. from the side and 2 in. from the bottom of the CP. Then the CP was covered with the transparent plastic lid and the control was turned to the low setting (200°F). Throughout cooking, temperatures were monitored on the chart of the recording potentiometer and recorded in the data book at 15-min intervals. In addition, the exact time that the center of the roast reached 60° and 120°F was recorded.

Each roast to be cooked in the LO or MO was placed on a rack in a 9 x 13 x 2 in. aluminum pan and weighed. The thermocouples were inserted into

the roasts at the locations described for a roast cooked in the CP. A thermocouple was placed near the center of the oven cavity to measure the air temperature during cooking. Each roast was placed on a shelf approximately 6 in. from the bottom of a preheated oven set at 200° or 350°F. Temperatures of the roasts and ovens were monitored as described for a roast cooked in the CP. Variables of oven temperature were assigned so that each of the two ovens was used an equal number of times at each setting.

When the temperature at the center was 150° ± 2°F, the roast was removed from the CP or the oven. Weights of the roast and drippings were obtained for calculation of cooking losses.

Statistical Analysis

Data for Experiments I and II and for Studies A and B of Experiment III were analyzed separately by an analysis of variance appropriate for the design. The treatments and design are presented in the introductory section of the procedure for each experiment. Four replications were made in each experiment or study. Sources of variation and degrees of freedom were:

Source of variation	Degrees of freedom
Experiment I	
Replication	3
Cooking method	2
Error	6
Total	11

Source of variation	Degrees of freedom	
Experiment II		
Replication	3	
Cooking method (CM)	1	
Final temperature (T)	3	
Interaction (CM x T)	3	
Error	21	
Total	31	
Experiment III		
	Study A	Study B
Replication	3	3
Cooking method	2	2
Error	5	6
Total	10	11

The 0.01 level of significance was used for all variables. When the F value indicated that the effect of cooking method (Experiments I and III) or of temperature (Experiment II) on cooking time or cooking losses was significant, the value for the least significant difference (LSD) among means at the 0.01 level was calculated. In Experiment II, comparisons among means for total cooking losses and for bacterial counts were made by partitioning the degrees of freedom for final temperature in the analysis of variance. The comparisons were as follows:

Total cooking losses	Bacterial counts
120° vs. 135°F	120° vs. 135°F
120°, 135° vs. 150°, 165°F	135° vs. 150°F
150° vs. 165°F	150° vs. 165°F.

RESULTS AND DISCUSSION

Three experiments were conducted to determine the effect of cooking at low temperatures in a crockery pot or an oven or at moderate temperatures in an oven on the safety of beef roasts and meat loaves. Data were obtained for calculation of cooking losses and rate of temperature increase in the center of inoculated rump roasts (Experiment I), inoculated meat loaves (Experiment II) and uninoculated top round roasts (Experiment III). Aerobic bacteria on the inside surfaces of the rump roasts and throughout the meat loaves were enumerated. Survival of vegetative cells and spores of C. perfringens also was determined for inoculated roasts and loaves. Rump roast samples were assayed for moisture, fat and vitamin B_6 content.

Experiment I - Inoculated Rump Roasts

Boneless rump roasts that weighed approximately 3.5 lb were unrolled, inoculated with C. perfringens S-45 vegetative cells and spores and re-rolled. Then the roasts were cooked in a 3 1/2-qt crockery pot (CP) for 10 hr, in an oven set at 225°F (LO) for 9 hr or in an oven set at 350°F (MO) to a final internal temperature of 170°F. Data were obtained for computation of rate of temperature increase and cooking losses. Survival of aerobic bacteria and of C. perfringens vegetative cells and spores was determined for the cooked roasts. Raw and cooked meat were analyzed for moisture, fat and vitamin B_6 content.

Air temperature

Initial temperature of the air in the crockery pot was 60°F. The air temperature rose slowly to 110°F at 1 hr, 135°F at 2 hr, 160°F at 4 hr and 185°F at 8 hr and then did not increase or fluctuate for the next 2 hr. In contrast, temperatures in the ovens rose to the set temperature within 15 min and thereafter fluctuated in the temperature range of 206°-242°F for the oven set at 225°F and of 325°-348°F for the oven set at 350°F.

Cooking time

The raw weight, final internal temperature and cooking time in total min and min/lb are presented for each roast in Table 19, Appendix. Examination of the data, summarized in Table 2, indicated that roasts cooked in the CP on low for 10 hr averaged 175 min/lb and reached an average

Table 2. Average[a] raw weight, final temperature, cooking time and rate of temperature increase for boneless rump roasts cooked by three methods, Experiment I

Cooking method	Raw weight lb	Final temperature °F	Cooking time		Rate of temperature increase °F/min
			Total min	Min/ lb	
Crockery pot, low, 10 hr	3.4	178	600	175	0.22
Oven, 225°F 9 hr	3.6	185	540	155	0.26
Oven, 350°F to 170°F	3.5	170	136	39	0.90

[a]Average for 4 roasts.

final internal temperature of 178°F. Roasts cooked in the LO (225°F) for 9 hr averaged 155 min/lb and reached a final internal temperature of 185°F, 7°F higher than for the CP roasts. MO (350°F) roasts reached the specified final internal temperature of 170°F in an average of 136 min or 39 min/lb.

Data from the strip chart of the recording potentiometer were used to determine the time required for each roast to reach 170°F. The average time was approximately 460 min (135 min/lb) for CP roasts and 285 min (79 min/lb) for LO roasts compared with 136 min (39 min/lb) for MO roasts. Thus, roasts cooked slower by the CP method than by either the LO or MO method.

If the end-point had been 160°F for roasts cooked in the oven at 225°F, the required cooking time would have been 63 min/lb. A much longer cooking time of 123 min/lb was reported by Nielsen and Hall (1965) for 4-lb rump roasts cooked in an oven at 225°F to 160°F.

Rate of temperature increase

The rate of temperature increase, averaged for the whole cooking period, is presented for each roast in Table 19, Appendix. The rate averaged 0.2°F/min from 47°F to 178°F for CP roasts, 0.3°F/min from 47°F to 185°F for LO roasts and 0.9°F/min from 47°F to 170°F for MO roasts (Table 2). The rate of temperature increase also was calculated for the interval 60°-120°F, the growth zone for mesophilic bacteria. The rate in °F/min was 0.4 for CP roasts, 0.7 for LO roasts and 1.2 for MO roasts.

Cooking losses

Total losses

Total losses for individual rump roasts are presented in Table 20, Appendix. Analysis of variance indicated that cooking method significantly ($p<0.01$) affected total losses (Table 21, Appendix). Use of the LSD criterion indicated that the only significant difference in total losses among cooking methods was between the mean of 32.0% for MO roasts and the mean of 38.2% for CP roasts or of 39.4% for LO roasts (Table 3).

Total cooking losses of 38.2% for roasts cooked 10 hr in the CP were similar to losses of 37% reported by Paul et al. (1950) for boneless rump roasts braised 3 1/2-4 hr. Total cooking losses of 32.0% for roasts cooked to 170°F in the MO were practically the same as losses of 32.9% reported for 4-lb rump roasts cooked at 325°F to 160°F by Nielsen and Hall (1965).

Volatile losses

Volatile losses for individual rump roasts are presented in Table 20, Appendix. Analysis of variance indicated that the cooking method significantly ($p<0.01$) affected volatile losses (Table 21, Appendix). Comparison of the average volatile losses for each cooking method and use of the LSD criterion indicated that the mean of 2.8% for CP roasts was significantly ($p<0.01$) less than the means of 34.0% for LO roasts and of 27.5% for MO roasts (Table 3). But the average volatile losses for LO and MO roasts also were significantly different.

Drip losses Drip losses for individual rump roasts are presented in Table 20, Appendix. Analysis of variance indicated that cooking method significantly ($p<0.01$) affected drip losses (Table 21, Appendix). Examination of the data and use of the LSD criterion indicated that the only treatment that made any difference in the drip losses was cooking in the CP (Table 3). The mean of 35.3% for CP roasts was significantly greater than the means of 5.5% for LO roasts and of 4.5% for MO roasts.

Table 3. Average[a] total, volatile and drip losses for boneless rump roasts (3.5 lb) cooked by three methods, Experiment I

Cooking method	Cooking losses		
	Total %	Volatile %	Drip %
Crockery pot, low, 10 hr	38.2	2.8	35.3
Oven, 225°F, 9 hr	39.4	34.0	5.5
Oven, 350°F to 170°F	32.0	27.5	4.5
LSD[b]	4.6	4.4	3.0

[a]Average for 4 roasts.

[b]LSD, least significant difference at 0.01.

In summary, composition of the cooking losses differed markedly among the treatments. Total losses were composed of 92% drip losses in the CP treatment, but were composed of 86% volatile losses in the LO and MO treatments.

Aroma and appearance of fat and lean

On the basis of recorded observations, roasts cooked 10 hr in the CP smelled like stewed meat. The fat cover remained ivory but the lean meat was medium brown with a reddish cast. LO and MO roasts had a more intense beef aroma than CP roasts. The fat cover on these roasts was golden brown or bronze and the cooked lean meat was greyish tan to medium brown (MO roasts) or medium brown with very dark brown areas (LO roasts). Vollmar et al. (1976) reported that 3-lb top round roasts cooked from the frozen state in a slow-cooker at 85°C for 10 hr were gray-brown at the surface and were brown throughout most of the roast.

Chemical composition

Moisture content and ether-extractible material (fat content) of raw and cooked rump roasts were measured to compare the effects of long slow cooking and of conventional roasting on the composition of the meat. Vitamin B_6 content of the roasts was assayed to obtain an indication of the effects of the cooking methods on the retention of a water-soluble vitamin.

Moisture content Moisture content of samples of raw and cooked rump roasts are presented in Table 22, Appendix. Analysis of variance indicated that the three cooking treatments did not differ in their effects on the moisture content of the cooked meat (Table 23, Appendix). The average moisture content for the 12 raw rump roasts was 70.5%. For the four roasts cooked by each method, the moisture content averaged 56.5% for CP roasts, 54.0% for LO roasts and 57.4% for MO roasts (Table 4).

Thus the moisture content of the roasts was reduced by 13-16% during cooking.

The moisture content of cooked roasts in my experiment was similar to the 54.9% reported by Leverton and Odell (1958) for the "lean-plus-marble" samples from rump roasts braised 3 1/2 hr. All roasts cooked by the three methods had lower moisture content than the average of 60.4% reported by Watt and Merrill (1963) for the separable lean portion of rump roasts.

Table 4. Means and standard deviations for moisture and fat content of boneless rump roasts (3.5 lb), Experiment I

Treatment	Moisture %	Fat %
Raw roasts[a]	70.5 ± 1.6	7.7 ± 2.0
Cooked roasts[b]		
Crockery pot, low, 10 hr	56.5 ± 1.4	10.2 ± 1.5
Oven, 225°F, 9 hr	54.0 ± 1.4	11.4 ± 1.5
Oven, 350°F to 170°F	57.4 ± 1.4	9.7 ± 1.5

[a] 12 samples; 2 determinations/sample.

[b] 4 samples/treatment; 2 determinations/sample.

Fat content Fat content of individual raw and cooked rump roasts is presented in Table 22, Appendix. Analysis of variance indicated that the cooking method did not have a significant effect on the fat content of the cooked roasts (Table 23, Appendix). For the 12 raw roasts the fat content averaged 7.7%. The fat content for the four roasts cooked by each

method was generally higher than for the raw roasts and averaged 10.2% for CP roasts, 11.4% for LO roasts and 9.7% for MO roasts (Table 4). The increase in the proportion of fat in the meat during cooking might be attributed to the loss of moisture from the muscle. The values for fat content compared favorably with values in the literature; 9.3% was reported by Watt and Merrill (1963) for the separable lean of rump roasts and 10.9% was reported by Leverton and Odell (1958) for the "lean-plus-marble" portion of braised rump roasts.

Vitamin B_6 content The vitamin B_6 content, calculated on both moist- and dry-weight basis and expressed as pyridoxine, is presented for raw and cooked rump roasts in Table 24, Appendix. The analysis of variance, calculated on the dry-weight basis, indicated that the cooking method did not have a significant effect on the vitamin B_6 content of the cooked meat (Table 25, Appendix).

The average vitamin B_6 content for the 12 raw rump roasts was 0.50 mg/100 g (moist-weight basis, Table 5). Similar vitamin B_6 content of 0.50 mg and 0.51 mg/100 g of raw round roasts were reported by Meyer et al. (1969) and by Polansky and Toepfer (1969). For the four roasts cooked by each method, the vitamin B_6 content averaged 0.29 mg/100 g for the CP method, 0.33 mg/100 g for the LO method and 0.34 mg/100 g for the MO method (Table 5). A slightly higher value of 0.38 mg/100 g was reported by Leverton and Odell (1958) for "lean-plus-marble" samples from rump roasts braised 3 1/2 hr. But their value may have been calculated on the basis of pyridoxine hydrochloride rather than the free base, pyridoxine.

In summary, a 100-g serving of rump roast slow-cooked in the crockery

pot or oven or roasted conventionally might contribute approximately 0.3 mg of vitamin B_6 to the diet.

Vitamin B_6 retention Vitamin B_6 retention in the cooked meat, calculated on the dry-weight basis, is presented for individual rump roasts in Table 24, Appendix. Analysis of variance indicated that cooking method did not have a significant effect on the retention of vitamin B_6 (Table 25, Appendix).

For the four roasts cooked by each method, the retention of vitamin B_6 in the cooked meat averaged approximately 41% for CP roasts, 45% for LO roasts and 43% for MO roasts (Table 5). The results were similar to

Table 5. Means and standard deviations for vitamin B_6 content[a] and B_6 retention in boneless rump roasts (3.5 lb), Experiment I

Treatment	Vitamin B_6 content		Vitamin B_6 retention
	Moist[b] mg/100 g	Dry[b] mg/100 g	dry %
Raw roasts[c]	0.50 ± 0.05	1.69 ± 0.21	-
Cooked roasts[d]			
Crockery pot, low, 10 hr	0.29 ± 0.04	0.66 ± 0.14	41.2 ± 3.1
Oven, 225°F, 9 hr	0.33 ± 0.04	0.72 ± 0.14	44.7 ± 3.1
Oven, 350°F to 170°F	0.34 ± 0.04	0.80 ± 0.14	43.3 ± 3.1

[a]Calculated as pyridoxine.

[b]Basis of calculation.

[c]12 samples; 12 readings/sample.

[d]4 samples/treatment; 12 readings/sample.

the 49% retention reported by Meyer et al. (1969) for round roasts oven-braised to 210°F and to the 42% retention reported by Lushbough et al. (1959) for a Boston cut roasted at 325°F to 170°F.

Vitamin B_6 is water-soluble, thus it might be extracted in the drippings. So low retention of vitamin B_6 could be caused by the high total cooking losses (32-39%) of all the roasts. A preliminary experiment in which 4 1/2-lb top round roasts were cooked 5 hr to 150°F in a crockery pot indicated that 20-25% of the vitamin B_6 were recovered in the drip. But no data were obtained to determine the vitamin B_6 content of drip from the rump roasts cooked 10 hr in the crockery pot, 9 hr in the oven at 225°F or to 170°F in the oven at 350°F.

Bacterial enumeration

Raw and cooked samples from rump roasts surface-inoculated before cooking with C. perfringens S-45 vegetative cells and spores were tested for numbers of aerobic bacteria and of C. perfringens. Counts for individual roasts are expressed in the logarithmic form in Tables 26 and 28, Appendix, but the geometric means for each treatment are given in Table 6.

Aerobic plate count Aerobic bacteria on the raw and cooked roasts were enumerated on Plate Count agar by the pour-plate method and the plates were incubated at 30°C for 48 hr. The counts for the raw and cooked samples from each rump roast are presented in Table 26, Appendix. Analysis of variance indicated that cooking method did not have a significant effect on the aerobic plate counts of the cooked roasts (Table 27, Appendix).

The counts on the 12 raw rump roasts averaged 53,000/g and decreased on the four roasts cooked by each method to approximately 28/g for the CP method, 46/g for the LO method and 23/g for the MO method (Table 6).

Most of the aerobic bacteria present on the interior surface of the boneless rump roasts were killed during cooking by each of the three methods. At the low concentrations of surviving bacteria measured on the cooked roasts, the plate count technique has a relatively high degree of error, but the results can be interpreted to mean that only a few thermoduric bacteria survived either long slow cooking or conventional roasting.

Table 6. Geometric mean counts of aerobic mesophilic bacteria and of Clostridium perfringens vegetative cells and spores on inoculated rump roasts (3.5 lb), Experiment I

Treatment	Aerobic plate count/g	Clostridium perfringens	
		Vegetative cells/g	Spores/g[a]
Raw roasts[b]	53,000	2,000,000	1,500
Cooked roasts[c]			
Crockery pot, low, 10 hr	28	220	160
Oven, 225°F, 9 hr	46	140	110
Oven, 350°F to 170°F	22	800	390

[a]Heat-shocked at 80°C for 15 min.

[b]12 samples; duplicate plates or pouches/sample.

[c]4 samples/treatment; duplicate plates or pouches/sample.

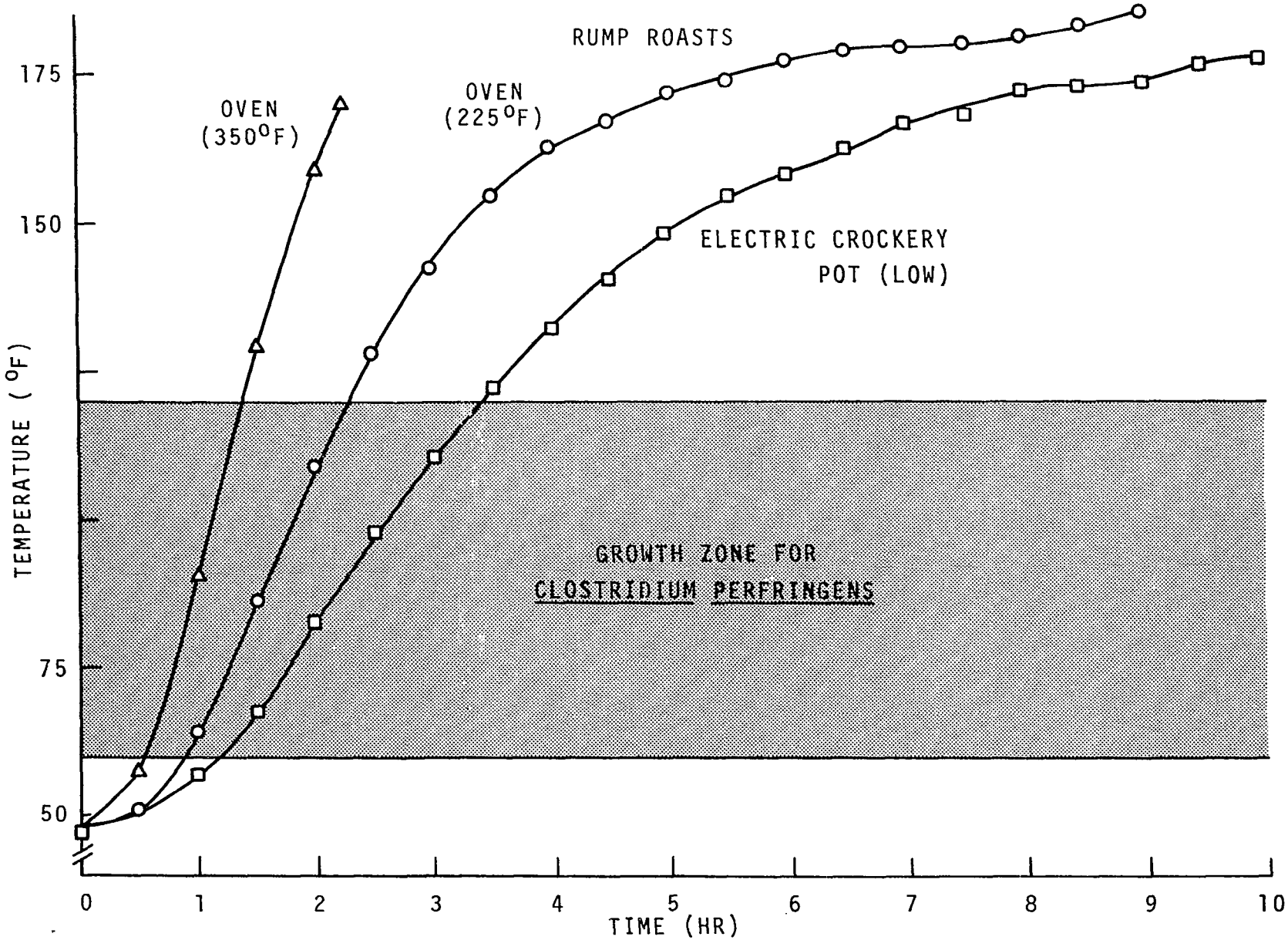
Clostridium perfringens vegetative cells C. perfringens has been isolated from beef roasts by several researchers (Hall and Angelotti, 1965; Bryan and Kilpatrick, 1971). C. perfringens was used in this experiment to test the safety of long slow cooking because it is a foodborne pathogen and because some strains grow at temperatures as high as 50°C (Rey et al., 1975). A mixed inoculum of C. perfringens S-45 vegetative cells and spores was used.

Vegetative cells are defined in this thesis as the counts obtained when samples taken from the raw or cooked roasts were plated without an additional heat-shock treatment. The cells were enumerated in SPS agar in plastic pouches. The vegetative cell counts in the samples from the cooked roasts may have included germinated spores since the final internal temperatures of the roasts (178°F in the CP, 185°F in the LO and 170°F in the MO) were sufficient to heat-shock the spores.

C. perfringens vegetative cell counts for raw and cooked samples from individual inoculated rump roasts are presented in Table 28, Appendix. Analysis of variance indicated that reductions in the vegetative cell counts caused by the three cooking methods did not differ significantly (Table 29, Appendix). The vegetative cell counts made on the 12 raw samples from the roasts averaged 2.0×10^6/g. For the samples from the roasts cooked by each method, cell counts averaged 220/g for CP roasts, 140/g for LO roasts and 800/g for MO roasts (Table 6).

Figure 4 illustrated that CP roasts averaged approximately 2 1/4 hr in the growth zone for C. perfringens compared with 1 1/2 hr for LO roasts and 53 min for MO roasts. Thus, more opportunity existed for increase in

Figure 4. Average rise in temperature at the center in 3.5-lb rump roasts during cooking by three methods, Experiment I


RUMP ROASTS
OVEN (350°F)
OVEN (225°F)
ELECTRIC CROCKERY POT (LOW)
GROWTH ZONE FOR CLOSTRIDIUM PERFRINGENS
TEMPERATURE (°F)
175
150
75
50
0
1
2
3
4
5
6
7
8
9
10
TIME (HR)

numbers of vegetative cells in CP and LO roasts than in MO roasts. On the other hand, a reduction in numbers would be expected during the period that the temperature at the center of the roasts was above 120°F, i.e., approximately 6 1/2 hr for roasts cooked in the CP for 10 hr or in the LO for 9 hr compared with 50 min for roasts cooked in the MO to 170°F.

Cooking caused a mean log reduction in C. perfringens vegetative cell counts of 4.0 for CP roasts, 4.1 for LO roasts and 3.4 for MO roasts. The similar decrease in numbers of cells indicated that roasts cooked in the crockery pot for 10 hr or in the oven set at 225°F for 9 hr would not be any more likely to cause C. perfringens food poisoning than roasts cooked in the oven set at 350°F to 170°F. The recovery of some cells from the cooked roasts, however, indicated that care should be taken to refrigerate meat not eaten immediately as any remaining cells might grow rapidly because competing microflora were eliminated and an anaerobic environment was created in the roasts during cooking.

Clostridium perfringens spores Reports were found of isolation from raw meat of C. perfringens strains that produce moderately heat-resistant spores (Hall and Angelotti, 1965; Lillard, 1971). Spores are defined in this thesis as the counts obtained from raw- or cooked-sample homogenates that had been heated for 15 min at 80°C. The spores were enumerated in SPS agar in plastic pouches.

C. perfringens spore counts on individual inoculated rump roasts are presented in Table 28, Appendix. Analysis of variance indicated that cooking methods did not differ in the effects on the spore counts (Table 29, Appendix). The spore counts made for the 12 samples from the raw rump

roasts averaged 1500/g. For the four samples from the roasts cooked by each method, spore counts averaged 160/g on CP roasts, 110/g on LO roasts and 390/g on MO roasts (Table 6).

Cooking caused a reduction in C. perfringens spore counts of 1.0 and 1.1 log cycles on CP and LO roasts and of 0.6 log cycle on MO roasts. As was true for the vegetative cell counts, the spore counts indicated that slow-cooked roasts were no more likely to cause C. perfringens food poisoning than roasts cooked conventionally.

The recovery of >100 spores/g from inoculated rump roasts indicated that some spores of C. perfringens S-45 could withstand temperatures of 170°-185°F during cooking of meat. Consequently, care should be taken in handling the cooked meat as the viable spores could germinate and multiply to numbers sufficient to cause food poisoning.

Experiment II - Inoculated Meat Loaves

The objective of Experiment II was to compare the survival of bacteria in inoculated meat loaves cooked by two methods (crockery pot or oven) to four final temperatures. Ground chuck for the loaves was inoculated with C. perfringens vegetative cells and spores and then mixed with milk, eggs, bread crumbs and salt. The 2-lb cylindrical meat loaves were cooked either in a 3 1/2-qt electric crockery pot on low setting (CP method) or in an oven set at 325°F (MO method). Each loaf was cooked to one of four final temperatures, 120°, 135°, 150° or 165°F, and four replications were done at each temperature for each cooking method. The cooking time, rate of temperature increase at the center, appearance of the cooked loaves and cooking losses were determined. Populations of aerobic

bacteria and of C. perfringens vegetative cells and spores were enumerated in the raw and cooked loaves.

Air temperature

Just before the CP was turned on, the air temperature in the crockery pot was 72°F. The temperature rose to approximately 169°F at 1 hr, 183°F at 2 hr, 198°F at 4 hr and the maximum, 204°F, at 6 1/2 hr (near the end of the cooking period). During cooking of the meat loaves in the preheated oven set at 325°F, the air temperature cycled in the range 306°-342°F throughout the 1 1/2 hr of cooking time.

Rate of temperature increase

The rate of temperature increase is the average rise in temperature in °F/min. For the 2-lb meat loaves cooked in Experiment II the rate of temperature increase was calculated for the following temperature intervals: 60° to 120°F, 120° to 135°F, 135° to 150°F and 150° to 165°F. The

Table 7. Average[a] rate of temperature increase in °F/min at the center of meat loaves (2.0 lb) cooked by two methods, Experiment II

Temperature range °F	Cooking method	
	Crockery pot, low	Oven, 325°F
60-120	0.53	1.61
120-135	0.36	1.50
135-150	0.21	1.40
150-165	0.10	1.55

[a]Average for 16 loaves (60-120°F), 12 loaves (120-135°F), 8 loaves (135-150°F) or 4 loaves (150-165°F).

average rate for each interval for loaves cooked by each method is presented in Table 7. The rate of temperature increase from 60° to 120°F was slower for CP than for MO loaves, 0.5° vs. 1.6°F/min. For MO loaves the rate was essentially constant throughout cooking, but for CP loaves the rate decreased markedly above 120°F, and the rate from 150° to 165°F had decreased 81% compared with the rate from 60° to 120°F. The slower rate of temperature increase at the higher temperatures might be attributed to the smaller difference between the temperature of the loaves and of the air in the CP.

The average temperature at the sides (1 in. from the edge) of the cylindrical loaves when the temperature at the center was 120°, 135°, 150° or 165°F is given in Table 8. In CP loaves, the temperatures in the centers and at the sides became approximately the same at 150°F, but in MO

Table 8. Average[a] final temperature at the sides[b] of cylindrical meat loaves (2.0 lb) cooked to various final temperatures by two methods, Experiment II

Cooking method	Final internal temperature (°F)			
	120 (°F)	135 (°F)	150 (°F)	165 (°F)
Crockery pot, low	127	140	152	166
Oven, 325°F	138	150	164	177

[a]Average for 4 loaves.

[b]1 in. from the edge of the loaf at a depth equal to half the height of the loaf.

loaves, the temperatures at the sides were approximately 15°F higher than those in the centers at all temperatures tested. These trends agree with the report by Funk and Boyle (1972) that temperatures at various locations in 100% ground beef cylinders (1 lb) equalized at about 140°F when the meat was cooked at 121°C (250°F), but remained different when the meat was cooked at 177°C (350°F).

Cooking time

Cooking time for individual loaves is presented in Table 30, Appendix. Analysis of variance indicated that cooking method, final temperature and the interaction of cooking method and final temperature significantly ($p<0.01$) affected the cooking time of the loaves (Table 31, Appendix). Thus, the effect of cooking method was not the same at each final internal temperature. Examination of the data in Table 9 indicated that CP loaves required 3 times longer to reach 120°F but 4.7 times longer to reach 165°F

Table 9. Average[a] time required to cook meat loaves (2.0 lb) to various final internal temperatures by two methods, Experiment II

Cooking method	Final internal temperature (°F)			
	120 (min)	135 (min)	150 (min)	165 (min)
Crockery pot, low	163	206	262	423
Oven, 325°F	53	66	75	91

[a]Average for 4 replications.

than MO loaves. The total cooking time to 165°F averaged 1 1/2 hr for MO loaves and 7 hr for CP loaves.

Cooking losses

Total losses

Total losses for individual 2-lb meat loaves are presented in Table 32, Appendix. Analysis of variance indicated that the losses were affected significantly ($p<0.01$) by the final temperature and by the interaction of cooking method and final temperature (Table 33, Appendix). Partitioning of the degrees of freedom indicated that the significant interaction was between the cooking method and the average effects of 120° and 135°F vs. 150° and 165°F.

The interaction between cooking method and final temperature was exemplified by a more gradual increase in total cooking losses for MO than for CP loaves in the temperature range tested. Data in Table 10 indicated that losses tended to be greater for MO than for CP loaves at 120° and 135°F but smaller at 150° and 165°F. And at 165°F, a *t*-test indicated that losses of 27.1% for CP loaves were significantly ($p<0.01$) greater than losses of 20.1% for MO loaves. Peters (1974) also found that total losses were greater if meat loaves were cooked in a slow electric cooker than if cooked in an oven.

To clarify the relation between final temperature and total cooking losses, the LSD criterion was used (Table 10). Each 15°F rise in final temperature for loaves cooked in the CP and each 30°F rise for loaves cooked in the MO caused a significant increase in total cooking losses. Others have reported that cooking losses increased as internal temperature of the meat rose at low cooking temperatures (Bayne et al., 1973a).

Table 10. Average[1] total, volatile and drip losses for meat loaves (2.0 lb) cooked to various final internal temperatures by two methods, Experiment II

Cooking method	Final internal temperature (°F)				LSD[2]
	120 (%)	135 (%)	150 (%)	165 (%)	
			Total losses		
					5.0
Crockery pot, low	6.7c[3]	12.8d	21.6f	27.4g	
Oven, 325°F	10.1cd	13.7de	18.6ef	20.1f	
			Volatile losses		
					1.1
Crockery pot, low	1.2c	1.6c	2.0cd	3.0d	
Oven, 325°F	4.4e	6.2f	8.4g	10.6h	
			Drip losses		
					4.4
Crockery pot, low	5.5c	11.3d	19.6e	24.3f	
Oven, 325°F	5.7c	7.5cd	10.2d	9.5cd	

[1]Average for 4 replications.

[2]LSD, least significant difference at 0.01.

[3]Means followed by the same letter within a category of losses do not differ significantly at the 0.01 level.

Volatile losses Volatile losses for individual meat loaves are presented in Table 32, Appendix. Analysis of variance indicated that the losses were affected significantly ($p<0.01$) by the cooking method, final temperature and interaction of cooking method and final temperature (Table 33, Appendix). For loaves cooked in the CP, volatile losses were only a small portion of the total losses and remained essentially unchanged as the internal temperature rose (Table 10). For loaves cooked in the MO, volatile losses were about half of the total losses and increased by approximately two percentage points with each 15°F rise in final temperature.

Drip losses Drip losses for individual meat loaves are presented in Table 32, Appendix. Analysis of variance indicated that drip losses were affected significantly ($p<0.01$) by cooking method, final temperature and the interaction of cooking method and final temperature (Table 33, Appendix). Drip losses constituted most of the total cooking losses for CP loaves and increased 5-8 percentage points with each 15°F rise in final temperature (Table 10). For MO loaves, drip losses were about half of the total losses and tended to increase only slightly as the temperature rose.

In summary, the effect of final temperature on cooking losses varied with the cooking method. At the final temperature of 165°F, total cooking losses were greater for CP than for MO loaves. The total losses for MO loaves were divided evenly between drip and volatile losses, but most of the total losses for CP loaves were drip losses.

Appearance and aroma of cooked loaves

Questions have been raised about the "doneness" as judged by the color of meat loaves cooked for 4-4 1/2 hr in the CP or to approximately 150°F. On the basis of observations recorded by the experimenter, the tops of CP loaves cooked to 150°F looked done; but near the bottoms of the loaves, the exterior was pinkish tan and the center was pink. In contrast, for loaves cooked 7 hr in the CP to approximately 165°F, both the exterior and the center were medium brown, although there was a slight pinkish cast near the base of the cylinder. The loaves cooked in the MO to 165°F had dark brown exteriors and the centers were medium brown with an occasional slight pinkish cast. Loaves cooked to 150° or 165°F either in the CP or MO had a characteristic cooked-beef aroma.

Bacterial enumeration

Aerobic plate count An aerobic plate count was made on a 50-g sample from each lot (6.4 lb) of ground chuck purchased for a batch of four meat loaves. The samples were held 24 hr at 45°F before plating. Log counts for the eight samples ranged from 6.81 to 8.28/g and averaged 7.42/g (Table 34, Appendix). Similar counts of 10^7/g were obtained by Haziak (1973) for ground beef samples from four stores in Ames that sold the meat from bulk bins.

The aerobic population just before cooking was determined for a 50-g sample from one of the four 916-g meat loaves cooked on each of the eight test days. The log counts, presented in Table 34, Appendix, ranged from 6.30 to 7.45/g and averaged 7.04 cells/g. Ziprin (1975) reported similar

aerobic populations (log counts/g ranging from 5.74 to 7.66) for raw meat loaves.

Two sample cores, each weighing 70-100 g, were removed from each loaf immediately after cooking. Aerobic plate counts for 50-g subsamples from each core are presented for the 32 meat loaves in Table 35, Appendix. Analysis of variance indicated that the aerobic plate counts for both the center and side locations in the loaves were affected significantly ($p<0.01$) by the final temperature but not by the cooking method (Table 36, Appendix). Nonorthogonal partitioning of the degrees of freedom for final temperature in each location indicated that counts did not differ significantly between loaves cooked to 120° and 135°F. Counts were significantly different between loaves cooked (1) to 135° and 150°F and (2) to 150° and 165°F. The analyses also indicated that the counts for the center cores were affected significantly by the interaction of cooking method and final temperature. Partitioning of the degrees of freedom revealed that the only significant interaction was between cooking method and the comparison of the final temperatures of 150° and 165°F.

The mean log aerobic plate counts for the two locations in the meat loaves cooked to each final temperature by each method are presented in Table 11. Increasing the final temperature from 120° to 135°F had only a slight effect on bacterial counts, but increasing the temperature from 135° to 150°F caused a decline in log counts in the centers of the loaves from 6.11 to 4.72/g for CP and from 5.56 to 3.58/g for MO treatments. At the sides of the loaves cooked to 150°F, compared with loaves cooked to 135°F, the counts were reduced from 5.54 to 3.80/g for the CP and from

Table 11. Mean[a] log counts/g for aerobic bacteria in two locations in meat loaves (2.0 lb) cooked to various final temperatures by two methods, Experiment II

Cooking method	Final internal temperature (°F)			
	120	135	150	165
		Center core		
Crockery pot, low	6.36	6.11	4.72	1.40
Oven, 325°F	6.18	5.56	3.58	3.09
		Side core		
Crockery pot, low	5.99	5.54	3.80	1.34
Oven, 325°F	5.60	5.04	2.74	1.83

[a] 4 samples/treatment; duplicate plates/sample.

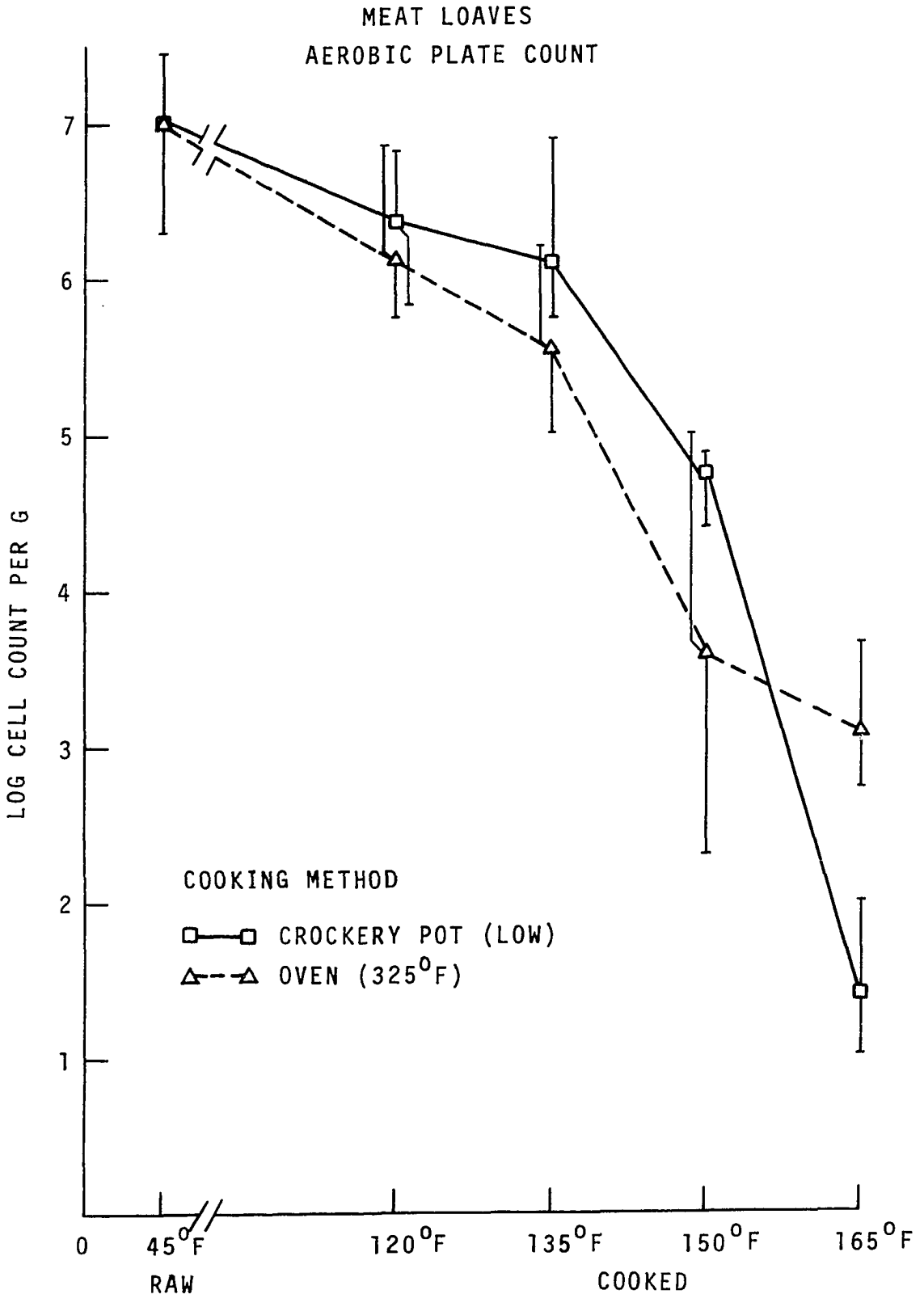
5.04 to 2.74/g for MO treatments. Then from 150° to 165°F, in the CP loaves only, counts were reduced markedly from 4.72 to 1.40/g in the centers and from 3.80 to 1.34/g on the sides. From 150° to 165°F counts were reduced only slightly in MO loaves. The difference in counts between loaves cooked to 150° and 165°F may have been greater for CP than for MO loaves because the time required for the temperature to rise from 150° to 165°F averaged 161 min for CP loaves, 10 times as long as the 16 min required for MO loaves. The consistently lower aerobic populations found in samples from the sides than from the centers of the loaves may be attributed to the higher temperatures in the sides throughout the cooking period for MO loaves and during the first part of the period for CP loaves, as discussed in the section on rate of temperature increase.

Means and ranges for the log counts of aerobic organisms/g were plotted in Figure 5 for (1) the raw meat loaves at 45°F and (2) the center cores of the meat loaves cooked by each method to the various final temperatures. The figure illustrated that (1) bacterial numbers in the central cores had not increased but had declined slightly during cooking to 120°F, (2) between 120° and 135°F counts continued to decline slightly, (3) between 135° and 150°F a large decline in the aerobic count occurred both in the CP and in the MO loaves, and (4) between 150° and 165°F numbers declined more in CP than in MO loaves exemplifying the interaction of cooking method and final temperature in causing bacterial destruction.

Aerobic populations surviving at 165°F are of special interest because 165°F is a recommended final internal temperature for cooked meat loaves. A t-test indicated that the numbers of aerobic survivors in the center cores of loaves cooked to 165°F were significantly lower for CP than for MO loaves (<100 vs. 1000/g, respectively). Based on counts of 10^7/g in the raw loaves, cooking to 165°F caused a decline of 5.6 log cycles in aerobic plate counts in CP loaves and of 4.0 log cycles in MO loaves.

My results agreed with the report by Peters (1974) of large reductions in the aerobic populations in meat loaves cooked in a slow-cooker, but failed to confirm the report by Wells and Kennedy (1972) that counts declined from 10^7/g at 80°F to none recoverable at 150°F. Under the conditions of my experiment, counts declined from 10^7/g at 45°F to 5×10^4/g at 150°F. My study failed to confirm Ziprin's report (1975) that aerobic counts in meat loaves were reduced from 10^6/g to insignificant numbers

Figure 5. Means and ranges of log counts of aerobic organisms/g in raw meat loaves and in the centers of meat loaves cooked to various final internal temperatures by two methods, Experiment II


MEAT LOAVES
AEROBIC PLATE COUNT
LOG CELL COUNT PER G
7
6
5
4
3
2
1
0
COOKING METHOD
CROCKERY POT (LOW)
OVEN (325°F)
45°F
120°F
135°F
150°F
165°F
RAW
COOKED

(<10/g) when loaves were cooked in an oven at 325°F to 165°F. The higher counts (approximately 1000/g) for loaves cooked at 325°F to 165°F in my study might be attributed to higher initial aerobic populations, to the cylindrical rather than oblong loaf shape of the meat or to differences in sampling and plating procedures.

In summary, the aerobic populations in the meat loaves (2 lb) cooked in an electric crockery pot or in an oven at 325°F tended to decrease slowly as the meat loaf temperature rose to 120° and 135°F and moderately as the temperature rose to 150°F. Between 150° and 165°F for the CP loaves, numbers decreased markedly, but for MO loaves only slightly; thus the aerobic population that averaged 10^7/g in the raw loaves was reduced in loaves cooked to 165°F to <100/g by the CP method and to approximately 1000/g by the MO method. In spite of the low final counts for meat loaves cooked in the crockery pot, more research would be desirable to rule out the production of heat-stable toxins by aerobic bacteria during the 7 hr required to reach 165°F.

Clostridium perfringens vegetative cells Samples (50 g) from each of the eight 6.4-lb lots of raw uninoculated ground chuck were plated with SPS agar in anaerobic pouches for enumeration of C. perfringens vegetative cells. Counts on three of the samples were 10 to 50/g, on two were <10/g, and on three, no growth was observed (Table 34, Appendix). The number of samples presumably positive for C. perfringens agreed favorably with Ziprin's report (1975) that four of the six lots of ground chuck purchased from Ames supermarkets for her experiment contained at least 10 cells/g. In another study, Haziak (1973) reported that 20 of the 48 ground beef

samples obtained from retail groceries in Ames contained C. perfringens at a concentration of >10 cells/g.

The ground chuck was inoculated with a suspension of C. perfringens that had a mean log count of 8.67 vegetative cells and 5.67 spores/ml. Then meat loaves were prepared and held overnight. The next day, vegetative cells were enumerated in samples (50 g) taken from each raw loaf. The log counts, averaged for the four raw loaves tested each day, ranged from 5.34 to 5.91 cells/g (Table 34, Appendix). The overall average of 5.62 cells/g was approximately 1 log cycle less than would have been predicted if the recovery of the inoculum had been complete. One plausible explanation for the incomplete recovery is that some cells were destroyed during overnight storage of raw inoculated loaves at 45°F.

Vegetative cell counts made on sample cores taken from the center and side of each cooked meat loaf are presented in Table 37, Appendix. Analysis of variance indicated that the counts at both locations were affected significantly by the final temperature but not by the cooking method (Table 38, Appendix). Partitioning of the degrees of freedom for nonorthogonal comparisons indicated that counts in the center differed significantly between loaves cooked (1) to 120° and 135°F and (2) to 135° and 150°F. There was no significant difference in counts between loaves cooked to 150° and 165°F. In the sides of the loaves, counts differed significantly between loaves cooked to 120° and 135°F but did not differ significantly between loaves cooked (1) to 135° and 150°F and (2) to 150° and 165°F.

The log vegetative cell counts averaged for each final temperature

and each cooking method in each location in the meat loaves are presented in Table 12. In general, the C. perfringens vegetative cell counts were lower in the side than in the center cores. Specifically, between 120° and 135°F, the counts in the center cores declined by more than 1 log cycle from 5.70 to 4.67/g for CP loaves and from 5.37 to 4.00/g for MO loaves. A similar important reduction of 0.7-0.8 log cycle occurred in counts in the side cores as the center temperature rose from 120° to 135°F. Between 135° and 150°F, the counts for the center cores of CP loaves declined from 4.67 to 3.46/g. A smaller decline (0.3-0.6 log cycle) occurred for counts in the centers of the MO loaves and for counts in the sides of both the CP and the MO loaves as the center temperature rose from 135° to 150°F. Finally, between 150° and 165°F, counts tended to stabilize at both locations in loaves cooked by both methods. The stabilization in counts may be related to heat-activation and germination of spores. Temperatures of 60°-80°C (140°-176°F) have been shown to activate spores of C. perfringens S-45, the strain used in this experiment (Ahmed and Walker, 1971).

Examination of Figure 6, in which temperatures at the center of the meat loaves were plotted, indicated that loaves were in the zone favorable for growth of C. perfringens, 60°-120°F, for 38 min for the MO compared with 113 min for the CP loaves. During the interval that the center was in the growth zone and on the basis of generation times reported at 5°C intervals by Smith (1972), the C. perfringens population could have increased approximately 1.2 log cycles in CP loaves and 0.3 log cycle in MO loaves. Heat-activation and subsequent germination of the spores also

Figure 6. Average rise in temperature at the center in 2-lb meat loaves during cooking by two methods, Experiment II

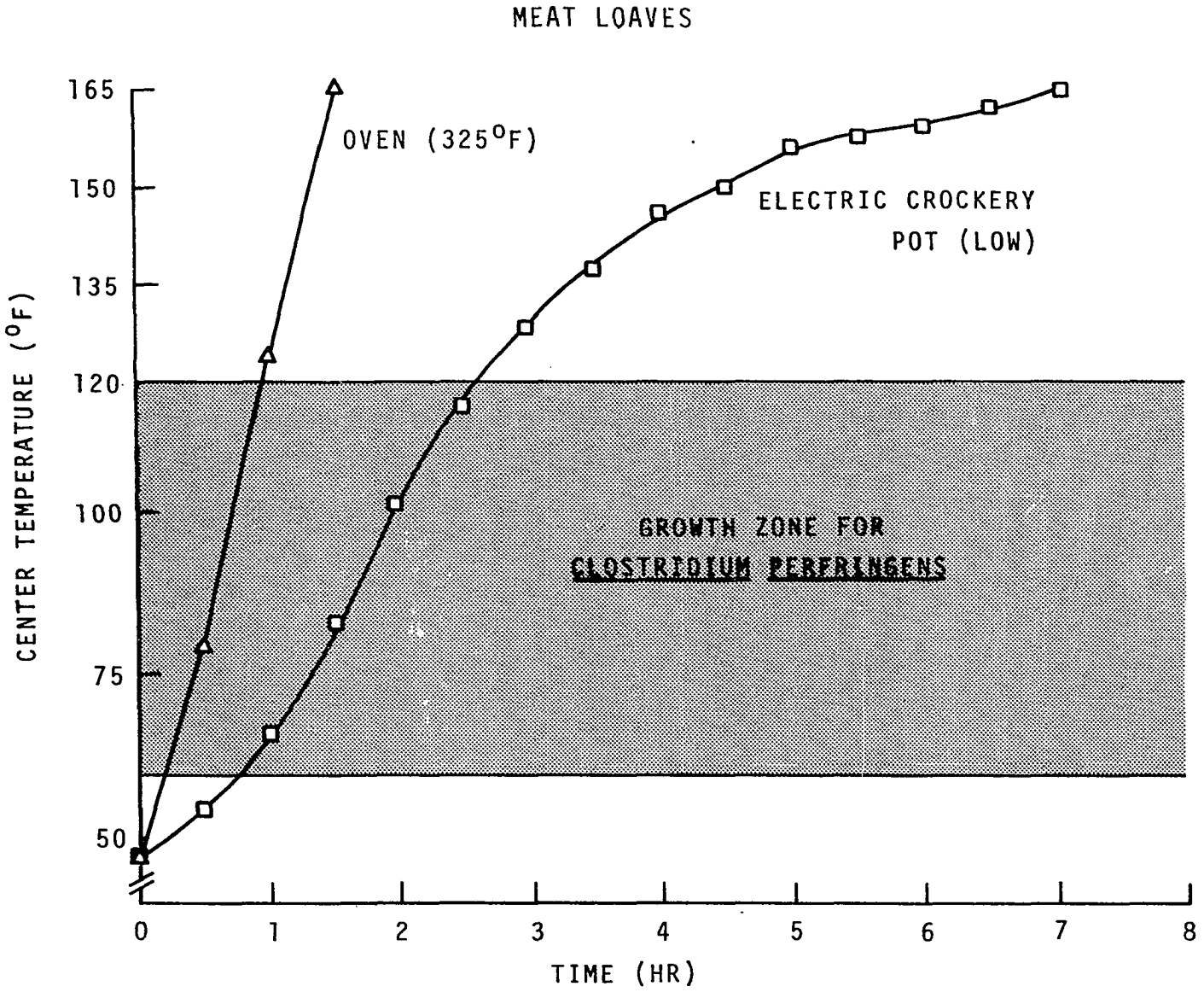

MEAT LOAVES
165
150
135
120
100
75
50
CENTER TEMPERATURE (°F)
OVEN (325°F)
ELECTRIC CROCKERY POT (LOW)
GROWTH ZONE FOR CLOSTRIDIUM PERFRINGENS
0
1
2
3
4
5
6
7
8
TIME (HR)

Table 12. Mean[a] log counts/g for Clostridium perfringens vegetative cells in two locations in inoculated meat loaves (2.0 lb) cooked to various final temperatures by two methods, Experiment II

Cooking method	Final internal temperature (°F)			
	120	135	150	165
		Center core		
Crockery pot, low	5.70	4.67	3.46	3.31
Oven, 325°F	5.37	4.00	3.69	3.56
		Side core		
Crockery pot, low	5.03	4.18	3.54	3.24
Oven, 325°F	4.60	3.92	3.46	3.34

[a]4 samples/treatment; duplicate pouches/sample.

could have caused an increase in cell populations. For loaves cooked to 165°F, the temperature at the center was high enough to heat-shock spores for 20 min in the MO treatment and for 3 1/3 hr in the CP treatment. But results of C. perfringens cell counts in my experiment indicated that in spite of the longer time in the cell growth and spore activation zones, the CP loaves did not have significantly greater cell populations than the MO loaves. Possibly the cells remained in the lag phase during the time that the loaf temperature was in the growth zone.

A reduction in the numbers of cells, including outgrown spores, would be expected during the period that the loaf temperature was above 120°F. The length of time above 120°F varied with the cooking method and final temperature; for loaves cooked to 165°F the time averaged 30 min for the

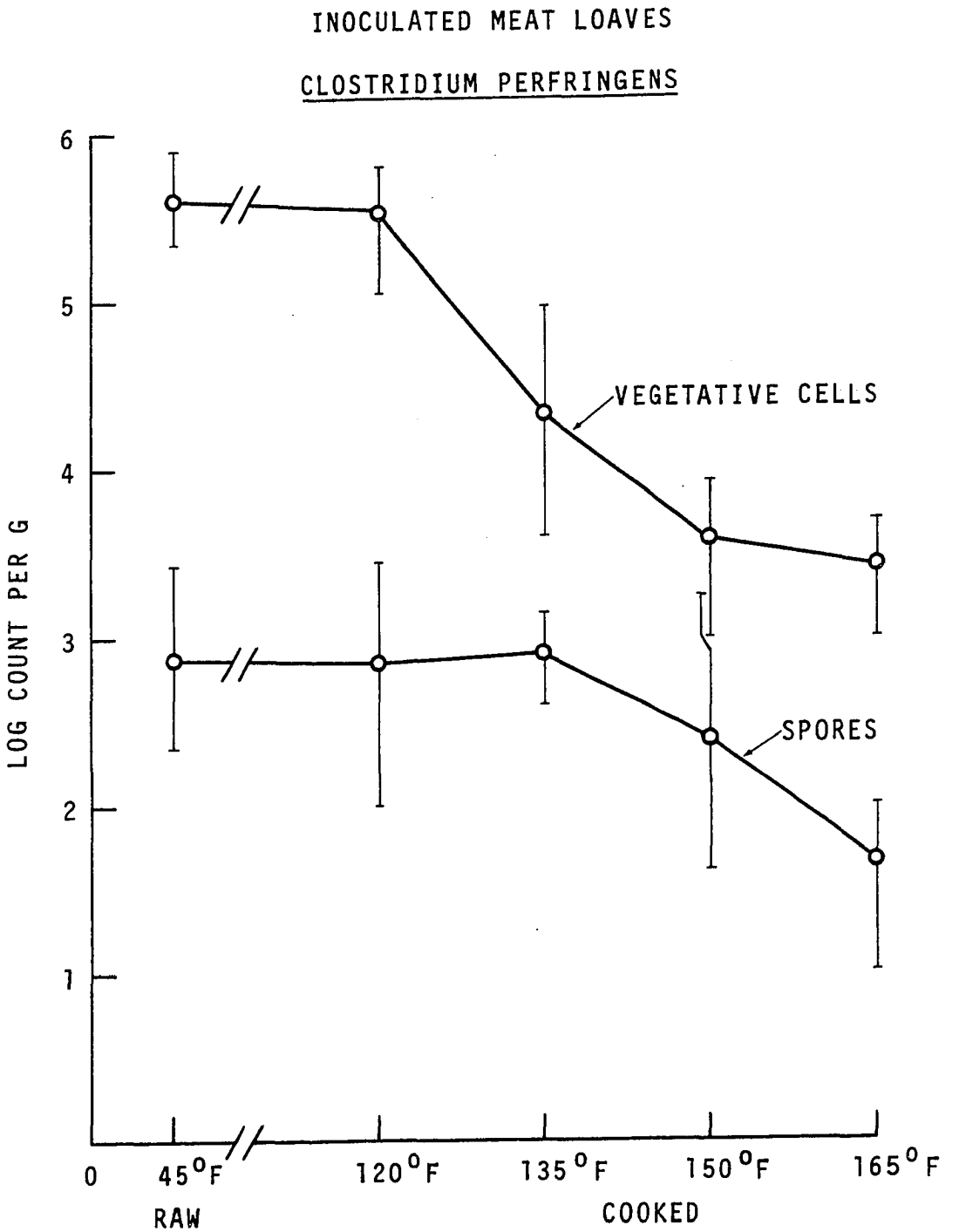
MO treatment compared with 4 1/3 hr for the CP treatment. But the cell counts did not indicate that the longer time in the zone for cell destruction resulted in a smaller number of cells surviving at 165°F for CP than for MO loaves (Table 12).

Because cooking method did not have a significant effect on the C. perfringens cell population, counts for the center cores of the eight loaves cooked to the same final temperature were pooled. The means and ranges of counts for raw loaves and for loaves cooked to the four final internal temperatures were plotted in Figure 7. The figure illustrated first that cell counts were about the same in the cooked loaves at 120°F as in the raw loaves at 45°F. Secondly, a marked reduction in cell counts occurred between 120° and 150°F. Finally, the graph emphasized the stabilization of cell counts between 150° and 165°F. The stabilization is consistent with the report by Strong and Ripp (1967) of a slight increase in counts of C. perfringens in ground beef casseroles inoculated with a mixture of vegetative cells and spores and held 6 hr at 68°C (155°F).

The average count of C. perfringens vegetative cells for loaves cooked to 165°F was reduced by 2.2 log cycles compared with the count in the raw loaves. A similar reduction of approximately 2.5 log cycles was reported by Ziprin (1975) for meat loaves inoculated with a mixture of C. perfringens vegetative cells and spores and cooked at 325°F to 165°F.

In summary, C. perfringens vegetative cell counts did not differ significantly between inoculated loaves cooked in the crockery pot on low or in the oven at 325°F. The cell counts did not increase in the centers of loaves cooked to 120°F although the loaf temperature was in the growth

Figure 7. Means and ranges of log counts of *Clostridium perfringens* vegetative cells and spores in inoculated meat loaves either sampled raw or after cooking to various internal temperatures, Experiment II


INOCULATED MEAT LOAVES
CLOSTRIDIUM PERFRINGENS
LOG COUNT PER G
6
5
4
3
2
1
0
VEGETATIVE CELLS
SPORES
45°F
120°F
135°F
150°F
165°F
RAW
COOKED

zone for C. perfringens for nearly 2 hr for the CP treatment and 40 min for the MO treatment. As the temperature rose from 120° to 135°F and then to 150°F, the cell population declined rapidly, but between 150° and 165°F, the numbers stabilized. Thus, the count of vegetative cells was reduced from 4 x 10^5/g in the raw loaves to approximately 2700/g in the loaves cooked to 165°F by either method. The counts indicated the effects of various final temperatures on the C. perfringens population when vegetative cells and spores were both present in the raw loaves; different results might have been obtained if the loaves had contained vegetative cells only.

Clostridium perfringens spores C. perfringens spores in raw or cooked meat in Experiment II were enumerated by first heating a portion of a 1:5 dilution of each sample at 80°C (176°F) for 15 min to activate the spores and then plating the heated sample in SPS agar. No spores were isolated from the eight lots of raw ground chuck used in the meat loaves (Table 34, Appendix). In her experiment, Ziprin (1975) also did not recover any spores of C. perfringens from six lots of ground chuck purchased from the same supermarket as used in this study.

Meat loaves (916 g), containing inoculated ground chuck, were held 19 hr at 45°F. Then spore counts were made on samples (50 g) from the raw loaves. The log counts, averaged for the four loaves on each test day, ranged from 2.34 to 3.43/g and averaged 2.88/g (Table 34, Appendix).

After cooking, the spore population was determined at two locations, the center and the side of each loaf. Individual counts at each location for each loaf are presented in Table 39, Appendix. Analysis of variance

indicated that spore counts at both locations were affected significantly ($p<0.01$) by final temperature but not by cooking method (Table 40, Appendix). Nonorthogonal partitioning of the degrees of freedom indicated that counts were not significantly different in the center cores of loaves cooked to 120°, 135° and 150°F. Counts did differ significantly between loaves cooked to 150° and 165°F. In the sides of the loaves, the spore counts were not significantly different between loaves cooked (1) to 120° and 135°F and (2) to 150° and 165°F, but counts differed significantly between loaves cooked to 135° and 150°F.

The data on mean log spore counts/g for the CP and the MO loaves for the center and side cores are summarized in Table 13. Although spore counts in either location did not differ significantly between the two

Table 13. Mean[a] log counts/g for Clostridium perfringens spores in two locations in inoculated meat loaves (2.0 lb) cooked to various final temperatures by two methods, Experiment II

Cooking method	Final internal temperature (°F)			
	120	135	150	165
		Center core		
Crockery pot, low	2.90	2.97	2.50	1.87
Oven, 325°F	2.79	2.83	2.30	1.44
		Side core		
Crockery pot, low	2.96	2.82	2.23	2.00
Oven, 325°F	2.86	2.53	1.74	1.77

[a]4 samples/treatment; duplicate pouches/sample.

cooking methods, a comparison can be made for different locations for loaves cooked by the same method by examination of the table. At 120°F the spore counts for both the center and side samples were similar and ranged from 2.79 to 2.96/g. The counts remained essentially unchanged as the temperature rose to 135°F. Between 135° and 150°F, the counts in the centers did not change significantly and the counts in the sides declined moderately from 2.82 to 2.23/g for CP loaves and from 2.53 to 1.74/g for MO loaves. Between 150° and 165°F, the counts in the centers declined significantly from 2.50 to 1.87/g for CP loaves and from 2.30 to 1.44/g for MO loaves, but the counts in the sides remained constant. Thus at 165°F, throughout the loaf, counts were similar. Loaves cooked to 165°F were at temperatures that heat-activate spores of C. perfringens, i.e., 140°F or higher, for a much shorter time in the MO than in the CP (20 min vs. 3 1/3 hr, see Figure 6). On the other hand, temperatures at the sides reached a higher average temperature in MO than in CP loaves (177° vs. 166°F, see Table 8). Thus, similarity in spore counts for loaves cooked to 165°F could have resulted even though the time-temperature treatment differed for the two cooking methods.

Because cooking method did not affect the spore counts significantly, the data for samples from the center cores were pooled for all eight loaves cooked to the same final temperature. The pooled means and ranges of the log spore counts in the raw meat loaves and in the meat loaves cooked to the four final internal temperatures were plotted in Figure 7. The figure illustrated that the spore counts remained essentially the same in the loaves cooked to 120°, 135° or 150°F as in the raw loaves at 45°F;

but in loaves cooked to 165°F, the number of spores declined significantly. It is likely that the reduction in counts in loaves cooked to 165°F resulted both from inactivation of some of the spores during cooking and from the lethal effect of the heat-shock during plating on the spores activated during cooking. Barnes et al. (1963) noted that most of the spores in inoculated beef cubes cooked in a water bath at 158°F for 30 min lost their resistance to heat-shock during plating.

Spore counts for loaves cooked to 165°F were reduced an average of 1.2 log cycles compared with the number of spores in the raw loaves. A similar reduction of 1.3 log cycles has been reported for spore counts in meat loaves inoculated with vegetative cells and spores of C. perfringens and cooked in an oven at 325°F to 165°F (Ziprin, 1975).

In summary, C. perfringens spore counts in the centers of the loaves did not differ significantly between loaves cooked in the crockery pot on low or in the oven at 325°F. The spore counts were not significantly different at final temperatures of 120°, 135° or 150°F, but declined significantly in loaves cooked to 165°F. The spore population in the inoculated meat was reduced from 770/g in the raw loaves to 50-100/g in the cooked loaves. Because any spores that were heat-activated during cooking could germinate and multiply rapidly at room temperature, cooked loaves should be stored below 50° or above 130°F and not left in the crockery pot or oven for an extended period.

Experiment III - Top Round Roasts

The two studies (A and B) in Experiment III were conducted to compare the cooking time and cooking losses of top round roasts cooked to 150°F in a 4 1/2-qt electric crockery pot (CP) set on low or in an oven set at 200°F (LO) or at 350°F (MO). Study A, conducted in 1973, and Study B, conducted in 1975, were alike in all respects except the model of General Electric ranges used, model J349001DC (A) or model J390003HT (B). Each study consisted of four replications done on consecutive days; all three cooking methods were tested the same day. The raw weight of the roasts, presented in Table 41, Appendix, ranged from 3.8 to 5.0 lb and averaged 4.4 lb. The initial temperature of the roasts ranged from 35° to 43°F and averaged 38°F.

Air temperature

The temperatures in the ovens, measured with thermocouples suspended near the centers of the oven cavities, were similar for the two studies. The temperatures in the ovens preheated to 200°F were 198° ± 18°F and in the ovens preheated to 350°F were 345° ± 13°F throughout the cooking period. The temperature of the air in the CP was measured with a thermocouple suspended approximately 1 in. from the side and 2 in. from the bottom of the pot. The temperature in the CP at 30 min intervals, averaged for the four replications in each study, is presented in Table 43, Appendix. Since the CP was a continuous-heat model, the air temperature did not fluctuate. The temperature was similar for both studies and rose slowly from 63°F at the start of the cooking period to 185°F (A) or 179°F

(B) near the end. Thus, temperatures in the CP were below those in the LO during most of the cooking period.

Cooking time

All top round roasts were cooked to 150° ± 2°F. The cooking time in min and in min/lb is presented for each roast in Table 41, Appendix. Analysis of variance for each study indicated that total cooking time varied significantly ($p<0.01$) among cooking methods (Table 42, Appendix). Examination of the average cooking time in Table 14 and use of the LSD criteria indicated that the time for CP and LO roasts did not differ significantly in Study A, but the cooking time was significantly longer for

Table 14. Average[a] raw weight, cooking time and rate of temperature rise for top round roasts cooked by three methods to 150°F, Experiment III, Studies A and B[b]

Cooking method[c]	Raw weight		Cooking time		Min/lb		Temperature rise/min	
	A lb	B lb	A min	B min	A	B	A °F	B °F
CP	4.4	4.3	284	303	64.8	71.1	0.39	0.36
LO	4.6	4.4	335	246	72.5	55.7	0.33	0.46
MO	4.3	4.4	121	103	28.3	23.4	0.92	1.09
LSD[d]			61	43				

[a]Average for 4 roasts; except Study A, LO method, average for 3 roasts.

[b]A = 1973, General Electric range model J349001DC; B = 1975, General Electric range model J390003HT.

[c]CP = crockery pot, low; LO = oven, 200°F; MO = oven, 350°F.

[d]LSD, least significant difference at 0.01.

CP roasts than for LO roasts in Study B. In both studies, the cooking time was longer for the low temperature methods, CP and LO, than for the conventional method.

The average cooking time tended to be longer for LO than for CP roasts in Study A, but in Study B, the reverse was true. Vollmar et al. (1976) reported that when frozen 3-lb top round roasts were cooked to 140° or 158°F, the cooking time was shorter in the slow-cooker than in the oven at low temperatures. They used a porcelain cooking pot with an electric base, set at 185°F, or a rotary hearth oven, set at 200°F. Thus, the answer to the question "Does meat cook faster in a slow-cooker on low or in an oven at 200°F?" depends on conditions such as the appliances used and the initial and final temperatures of the meat.

The cooking time in my study, calculated as min/lb, averaged approximately 65 (A) or 71 (B) for CP roasts, 72 (A) or 56 (B) for LO roasts and 28 (A) or 23 (B) for MO roasts (Table 14). Bayne et al. (1973b) reported an average cooking time of 64 min/lb for 5.9-lb top round roasts cooked in an oven at 200°F to 152°F.

Rate of temperature increase

The rate of temperature increase, averaged for the whole cooking period, from 38° to 150°F, is presented for each roast in Table 41, Appendix. The mean rates were approximately 0.4°F/min (A or B) in the CP roasts, 0.3°F (A) or 0.5°F/min (B) in the LO roasts and 0.9°F (A) or 1.1°F/min (B) in the MO roasts (Table 14). The rate of temperature increase also was calculated for the interval 60°-120°F, a zone of rapid growth of bacteria and of production of toxins by some bacteria. Between

60° and 120°F, the average rate was 0.5°F/min in CP roasts (A or B), 0.5°F (A) or 0.6°F/min (B) in LO roasts and 1.3°F/min in MO roasts (A or B). Thus the rate of temperature increase in the CP and LO roasts was approximately 1/3 that in the MO roasts.

Heat penetration curves

Data on the average temperatures at the centers and near the surfaces of the roasts during cooking in Study IIIB were plotted in Figure 8. The temperature curves illustrate the variability in temperature between two locations within the roasts. After one hour of cooking, the temperature near the surface, at a depth of 1/2 in., exceeded that in the center by 60°F for MO roasts, by 27°F for LO roasts and by 12°F for CP roasts. The figure also illustrates the variability in roast temperature among treatments. At the end-point, 150°F in the center, temperatures near the surface averaged 183°F in MO roasts compared with 155° or 158°F in CP or LO roasts. Thus, microorganisms near the surface of the roasts were subjected to higher temperatures in the MO than in the CP or LO.

Cooking losses

Total, volatile and drip losses for individual roasts in Experiment III are presented in Table 44, Appendix.

Total losses Analyses of variance indicated that the effect of cooking method on total cooking losses was significant only in Study A (Table 45, Appendix). Examination of the data in Table 15 and use of the LSD criterion for Study A revealed that the average total cooking losses for CP and LO roasts differed significantly (22.8 vs. 17.2%), but the

Figure 8. Average rise in temperature near the surface and at the center of 4.4-lb top round roasts during cooking by three methods, Experiment III, Study B

TOP ROUND ROASTS

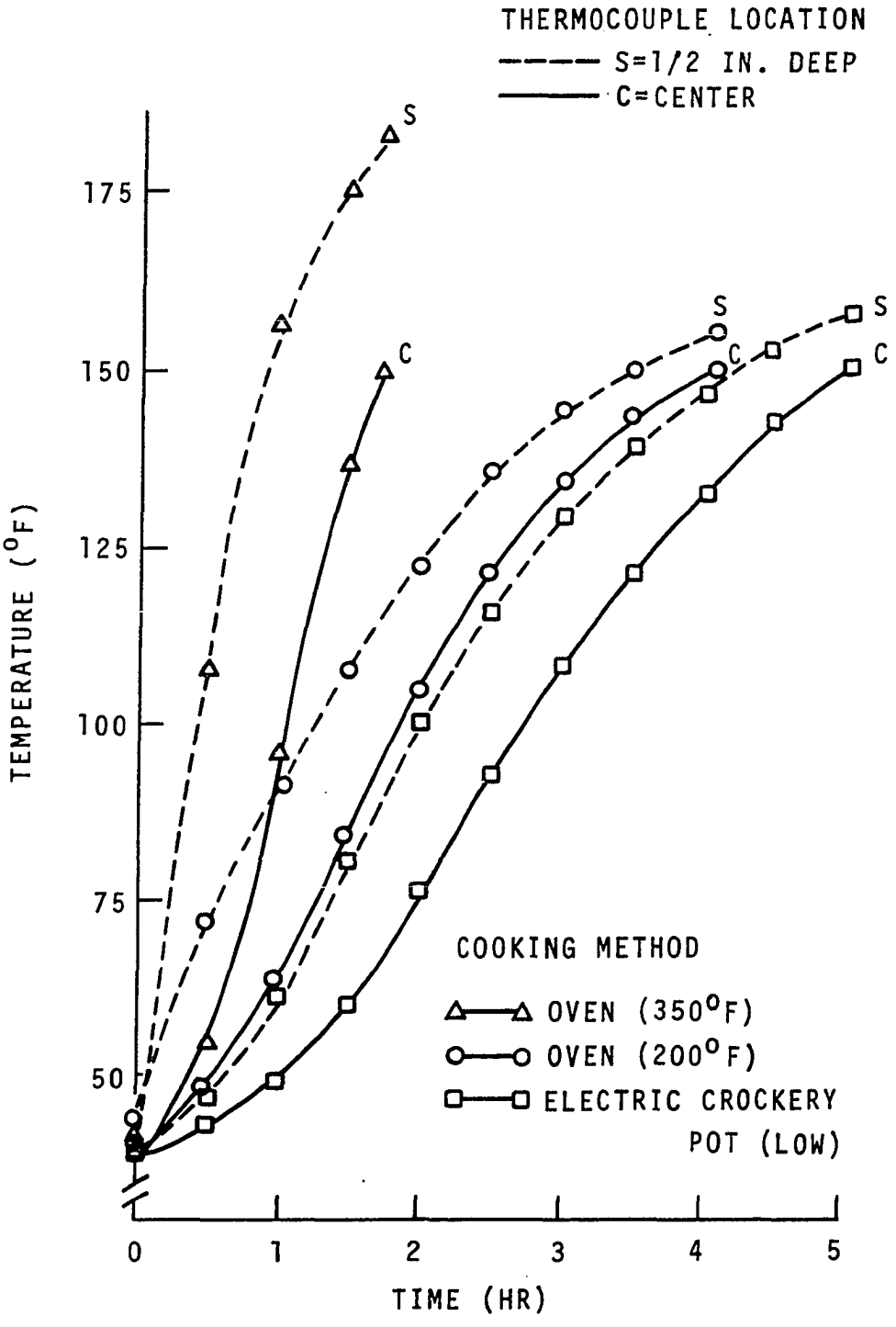


Table 15. Average[a] total, volatile and drip losses for top round roasts (4.4 lb) cooked to 150°F by three methods, Experiment III, Studies A and B[b]

Cooking method[c]	Cooking losses					
	Total		Volatile		Drip	
	A %	B %	A %	B %	A %	B %
CP	22.8	24.9	3.0	3.0	19.8	21.9
LO	17.2	20.6	11.4	7.3	5.8	13.2
MO	23.6	25.4	20.1	17.3	3.5	8.1
LSD[d]	4.6	-[e]	2.6	2.2	3.9	4.9

[a]Average for 4 roasts; except Study A, LO method, average for 3 roasts.

[b]A = 1973, General Electric range model J349001DC; B = 1975, General Electric range model J390003HT.

[c]CP = crockery pot, low; LO = oven, 200°F; MO = oven, 350°F.

[d]LSD, least significant difference at 0.01.

[e]F value for treatments was not significant.

losses for CP and MO roasts did not differ. In Study B, losses did not differ significantly among treatments. Results for slow cooking in Study B agree favorably with those reported by Vollmar et al. (1976). They cooked 3-lb top round roasts from the frozen state to 140° or 158°F in a slow-cooker at 185°F or in an oven at 200°F and concluded that total cooking losses were similar for the two methods.

Volatile losses The analyses of variance, presented in Table 45, Appendix, revealed that cooking method significantly affected the volatile losses in both studies. Comparison of the average volatile losses for the cooking methods in each study and use of the LSD criteria (given in Table 15) indicated that the mean of 3.0% for CP roasts (A or B) was significantly less than the means of 11.4% (A) or 7.3% (B) for LO roasts that were also lower than the 20.1% (A) or 17.3% (B) for MO roasts.

Drip losses Analyses of variance indicated that drip losses were affected significantly by the cooking method in each study (Table 45, Appendix). Examination of the data in Table 15 and use of the LSD criteria revealed that in both studies, drip losses for CP roasts (19.8% in A or 21.9% in B) were significantly greater than drip losses for LO or MO roasts. In Study A, average drip losses of 5.8% for LO roasts and 3.5% for MO roasts did not differ significantly. But in Study B, losses of 13.2% for LO roasts were significantly greater than losses of 8.1% for MO roasts.

In summary, total cooking losses were similar, approximately 25%, for roasts cooked to 150°F in the crockery pot or in the oven at 350°F and were somewhat lower, approximately 20%, for roasts cooked in the oven at 200°F. Composition of the total losses differed among the treatments. Most of the losses for roasts cooked in the crockery pot were drip (87% of the total, A or B), whereas most of the losses for roasts cooked in the ovens at 350°F were volatile (85% of the total in A or 68% in B). Composition of losses for roasts cooked in the ovens at 200°F was intermediate. When the average cooking time at 200°F was longer (335 min in A), volatile

losses predominated, but when the average cooking time was shorter (246 min in B), drip losses predominated.

Summary of Statistical Analysis

In order to obtain a concise review of the effect on beef roasts or loaves of cooking in a crockery pot or in a slow or moderate oven, the F values for the variables in each experiment were summarized in Tables 16, 17 and 18.

In Experiment I, F values in Table 16 indicated that of the 10 parameters tested, only the cooking losses were affected significantly ($p<0.01$) by the cooking method. Counts of aerobic organisms and of C. perfringens and the chemical composition and retention of vitamin B_6 did not differ significantly among roasts cooked 10 hr to 178°F in a 3 1/2-qt crockery pot on low, 9 hr to 185°F in an oven at 225°F or 2 1/4 hr to 170°F in an oven at 350°F.

In Experiment II, values in Table 17 indicated that only cooking time and volatile and drip losses were affected significantly ($p<0.01$) by the cooking method (crockery pot on low or oven at 325°F). All 10 parameters tested were affected significantly by the final temperature (120°, 135°, 150° or 165°F). In addition, for cooking time, cooking losses and aerobic organisms (center location), there existed an interaction between cooking method and final temperature.

Table 18 indicated that, in Experiment III, Studies A and B, cooking time and volatile and drip losses were affected significantly ($p<0.01$) by the cooking method (crockery pot on low or oven at 200° or at 350°F).

Total cooking losses were affected significantly by the cooking method in Study A only.

Table 16. Summary of results of analyses of variance for cooking method[a], Experiment I

Parameter	F value[b]
Cooking losses	
Total	20.64**
Volatile	375.27**
Drip	910.48**
Aerobic organisms	0.48
Clostridium perfringens	
Vegetative cells	5.76
Spores	2.93
Chemical composition	
Moisture	6.52
Fat	1.32
Vitamin B_6	
Content	1.51
Retention	1.31

[a]Crockery pot on low, 10 hr; oven at 225°F, 9 hr; or oven at 350°F to 170°F.

[b]$F_{0.01} = 10.92$.

**$p<0.01$.

Table 17. Summary of results of analyses of variance for cooking method (CM)[a] and final temperature (T)[b], Experiment II

Parameter	F values		
	CM[c]	T[d]	CM x T[d]
Cooking time	2919.22**	329.84**	191.79**
Cooking losses			
Total	2.76**	59.13**	6.81**
Volatile	819.73**	80.68**	23.65**
Drip	80.39**	44.50**	17.94**
Aerobic organisms			
Center	0.04	76.80**	8.59**
Side	1.52	126.54**	3.47
Clostridium perfringens			
Vegetative cells			
Center	1.22	68.68**	3.70
Side	1.18	20.27**	0.56
Spores			
Center	2.53	17.61**	0.28
Side	7.55	25.43**	0.67

[a]Crockery pot on low or oven at 325°F.

[b]120°, 135°, 150° or 165°F.

[c]$F_{0.01} = 8.02$.

[d]$F_{0.01} = 4.87$.

**$p<0.01$.

Table 18. Summary of results of analysis of variance for cooking method[a], Experiment III

Parameter	F values[b]	
	Study A[c]	Study B[c]
Cooking time	131.06**	154.79**
Cooking losses		
Total	23.32**	8.10**
Volatile	437.57**	313.87**
Drip	208.41**	55.41**

[a]Crockery pot on low; oven at 200°F or oven at 350°F.

[b]In Study A, $F_{0.01} = 13.27$; in Study B, $F_{0.01} = 10.92$.

[c]A = 1973, General Electric range model J349001DC; B = 1975, General Electric range model J390003HT.

**$p<0.01$.

SUMMARY

The objective of my research was to compare the safety, chemical composition and vitamin B_6 retention of beef cooked in electric crockery pots (3 1/2 or 4 1/2 qt) on low or in electric ovens at 200° or 225°F or at 325° or 350°F. The research was divided into three different investigations.

The main objective of Experiment I was to compare the survival of aerobic bacteria and of Clostridium perfringens in inoculated boneless rump roasts cooked by two low temperature methods versus the conventional method. The low temperature methods included cooking in a 3 1/2-qt electric crockery pot, on low setting, for an interval of 10 hr (chosen to represent an all day cooking period) and roasting at 225°F for an interval of 9 hr (chosen because roasts cooked any longer appeared charred and shrunken). The conventional method was roasting in an oven at 350°F to a final internal temperature of 170°F (chosen to typify the well-done stage). Thus, in the two low temperature methods, the cooking times were determined and the final internal temperatures were measured but in the conventional method, the final temperature was determined and the cooking time was measured. Other parameters that were compared included rate of temperature increase, cooking losses, appearance, chemical composition and vitamin B_6 retention.

Twelve roasts (two/week), that averaged 3.5 lb, were purchased from a retail store. Marked areas (2 x 3 1/2 in.) on the inner surface of each roast were inoculated with 1 ml of a suspension containing C. perfringens

S-45 (log counts, 8.89 vegetative cells and 5.32 spores/ml). Roasts were held 16 hr at 42°F and the next day were cooked by two of the three methods. Over a 6-week period, each cooking method was replicated four times.

Aerobic plate counts and differential counts for cells and spores of C. perfringens were made on 3/8-in. thick slices removed from the inoculated inner surface areas of the roasts (1) just before cooking or (2) 10 min after cooking. Raw and cooked samples were held at 42°F for a maximum of 6 hr until plated. Aerobic organisms were enumerated in Plate Count agar by the pour-plate method with incubation at 30°C for 48 hr. C. perfringens vegetative cells were counted after growth in SPS agar in anaerobic pouches for 24 hr at 37°C. C. perfringens spores in homogenates of the samples were heat-shocked at 80°C for 15 min and then plated and counted as described for the vegetative cells.

For the chemical analyses, two samples (approximately 50 g) were taken from the outside of each raw roast and two samples (approximately 200 g) were taken from each cooked roast. The samples were frozen and held at 0°F until assayed for fat and moisture content after 2 mo and for vitamin B_6 content after 6 mo. The procedure for the moisture analysis was to dry the sample in a Brabender forced draft oven and for fat analysis to extract the ether-soluble material from the sample in a Goldfisch apparatus. Vitamin B_6 was determined by a microbiological assay method using Saccharomyces uvarum (carlsbergensis) as the assay organism.

Analysis of variance was used to determine the significance of the effect of cooking method on the parameters studied and the 0.01 level of

significance was used.

Under the conditions of this experiment, the following results were obtained:

1. In the crockery pot set on low the air temperature rose slowly from an initial temperature of 60°F to a maximum of 185°F reached after 8 hr and then did not fluctuate or increase for the next 2 hr. The air temperature in all the ovens reached the set temperature within 15 min. During the rest of the cooking period, the temperatures in the ovens set at 225°F were 224° ± 18°F and in the ovens set at 350°F were 336° ± 12°F.

2. The average final internal temperature was 178°F for roasts cooked 10 hr in the CP and 185°F for those cooked 9 hr in the LO. Roasts cooked to 170°F in the MO required 2 1/4 hr.

3. The average rate of temperature increase in °F/min from the initial temperature (47°F) to 178°F was 0.2 for CP roasts, to 185°F was 0.3 for LO roasts and to 170°F was 0.9 for MO roasts. The rate of temperature increase in °F/min through the growth zone for mesophilic bacteria, 60°-120°F, was 0.4 for CP roasts, 0.7 for LO roasts and 1.2 for MO roasts.

4. Total cooking losses were similar, 38 and 39%, for roasts cooked in the CP for 10 hr to 178°F or in the LO for 9 hr to 185°F. These losses were significantly greater ($p<0.01$) than losses of 32% for MO roasts cooked for 2 1/4 hr to 170°F.

5. Composition of the total cooking losses differed significantly ($p<0.01$) among the treatments. Volatile losses were negligible, 2.8%, for CP roasts cooked for 10 hr to 178°F, but were large, 34%, for LO roasts cooked 9 hr to 185°F, or 28%, for MO roasts cooked for 2 1/4 hr to

170°F. Drip losses were large, 35%, for CP roasts and small, approximately 5%, for either the LO or MO roasts.

6. The appearance of CP roasts differed from that of LO or MO roasts. The cooked meat of the CP roasts retained a reddish cast and the fat on the outside did not brown. But the cooked meat of the LO or MO roasts was medium to dark brown and the fat was bronze or golden brown.

7. The moisture content of the raw rump roasts averaged 70% and the fat content, 7.7%. The method of cooking did not have a significant effect on the composition of the cooked roasts. The chemical composition, pooled for the 12 cooked roasts in the three treatments, was 56% moisture and 10.4% fat.

8. The vitamin B_6 content/100 g (calculated as pyridoxine on a moist weight basis) was 0.50 mg in the raw and 0.32 mg in the cooked rump roasts and did not differ significantly among treatments. Calculated on the dry weight basis, the vitamin B_6 retention in the 12 rump roasts averaged 43.1%.

9. Aerobic plate counts on the surfaces of the raw rump roasts averaged 50,000/g. Regardless of cooking method, cooked roasts had <50 aerobic organisms/g on the inner surfaces.

10. The C. perfringens vegetative cell population on the inoculated surfaces of the raw rump roasts averaged 2×10^6/g. The cooking method did not have a significant effect on the number of cells recovered from the cooked roasts. All cooking methods decreased the cell count by $\geq$3.4 log cycles to an average of 300/g on the inoculated inner surfaces of the roasts.

11. C. perfringens spore counts averaged 1500/g on the inoculated surfaces of the raw roasts. The number of spores that survived cooking by the three methods did not differ significantly. All cooking methods decreased the spore count by ≥0.6 log cycle to an average of 200/g on the inoculated inner surfaces of the roasts.

The objective of Experiment II was to compare the extent of bacterial destruction in meat loaves cooked in a 3 1/2-qt electric crockery pot on low (CP method) or in an oven at 325°F (MO method) to final temperatures of 120°, 135°, 150° or 165°F. Also comparisons were made among loaves for the rate of temperature increase, cooking time, cooking losses and appearance.

Ground chuck (6.4 lb) for four meat loaves was purchased at one time from a retail grocery. The meat was divided into two lots, each sufficient for two meat loaves. A 20-ml suspension containing C. perfringens vegetative cells and spores (log counts 8.67 and 5.67/ml) was added to each lot. Then the inoculated chuck was combined with eggs, milk, bread crumbs and salt. The proportion of inoculum suspension to meat loaf mixture was 1 ml/100 g. The two batches of meat loaf mixture were molded into four 2-lb cylindrical loaves, 3 in. tall and 5 in. in diameter. After the loaves were held overnight (19 ± 2 hr) at 45°F, two loaves were cooked in the CP and the other two in the MO. One loaf assigned to each method was cooked to 120°F and the other to 150°F. The same two cooking methods were used on each of the eight test days, but final temperatures of 135° and 165°F were tested alternately with 120° and 150°F. Thus, each cooking method was replicated four times at each final temperature.

Counts of aerobic organisms and of C. perfringens vegetative cells and spores were made on 50-g subsamples from the 60 to 100-g samples taken (1) from the raw ground chuck before inoculation, (2) from the raw inoculated loaves just before cooking and (3 and 4) from the centers and sides of the inoculated loaves immediately after cooking. The raw uninoculated ground chuck samples were held at 45°F for 24 hr until plated; all other samples were held at 45°F for no longer than 9 hr. Procedures for the bacteriological determinations were the same as for Experiment I.

Analysis of variance was used to determine the significance of effects of cooking method and final temperature on the parameters measured. Also the significance of the differences between bacterial populations (1) at 120° and 135°F, (2) at 135° and 150°F and (3) at 150° and 165°F were tested.

Under the conditions of this experiment, the following results were obtained:

1. Air temperature in the 3 1/2-qt crockery pot set on low rose from 72°F at the start to 204°F near the end of the cooking period (6 1/2 hr). The temperature in the oven preheated to 325°F was 324° ± 18°F throughout the cooking period.

2. The rate of temperature increase between 60° and 120°F was 0.5°F/min for the CP loaves, only 1/3 that for the MO loaves, 1.6°F/min. Above 120°F, the rate became even slower for the CP roasts but remained constant for the MO roasts.

3. Temperatures at the side (1 in. from the edge) of CP loaves were 5-7°F higher than those at the center at 120° and 135°F, but temperatures

at the two locations were approximately the same at 150° and 165°F. Temperatures at the side of MO loaves were approximately 15°F higher than those at the center at all end-points tested.

4. The cooking time for the 2-lb meat loaves was affected significantly ($p<0.01$) by the cooking method, final temperature and the interaction of cooking method and final temperature. Cooking time to 120°F was approximately 3 times longer (163 vs. 53 min) and to 165°F was 4.7 times longer (7 hr vs. 1 1/2 hr) in the CP than in the MO.

5. Total cooking losses of the meat loaves were affected significantly ($p<0.01$) by the final temperature and by the interaction of cooking method and final temperature. Significant differences in total cooking losses occurred within the CP method for loaves cooked to final temperatures that differed by 15°F and within the MO method for loaves cooked to final temperatures that differed by 30°F. Losses tended to be less for CP than for MO loaves at 120° and 135°F but greater at 150°F. After cooking to 165°F, the difference between total losses of 27% for CP loaves and of 20% for MO loaves was significant ($p<0.01$).

6. Volatile and drip losses of the meat loaves were each affected significantly ($p<0.01$) by cooking method, final temperature and the interaction of cooking method and final temperature. Volatile losses for CP loaves were always very small, but volatile losses for MO loaves increased from 4% at 120°F to 11% at 165°F. Drip losses for CP loaves increased dramatically from 5% at 120°F to 24% at 165°F, but drip losses for MO loaves increased only slightly from 6% at 120°F to 10% at 165°F.

7. The appearance varied throughout the CP loaves cooked 4-4 1/2 hr to 150°F from "done" at the top to raw at the bottom. CP loaves cooked 7 hr to 165°F were medium brown with a slight pinkish cast at the bottom. MO loaves cooked 1 1/2 hr to 165°F were dark brown outside and medium brown with an occasional slight pinkish cast inside.

8. The aerobic plate counts for the eight lots of raw ground chuck averaged 3×10^7/g. In meat loaves prepared from the ground chuck, the counts averaged 1.1×10^7/g. The aerobic populations in the centers and sides of the cooked loaves were affected significantly ($p<0.01$) by the temperature but not by the cooking method. For aerobic plate counts in the centers, there existed a significant interaction between the effects of cooking method and of final temperature. Counts only in the centers of the loaves are summarized here. The counts for loaves cooked to 120° or 135°F were not significantly different, regardless of cooking method. The counts declined significantly in all loaves cooked to 150°F compared with counts at 135°F. But in loaves cooked to 165°F, counts declined dramatically in CP loaves but only moderately in MO loaves. Thus, at 165°F, compared with counts in raw loaves, the number of aerobic organisms was reduced 5.6 log cycles or to <100/g in CP loaves and 4.0 log cycles or to 1000/g in MO loaves.

9. C. perfringens was isolated from five of the eight lots of raw ground chuck. The C. perfringens vegetative cell counts in the raw inoculated loaves averaged 4×10^5/g. Populations in the centers and sides of the cooked meat loaves were affected significantly ($p<0.01$) by the temperature but not by the cooking method. Counts only in the centers of the

loaves are summarized here. Although the temperatures in the centers of the loaves were in the growth zone for C. perfringens, 60°-120°F, for nearly 2 hr in the CP and for 40 min in the MO, the cell counts were not increased in the loaves cooked to 120°F. The counts in all loaves cooked to 135° or 150°F decreased significantly compared with counts at 120°F and did not decrease further in loaves cooked to 165°F. A possible explanation for no change in log counts between 150° and 165°F is that some of the spores might have germinated which would have offset the kill of the cells. Inoculated meat loaves cooked to 165°F either in the CP or in the MO contained approximately 2700 vegetative cells/g, 2.2 log cycles fewer than in the raw loaves.

10. No spores of C. perfringens were isolated in samples from the eight lots of raw uninoculated ground chuck. Spore counts in the inoculated raw loaves averaged 770/g. Counts in the centers and in the sides of cooked loaves were affected significantly ($p<0.01$) by the temperature but not by the cooking method. Spore counts in the centers of CP or MO loaves cooked to 135° or 150°F were not significantly different from those in loaves cooked to 120°F. But the count was reduced significantly in loaves cooked to 165°F. In CP or MO loaves cooked to 165°F, the spore count was approximately 50/g, 1.2 log cycles fewer than in the raw loaves.

The main objective of Experiment III was to compare the cooking time and cooking losses of beef top round roasts cooked by two methods of slow cooking with conventional roasting. Study A, conducted in 1973, and Study B, conducted in 1975, differed only in the model of General Electric ranges used, model J349001DC (A) or model J390003HT (B). For each study,

12 roasts (4 replications x 3 cooking methods) were purchased from a retail grocery store. After the roasts (approximately 4.4 lb) were held at 38°F for 14 hr, they were cooked (1) in a 4 1/2-qt electric crockery pot set on low (CP method), (2) in an oven set at 200°F (LO method) or (3) in an oven set at 350°F (MO method). Air and roast temperatures were recorded during cooking. Roasts were weighed for determination of cooking losses. Analysis of variance was used to determine the significance of the effect of cooking method on the parameters studied.

Under the conditions of Experiment III (Studies A and B), the following results were obtained:

1. Air temperatures in the preheated ovens were similar for both studies. The temperatures in the ovens set at 200°F averaged 198° ± 18°F and in the ovens set at 350°F averaged 345° ± 13°F. Air temperature in the 4 1/2-qt crockery pot set on low rose slowly from 63°F at the start of the cooking period to a maximum of 185°F (A) or 179°F (B), reached near the end of cooking (4 1/2-5 hr).

2. Cooking time was affected significantly ($p<0.01$) by the cooking method. Average total min were 284 (A) or 303 (B) for roasts cooked in the CP, 335 (A) or 246 (B) for roasts cooked in the LO, and 121 (A) or 103 (B) for roasts cooked in the MO.

3. The average rate of temperature increase in °F/min from 38° to 150°F was 0.4 for CP roasts, 0.3 (A) or 0.5 (B) for LO roasts and 0.9 (A) or 1.1 (B) for MO roasts. The rate of temperature increase in °F/min in the growth zone for mesophilic bacteria, 60°-120°F, was 0.5 for CP roasts, 0.5 (A) or 0.6 (B) for LO roasts and 1.3 for MO roasts. Thus, the rate of

temperature increase in the growth zone in CP and LO roasts was approximately 1/3 that in MO roasts.

4. During cooking of roasts by the three methods in Study IIIB, the temperatures at a depth of 1/2 in. exceeded the temperatures at the center by 40-60°F in MO roasts and by 10-25°F in CP and LO roasts. At the end of cooking, the temperatures near the surface exceeded those in the center by 33°F in MO roasts but by only 5-8°F in CP or LO roasts.

5. Total cooking losses for top round roasts cooked to 150°F were affected significantly ($p<0.01$) by the cooking method in Study A but not in Study B. The losses from CP and MO roasts were similar in each study and averaged 23% in A and 25% in B. The losses from LO roasts, 17% in A and 21% in B, were somewhat lower than the losses from CP and MO roasts.

6. Composition of the cooking losses differed among roasts cooked to 150°F by the three methods. Most of the losses from CP roasts were drip (21%) and most from MO roasts were volatile (19%). The composition of the losses from the LO roasts was intermediate and differed between the two studies. In Study A, the volatile losses from LO roasts were greater than the drip; in Study B, the reverse was true.

Comparisons of the results from the three experiments indicated that the rise in air temperature in a CP with a continuous-heat unit set on low (200°F) was dependent on the load and the wattage. During cooking, the air temperature of 185°F was reached in approximately 2 hr for the 2-lb meat loaves and in 8 hr for the 3 1/2-lb rump roasts in the 3 1/2-qt CP (70 w), in 5 hr for the 4 1/2-lb top round roasts in the 4 1/2-qt CP (95 w).

Data on yield from the three experiments indicated that for 3 1/2-lb boneless rump roasts cooked either in a 3 1/2-qt CP on low (200°F) for 10 hr to 178°F or in an LO (225°F) for 9 hr to 185°F, the yield of cooked edible meat was 61% compared with 68% for roasts cooked in an MO (350°F) for 2 1/4 hr to 170°F. For 4 1/2-lb top round roasts cooked in 150°F in a 4 1/2-qt CP on low (200°F) or in an MO (350°F), the yield of cooked edible meat was 76% compared with 81% for roasts cooked in an LO (200°F). For 2-lb meat loaves cooked to 165°F in a 3 1/2-qt CP on low (200°F), the yield of cooked meat was 73% compared with 80% for loaves cooked in an MO (325°F).

Comparison of the data from microbiological analyses in Experiments I and II on the rump roasts and meat loaves indicated that the cooking method did not have a significant effect in either experiment on the survival of aerobic organisms or of C. perfringens vegetative cells and spores. The number of surviving organisms in any of the roasts or meat loaves tested was not sufficient to cause food poisoning.

CONCLUSIONS

In this research, long slow cooking, in a crockery pot (heating coils around the sides) or oven, was compared with conventional roasting in an oven in relation to survival of Clostridium perfringens or aerobic bacteria or to physical or chemical characteristics of beef. Under the conditions of the experiments on inoculated rump roasts, inoculated meat loaves and uninoculated top round roasts, the following conclusions are drawn:

1. The numbers of C. perfringens vegetative cells and spores that survive in beef roasts or loaves cooked at low temperatures (200°-225°F) in crockery pots or ovens for long periods, roasts, 9 or 10 hr or loaves, 7 hr, are similar to the numbers that survive on meat cooked at conventional temperatures (325°-350°F) in ovens. Beef roasts or loaves cooked by either the long slow methods or the conventional methods should not cause C. perfringens food poisoning if eaten immediately. But prompt refrigeration of leftover meat is necessary because cooking stimulates germination of C. perfringens spores in meat and drives off oxygen, creating anaerobic conditions favorable for spore outgrowth. Cooked meat should not be stored at room temperature in crockery pots or ovens because surviving cells and spores could multiply rapidly to numbers sufficient to cause illness.
2. Top round roasts (4 1/2 lb) cooked in crockery pots or low ovens (200°F) require 5 hr to reach 150°F, which is 2 1/2 times as long as roasts cooked in moderate ovens (350°F). Meat loaves (2 lb)

cooked to 165°F in crockery pots (200°F) require 7 hr, 4 3/4 times as long as in moderate ovens (325°F).

3. Manufacturers claim that cooking meat in crockery pots reduces the cooking losses, but, in fact, losses are greater for beef roasts or loaves cooked in crockery pots for long periods than for the meat cooked in moderate ovens (325°-350°F) for shorter periods.

LITERATURE CITED

Ahmed, M. and H. W. Walker
1971 Germination of spores of Clostridium perfringens. J. Milk Food Technol. 34:378.

Anonymous
1975 Crockery cookers. Consumer Reports 40:646.

The Association of Vitamin Chemists, Inc.
1966 Methods of vitamin assay. 3rd ed. New York, Interscience Publishers.

Atkin, L., A. S. Schultz, W. L. Williams and C. N. Frey
1943 Yeast microbiological methods for determination of vitamins. Pyridoxine. Ind. Eng. Chem., Anal. Ed. 15:141.

Ayres, J. C.
1955 Microbiological implications in the handling, slaughtering, and dressing of meat animals. Adv. in Food Res. 6:109.

Ayres, J. C.
1960 Temperature relationships and some other characteristics of the microbial flora developing on refrigerated beef. Food Res. 25:1.

Baity, M. R., A. E. Ellington and M. Woodburn
1969 Foil wrap in oven cooking. J. Home Economics 61:174.

Barnes, E. M., J. E. Despaul and M. Ingram
1963 The behaviour of a food poisoning strain of Clostridium welchii in beef. J. Appl. Bacteriol. 26:415.

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

Bayne, B. H., B. H. Meyer, G. E. Goertz and K. M. Kolasa
1973b A summary of current research. The University of Tennessee Agricultural Experiment Station Bulletin 516.

Bladel, B. O. and R. A. Greenberg
1965 Pouch method for the isolation and enumeration of clostridia. Appl. Microbiol. 13:281.

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

Brown, D. F. and R. M. Twedt
1972 Assessment of the sanitary effectiveness of holding temperatures on beef cooked at low temperature. Appl. Microbiol. 24:599.

Brubacher, G. and O. Wiss
1968 Vitamin B_6 group: Estimation in food and food supplements. Pages 19-20 in Sebrell, W. H. and R. S. Harris, eds. The vitamins: Chemistry, physiology, pathology, methods. Vol. 2. 2nd ed. New York, Academic Press.

Bryan, F. L. and E. G. Kilpatrick
1971 Clostridium perfringens related to roast beef cooking, storage, and contamination in a fast food service restaurant. Am. J. Public Health 61:1869.

Center for Disease Control
1976 Foodborne and waterborne disease outbreaks. Annual summary 1974. U.S. Department of Health, Education, and Welfare.

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

Difco Laboratories
1972 Difco supplementary literature. Detroit, Difco Laboratories.

Frazier, W. C.
1967 Food microbiology. 2nd ed. New York, McGraw-Hill Book Company.

Funk, K. and M. A. Boyle
1972 Beef cooking rates and losses. J. Am. Dietet. Assoc. 61:404.

Griswold, R. M.
1955 The effect of different methods of cooking beef round of Commercial and Prime grades. I. Palatability and shear values. Food Res. 20:160.

Hall, H. E. and R. Angelotti
1965 Clostridium perfringens in meat and meat products. Appl. Microbiol. 13:352.

Hall, H. E., R. Angelotti, K. H. Lewis and M. J. Foter
1963 Characteristics of Clostridium perfringens strains associated with food and food-borne disease. J. Bacteriol. 85:1094.

Hauschild, A. H. W. and F. S. Thatcher
1967 Experimental food poisoning with heat-susceptible Clostridium perfringens type A. J. Food Sci. 32:467.

Haziak, R. J.
1973 Microbial quality of meat samples from retail store meat counters. Proceedings of the Meat Science Day, Nov. 12, 1973. Iowa State University Cooperative Extension Service.

Hobbs, B. C.
1968 Food poisoning and food hygiene. 2nd ed. London, Edward Arnold Ltd.

Kim, C. H., R. Cheney and M. Woodburn
1967 Sporulation of Clostridium perfringens in a modified medium and selected foods. Appl. Microbiol. 15:871.

Ladiges, W. C., J. F. Foster and W. M. Ganz
1974 Incidence and viability of Clostridium perfringens in ground beef. J. Milk Food Technol. 37:622.

Leverton, R. M. and G. V. Odell
1958 The nutritive value of cooked meats. Oklahoma State University Agricultural Experiment Station Misc. Publ. MP-49.

Lillard, H. S.
1971 Occurrence of Clostridium perfringens in broiler processing and further processing operations. J. Food Sci. 36:1008.

Lushbough, C. H., J. M. Weichman and B. S. Schweigert
1959 The retention of vitamin B_6 in meat during cooking. J. Nutrition 67:451.

Marshall, N., L. Wood and M. B. Patton
1960 Cooking Choice grade, top round beef roasts. J. Am. Dietet. Assoc. 36:341.

Meyer, B. H., M. A. Mysinger and L. A. Wodarski
1969 Pantothenic acid and vitamin B_6 in beef. J. Am. Dietet. Assoc. 54:122.

Nielsen, M. M. and F. T. Hall
1965 Dry-roasting of less tender beef cuts. J. Home Economics 57:353.

Paul, P. C.
1972 Meat. Pages 335-494 in Paul, P. C. and H. H. Palmer, eds. Food theory and applications. New York, John Wiley and Sons, Inc.

Paul, P., M. L. Morr, L. Bratzler and M. A. Ohlson
1950 Effect of boning on cooking losses and palatability of beef. Food Technol. 4:348.

Peters, C. R.
1974 Effect of oven cooking and cooking in a slow electric cooker on microbiological quality, moisture content, cooking losses and palatability of meat loaves and whole broiler-fryer chickens. M.S. thesis. Urbana-Champaign, Library, University of Illinois. Abstracted in Home Economics Research Abstracts - 1974. American Home Economics Association.

Pike, R. L. and M. L. Brown
1975 Nutrition: An integrated approach. 2nd ed. New York, John Wiley and Sons, Inc.

Polansky, M. M. and E. W. Toepfer
1969 Vitamin B_6 components in some meats, fish, dairy products, and commercial infant formulas. J. Agr. Food Chem. 17:1394.

Price, J. M., M. J. Thornton and L. M. Mueller
1967 Tryptophan metabolism in women using steroid hormones for ovulation control. Am. J. Clin. Nutrition 20:452.

Rey, C. R., H. W. Walker and P. L. Rohrbaugh
1975 The influence of temperature on growth, sporulation and heat resistance of spores of six strains of Clostridium perfringens. J. Milk Food Technol. 38:461.

Rose, D. P.
1966 The influence of oestrogens on tryptophan metabolism in man. Clin. Sci. 31:265.

Smith, L. DS.
1972 Factors involved in the isolation of Clostridium perfringens. J. Milk Food Technol. 35:71.

Stringer, W. C., M. E. Bilskie and H. D. Naumann
1969 Microbial profiles of fresh beef. Food Technol. 23:97.

Strong, D. H. and N. M. Ripp
1967 Effect of cookery and holding on hams and turkey rolls contaminated with Clostridium perfringens. Appl. Microbiol. 15: 1172.

Sutton, R. G. A., M. Kendall and B. C. Hobbs
1972 The effect of two methods of cooking and cooling on Clostridium welchii and other bacteria in meat. J. Hygiene 70:415.

Sylvester, P. K. and J. Green
1961 The effect of different types of cooking on artificially infected meat. Medical Officer 105:231.

Vollmar, E. K., D. L. Harrison and M. G. Hogg
1976 Bovine muscle cooked from the frozen state at low temperature. J. Food Sci. 41:411.

Walker, H. W.
1975 Food borne illness from Clostridium perfringens. Critical Reviews in Food Science and Nutrition 7:71.

Watt, B. K. and A. L. Merrill
1963 Composition of foods: Raw, processed, prepared. U.S. Department of Agriculture, Agriculture Handbook No. 8.

Wells, F. E. and L. J. Kennedy
1972 Thermal death studies on bacteria associated with foods prepared in low temperature-long time cookers. Final Report MRI Project No. 3683-B, Midwest Research Institute, Kansas City.

Ziprin, Y. A.
1975 Eating quality, nutritive value and safety of beef and beef-soy loaves cooked in microwave or in conventional ovens. M.S. thesis. Ames, Library, Iowa State University.

ACKNOWLEDGMENTS

Particular gratitude is extended to Dr. Frances Carlin for her guidance throughout my graduate program, especially from the initiation of the experiments reported here through the completion of this thesis. Her application of methods of scientific inquiry to numerous food science problems continues to inspire me.

I wish to thank Dr. Paul Hartman and Dr. Homer Walker for advice and support related to the bacteriological aspects of my research. I am grateful to Dr. Charlotte Roderuck for information about vitamin assays. Sincere appreciation is expressed to Dr. Donald Hotchkiss for assistance with the statistical analysis of the data.

Grateful acknowledgment is made of the encouragement and help given by Mrs. Linda Nielsen and Mrs. Yolanda Ziprin, research associates.

Special appreciation goes to my husband, Ken, for his enthusiasm for scientific endeavor. Sincere thanks is expressed also to my parents, Mr. and Mrs. Junior Dittmer and Mrs. Della Sundberg, for their constant encouragement.

Acknowledgment is given to the Iowa Agriculture and Home Economics Experiment Station for supporting this NC-120 Project (Project Number 2060) and to the National Live Stock and Meat Board for their interest and for providing one of the Crock-Pots. My graduate program was supported in part by the National Science Foundation and by the General Foods Fund. I am grateful for this assistance.

APPENDIX

Preparation of *Clostridium perfringens* Inoculum Suspension

1. Maintain a stock culture of *C. perfringens* S-45 in Cooked Meat medium (Difco) at room temperature with biweekly transfers.

2. Transfer 0.5 ml of broth from the stock culture tube to fresh Fluid Thioglycollate medium (FTM, Difco) and incubate at 37°C for 16 hr.

3. Make two successive 4-hr transfers (0.5 ml) into FTM and incubate at 37°C.

4. Transfer 0.5 ml from the last FTM culture into each of several tubes of Kim's sporulation medium (Kim et al., Appl. Microbiol. 15:871) and incubate the tubes at 37°C for 20 hr.

5. Transfer the sporulated culture into centrifuge tubes, cap the tubes with foil and centrifuge at 6500 rpm (5000 r.c.f.) for 20 min in a Servall SS-4 centrifuge equipped with an SS-34 rotor.

6. Wash the cells by adding 10 ml of 0.1% peptone buffer to each centrifugate and stirring with a glass rod, then recentrifuging at 5000 rpm (3000 r.c.f.) for 20 min.

7. Repeat step 6.

8. Suspend the centrifugate in 0.1% peptone solution. Use 2.5 ml peptone per 10 ml of sporulated culture.

9. Combine the suspensions in a sterile container and stir vigorously with a glass rod.

Figure 9. Preparation of *Clostridium perfringens* inoculum suspension, Experiments I and II

Preparation of Inoculated Meat Loaves

Ingredients	g		%	
Coarse ground chuck	1368		68.4	
Reconstituted milk solids	340		17.0	
NFDM		24		1.2
Tap water		316		15.8
Whole egg	140		7.0	
Dry bread crumbs	120		6.0	
Cheese salt	12		0.6	
C. perfringens suspension	20		1.0	
Total	2000		100.0	

Source of ingredients

Coarse ground chuck, Ames Fruit and Grocery store, average fat content, 15%.

NFDM, Carnation Instant Nonfat Dry Milk, Carnation Company.

Whole egg, Grade A large.

Dry bread crumbs, white enriched bread, Hy-Vee Thinly Sliced Sandwich Bread, dried 2 hr at 150°F and then ground, KitchenAid grinder, 3/16 in. plate.

Cheese salt, evaporated, granulated, Morton Salt Co.

Mixing procedure

1. Mix milk, egg, bread crumbs and salt in a KitchenAid mixer at speed 4 for 40 sec.
2. Grind inoculated coarse ground chuck through the 3/16-in. breaker plate of the grinder attachment for the KitchenAid mixer into the 2-gal. bowl of a Hobart mixer.
3. Pour the liquid ingredients over the meat.
4. Using the Hobart mixer, cut and turn the mixture 5 times with a rubber spatula; mix at speed 2 for 3 one-sec. periods; cut and turn 5 times; mix for a continuous 3-sec.

Figure 10. Ingredients and their source and mixing procedure for inoculated meat loaves, Experiment II

Table 19. Raw weight, final temperature, cooking time and rate of temperature increase for boneless rump roasts cooked by three methods, Experiment I

Cooking method	Roast weight lb	Final temperature °F	Cooking time		Rate of temperature increase °F/min
			Total min	Min/ lb	
Crockery pot, low	3.1	176	600	194	0.21
	3.3	179	600	182	0.22
	3.6	177	600	167	0.22
	3.8	180	600	158	0.22
Av	3.4	178	600	175	0.22
Oven, 225°F	3.8	188	540	142	0.26
	3.1	185	540	174	0.25
	4.2	181	540	129	0.25
	3.1	187	540	174	0.26
Av	3.6	185	540	155	0.26
Oven, 350°F	3.3	170	132	40	0.92
	3.5	170	148	42	0.82
	3.5	170	129	37	0.95
	3.6	170	136	38	0.91
Av	3.5	170	136	39	0.90

Table 20. Total, volatile and drip losses for boneless rump roasts (3.5 lb) cooked by three methods, Experiment I

Cooking method	Cooking losses		
	Total %	Volatile %	Drip %
Crockery pot, low, 10 hr	39.4	3.6	35.8
	38.0	2.6	35.4
	39.7	2.6	37.1
	35.6	2.6	33.0
Av	38.2	2.8	35.3
Oven, 225°F, 9 hr	39.1	32.5	6.5
	38.7	34.7	4.1
	38.4	31.2	7.2
	41.6	37.4	4.2
Av	39.4	34.0	5.5
Oven, 350°F to 170°F	32.3	27.8	4.5
	33.0	28.8	4.2
	30.9	26.6	4.3
	31.9	26.9	5.0
Av	32.0	27.5	4.5

Table 21. Analysis of variance for percent total, volatile and drip losses for boneless rump roasts (3.5 lb) cooked by three methods, Experiment I

Source of variation	df	MS	F value
		Total losses	
Replication	3	0.22	0.07
Cooking method	2	62.76	20.64**
Error	6	3.04	
Total	11		
		Volatile losses	
Replication	3	2.66	0.93
Cooking method	2	1077.68	375.27**
Error	6	2.87	
Total	11		
		Drip losses	
Replication	3	2.74	2.04
Cooking method	2	1225.66	910.48**
Error	6	1.35	
Total	11		

**Significant at the 0.01 level.

Table 22. Average[a] moisture and fat content of raw and cooked samples[b] from boneless rump roasts (3.5 lb) cooked by three methods, Experiment I

Cooking method	Moisture		Fat	
	Raw %	Cooked %	Raw %	Cooked %
Crockery pot, low, 10 hr	69.4	56.0	8.4	10.4
	72.4	57.9	5.1	9.7
	69.3	56.3	9.5	9.9
	69.3	55.8	8.9	10.6
Av	70.1	56.5	8.0	10.2
Oven, 225°F, 9 hr	67.8	53.8	10.3	11.1
	70.6	53.5	6.3	10.6
	69.8	54.7	8.9	12.2
	71.1	54.3	8.5	11.5
Av	69.8	54.0	8.5	11.4
Oven, 350°F to 170°F	71.5	56.5	6.8	10.0
	69.2	55.2	9.4	12.3
	72.6	59.6	5.7	9.2
	73.0	58.4	4.1	7.2
Av	71.6	57.4	6.5	9.7

[a]Average of two determinations/sample.

[b]Composed of portions of several muscles.

Table 23. Analysis of variance for moisture and fat content of boneless rump roasts (3.5 lb) cooked by three methods, Experiment I

Source of variation	df	MS	F value
		Moisture	
Replication	3	1.31	0.71
Cooking method	2	12.00	6.52
Error	6	1.84	
Total	11		
		Fat	
Replication	3	0.64	0.28
Cooking method	2	3.01	1.32
Error	6	2.28	
Total	11		

Table 24. Average[a] vitamin B_6 content[b] and B_6 retention for raw and cooked samples[c] of boneless rump roasts (3.5 lb) cooked by three methods, Experiment I

Cooking method	Vitamin B_6 content				Vitamin B_6 retention %
	Raw samples		Cooked samples		
	Moist[d] mg/100 g	Dry[d] mg/100 g	Moist mg/100 g	Dry mg/100 g	
Crockery pot, low, 10 hr	0.49	1.59	0.32	0.73	45.8
	0.51	1.85	0.28	0.68	36.6
	0.48	1.56	0.26	0.60	38.6
	0.44	1.42	0.28	0.62	43.7
Av	0.48	1.61	0.29	0.66	41.2
Oven, 225°F, 9 hr	0.49	1.53	0.40	0.85	55.8
	0.56	1.90	0.34	0.73	38.6
	0.50	1.67	0.31	0.69	41.2
	0.40	1.39	0.27	0.60	43.3
Av	0.49	1.62	0.33	0.72	44.7
Oven, 350°F to 170°F	0.51	1.79	0.39	0.90	50.2
	0.52	1.67	0.25	0.56	33.7
	0.48	1.77	0.32	0.79	44.8
	0.58	2.14	0.40	0.95	44.4
Av	0.52	1.84	0.34	0.80	43.3

[a]Average of 12 readings on each sample (2 assays x 3 levels of extract x 2 readings).

[b]Calculated as pyridoxine.

[c]Composed of portions of several muscles.

[d]Basis of calculation.

Table 25. Analysis of variance for vitamin B_6 content and B_6 retention in boneless rump roasts (3.5 lb) cooked by three methods, Experiment I

Source of variation	df	MS	F value
		Vitamin B_6 content	
Replication	3	0.016	1.16
Cooking method	2	0.021	1.51
Error	6	0.014	
Total	11		
		Vitamin B_6 retention	
Replication	3	105.186	10.92**
Cooking method	2	12.660	1.31
Error	6	9.634	
Total	11		

**Significant at the 0.01 level.

Table 26. Log aerobic plate counts[a] for boneless rump roasts (3.5 lb) cooked by three methods, Experiment I

Cooking method	Raw roasts cells/g	Cooked roasts cells/g
Crockery pot, low, 10 hr	4.16	1.60
	4.03	1.08
	4.21	2.18
	4.11	0.90
Av	4.13	1.44
Oven, 225°F, 9 hr	4.86	2.08
	4.68	1.68
	4.77	1.34
	5.50	1.54
Av	4.95	1.66
Oven, 350°F to 170°F	4.98	1.65
	5.60	1.54
	4.58	0.90
	5.18	1.34
Av	5.08	1.36

[a]Average for two plates.

Table 27. Analysis of variance for aerobic plate counts for boneless rump roasts (3.5 lb) cooked by three methods, Experiment I

Source of variation	df	MS	F value
Replication	3	0.138	0.69
Cooking method	2	0.097	0.48
Error	6	0.200	
Total	11		

Table 28. Log counts[a] of Clostridium perfringens vegetative cells and spores for inoculated rump roasts (3.5 lb) cooked by three methods, Experiment I

Cooking method	Vegetative cells/g		Spores/g[b]	
	Raw roasts	Cooked roasts	Raw roasts	Cooked roasts
Crockery pot, low, 10 hr	6.52	1.81	2.86	1.84
	6.46	2.05	2.89	1.72
	6.18	3.04	3.20	2.75
	5.98	2.46	3.11	2.45
Av	6.29	2.34	3.01	2.19
Oven, 225°F, 9 hr	6.26	1.70	2.79	1.70
	6.36	2.54	3.67	2.32
	6.29	2.67	3.32	2.45
	6.26	1.70	3.37	1.70
Av	6.29	2.15	3.29	2.04
Oven, 350°F to 170°F	6.60	2.76	3.21	2.54
	6.38	2.65	2.86	2.09
	6.04	3.24	3.21	3.04
	6.34	2.98	3.59	2.71
Av	6.34	2.90	3.22	2.59

[a]Average for two pouches.

[b]Heat-shocked at 80°C for 15 min.

Table 29. Analysis of variance for counts of Clostridium perfringens vegetative cells and spores in inoculated rump roasts (3.5 lb) cooked by three methods, Experiment I

Source of variation	df	MS	F value
		Vegetative cells	
Replication	3	0.420	3.93
Cooking method	2	0.616	5.76
Error	6	0.107	
Total	11		
		Spores	
Replication	3	0.339	3.06
Cooking method	2	0.324	2.93
Error	6	0.111	
Total	11		

Table 30. Time required to cook meat loaves (2.0 lb) to various final internal temperatures by two methods, Experiment II

Cooking method	Final internal temperature (°F)			
	120 (min)	135 (min)	150 (min)	165 (min)
Crockery pot, low	163	208	278	410
	166	206	255	431
	156	210	254	400
	166	202	259	451
Av	163	206	262	423
Oven, 325°F	44	66	67	89
	56	62	78	93
	58	71	78	92
	54	65	78	89
Av	53	66	75	91

Table 31. Analysis of variance for cooking time for meat loaves (2.0 lb) cooked to various final internal temperatures by two methods, Experiment II

Source of variation	df	MS	F value
Replication	3	53.53	0.53
Cooking method (CM)	1	295488.28	2919.22**
Final temperature (T)	3	33387.36	329.84**
CM x T	3	19413.53	191.79**
Error	21	101.22	
Total	31		

**Significant at the 0.01 level.

Table 32. Total, volatile and drip losses for meat loaves (2.0 lb) cooked to various final internal temperatures by two methods, Experiment II

Cooking method	Final internal temperature (°F)			
	120 (%)	135 (%)	150 (%)	165 (%)
		Total losses		
Crockery pot, low	5.6	14.7	19.2	30.7
	6.9	12.7	21.8	26.4
	7.9	12.0	21.5	25.2
	6.4	12.0	23.7	27.1
Av	6.7	12.8	21.6	27.4
Oven, 325°F	5.1	15.8	13.9	23.7
	12.4	11.9	22.0	20.0
	12.1	13.7	17.8	17.3
	10.8	13.4	20.8	19.5
Av	10.1	13.7	18.6	20.1
		Volatile losses		
Crockery pot, low	1.3	1.6	2.1	3.3
	1.5	1.6	2.0	3.1
	1.1	1.5	1.9	2.9
	1.1	1.4	2.0	2.8
Av	1.2	1.6	2.0	3.0
Oven, 325°F	3.2	6.4	7.3	10.8
	4.9	5.0	8.8	10.5
	4.8	6.9	8.4	11.1
	4.9	6.5	9.0	10.2
Av	4.4	6.2	8.4	10.6

Table 32. Continued

Cooking method	Final internal temperature (°F)			
	120 (%)	135 (%)	150 (%)	165 (%)
		Drip losses		
Crockery pot, low	4.3	13.1	17.1	27.4
	5.3	11.0	19.9	23.4
	6.8	10.5	19.6	22.3
	5.4	10.6	21.7	24.2
Av	5.5	11.3	19.6	24.3
Oven, 325°F	2.0	9.4	6.6	12.9
	7.5	6.9	13.2	9.5
	7.3	6.7	9.4	6.2
	5.9	6.8	11.8	9.3
Av	5.7	7.5	10.2	9.5

Table 33. Analysis of variance for percent total, volatile and drip losses for meat loaves (2.0 lb) cooked to various final internal temperatures by two methods, Experiment II

Source of variation	df	MS	F value
	Total cooking losses		
Replication	3	1.40	0.22
Cooking method (CM)	1	17.54	2.76
Final temperature (T)	3	375.70	59.13**
120 vs. 135	1	94.12	14.81**
120, 135 vs. 150, 165	1	979.46	154.16**
150 vs. 165	1	53.53	8.42**
CM x T	3	43.25	6.81**
CM x 120 vs. 135	1	6.62	1.04
CM x 120, 135 vs. 150, 165	1	104.68	16.48**
CM x 150 vs. 165	1	18.45	2.90
Error	21	6.35	
Total	31		
	Volatile losses		
Replication	3	0.16	0.54
Cooking method (CM)	1	239.91	819.73**
Final temperature (T)	3	23.61	80.68**
CM x T	3	7.51	23.65**
Error	21	0.29	
Total	31		
	Drip losses		
Replication	3	1.54	0.32
Cooking method (CM)	1	387.20	80.39**
Final temperature (T)	3	214.34	44.50**
CM x T	3	86.40	17.94**
Error	21	4.82	
Total	31		

**Significant at the 0.01 level.

Table 34. Log counts of aerobic bacteria and of Clostridium perfringens vegetative cells and spores in raw ground chuck and in raw inoculated meat loaves, Experiment II

Product	Test day	Aerobic plate counts[a]	Clostridium perfringens[b]	
		Cells per g	Vegetative cells per g	Spores[c] per g
Raw ground chuck	1	7.36	NG[d]	NG
	2	7.00	1.60	NG
	3	6.81	<1.00	NG
	4	7.23	<1.00	NG
	5	7.66	1.00	NG
	6	8.28	NG	NG
	7	7.04	1.70	NG
	8	7.97	NG	NG
Av		7.42	<1.00	NG
Raw inoculated meat loaves	1	6.84	5.34	2.34
	2	7.04	5.53	3.08
	3	6.30	5.80	2.90
	4	7.45	5.35	2.80
	5	7.26	5.70	3.43
	6	7.08	5.81	2.96
	7	7.08	5.91	2.88
	8	7.23	5.55	2.70
Av		7.04	5.62	2.88

[a]Average of duplicate plates/sample; 1 sample/test day.

[b]Raw ground chuck: average of duplicate pouches/sample; 1 sample/day. Inoculated meat loaves: average of duplicate pouches/sample; 4 samples/test day.

[c]Heat-shocked at 80°C for 15 min.

[d]NG = no growth.

Table 35. Log counts[a] in cells/g for aerobic bacteria in two locations in meat loaves (2.0 lb) cooked to various final internal temperatures by two methods, Experiment II

Cooking method	Final internal temperature (°F)			
	120	135	150	165
		Center core		
Crockery pot, low	6.43	5.74	4.78	2.00
	5.82	5.78	4.86	1.30
	6.82	6.91	4.38	1.30
	6.36	6.00	4.86	1.00
Av	6.36	6.11	4.72	1.40
Oven, 325°F	6.84	5.28	4.99	2.94
	5.76	6.23	2.30	3.04
	6.11	5.00	4.26	3.67
	6.00	5.71	2.78	2.72
Av	6.18	5.56	3.58	3.09
		Side core		
Crockery pot, low	5.99	5.50	3.77	1.74
	5.76	5.42	4.38	1.30
	6.23	5.38	3.18	1.30
	5.98	5.84	3.85	1.00
Av	5.99	5.54	3.80	1.34
Oven, 325°F	6.38	5.04	4.00	1.60
	5.73	5.62	2.08	2.15
	5.08	4.40	2.74	2.28
	5.20	5.11	2.15	1.30
Av	5.60	5.04	2.74	1.83

[a]Average for two plates.

Table 36. Analysis of variance for aerobic plate counts made on samples from meat loaves (2.0 lb) cooked to various final temperatures by two methods, Experiment II

Source of variation	df	MS	F value
	Center core		
Replication	3	0.509	1.46
Cooking method (CM)	1	0.016	0.04
Final temperature (T)	3	26.762	76.80**
120 vs. 135	1	0.762	2.18
135 vs. 150	1	11.290	32.40**
150 vs. 165	1	14.516	41.66**
CM x T	3	2.992	8.59**
CM x 120 vs. 135	1	0.139	0.40
CM x 135 vs. 150	1	0.342	0.98
CM x 150 vs. 165	1	8.009	22.99**
Error	21	0.348	
Total	31		
	Side core		
Replication	3	0.361	1.52
Cooking method (CM)	1	1.037	4.37
Final temperature (T)	3	30.001	126.54**
120 vs. 135	1	1.020	4.30
135 vs. 150	1	16.322	68.84**
150 vs. 165	1	11.357	47.90**
CM x T	3	0.822	3.47
Error	21	0.237	
Total	31		

**Significant at the 0.01 level.

Table 37. Log counts[a] in cells/g for Clostridium perfringens vegetative cells in two locations in inoculated meat loaves (2.0 lb) cooked to various final internal temperatures by two methods

Cooking method	Final internal temperature (°F)			
	120	135	150	165
		Center core		
Crockery pot, low	5.50	4.40	3.00	3.36
	5.70	4.67	3.36	3.42
	5.81	4.73	3.86	3.46
	5.78	4.87	3.62	3.00
Av	5.70	4.67	3.46	3.31
Oven, 325°F	5.57	3.60	3.74	3.58
	5.37	4.97	3.28	3.59
	5.04	3.67	3.93	3.36
	5.49	3.78	3.82	3.70
Av	5.37	4.00	3.69	3.56
		Side core		
Crockery pot, low	4.00	4.08	3.30	3.62
	5.32	4.32	3.34	3.32
	5.42	4.40	3.99	3.26
	5.38	3.90	3.53	2.74
Av	5.03	4.18	3.54	3.24
Oven, 325°F	5.20	3.89	3.20	3.34
	4.18	4.46	2.95	3.23
	4.30	3.60	4.00	3.62
	4.73	3.73	3.70	3.15
Av	4.60	3.92	3.46	3.34

[a]Average for two pouches.

Table 38. Analysis of variance for Clostridium perfringens vegetative cell counts in inoculated meat loaves (2.0 lb) cooked to various final internal temperatures by two methods, Experiment II

Source of variation	df	MS	F value
	Center core		
Replication	3	0.062	0.57
Cooking method (CM)	1	0.131	1.22
Final temperature (T)	3	7.383	68.68**
120 vs. 135	1	5.724	53.25**
135 vs. 150	1	2.310	21.49**
150 vs. 165	1	0.081	0.76
CM x T	3	0.398	3.70
Error	21	0.108	
Total	31		
	Side core		
Replication	3	0.097	0.53
Cooking method (CM)	1	0.218	1.18
Final temperature (T)	3	3.728	20.27**
120 vs. 135	1	2.364	12.85**
135 vs. 150	1	1.194	6.49
150 vs. 165	1	0.187	1.02
CM x T	3	0.103	0.56
Error	21	0.184	
Total	31		

**Significant at the 0.01 level.

Table 39. Log counts[a]/g for Clostridium perfringens spores[b] in two locations in inoculated meat loaves (2.0 lb) cooked to various final temperatures by two methods, Experiment II

Cooking method	Final internal temperature (°F)			
	120	135	150	165
		Center core		
Crockery pot, low	2.54	3.00	1.70	2.04
	2.45	3.00	2.15	1.90
	3.38	3.15	3.20	1.95
	3.23	2.73	2.93	1.60
Av	2.90	2.97	2.50	1.87
Oven, 325°F	2.78	2.82	2.30	1.00
	2.00	2.93	1.60	1.70
	3.46	2.97	3.26	1.60
	2.93	2.60	2.04	1.48
Av	2.79	2.83	2.30	1.44
		Side core		
Crockery pot, low	2.60	2.83	1.65	2.11
	2.53	2.76	2.04	2.00
	3.58	3.04	2.76	2.34
	3.11	2.64	2.48	1.54
Av	2.96	2.82	2.23	2.00
Oven, 325°F	2.78	2.28	1.78	1.95
	2.48	2.69	1.30	1.88
	3.20	2.76	2.42	1.78
	2.98	2.38	1.48	1.48
Av	2.86	2.53	1.74	1.77

[a]Average for two pouches.

[b]Heat-shocked for 15 min at 80°C.

Table 40. Analysis of variance for Clostridium perfringens spore counts in inoculated meat loaves (2.0 lb) cooked to various final internal temperatures by two methods, Experiment II

Source of variation	df	MS	F value
	Center core		
Replication	3	0.703	4.70
Cooking method (CM)	1	0.378	2.53
Final temperature (T)	3	2.636	17.61**
120 vs. 135	1	0.012	0.08
135 vs. 150	1	1.010	6.75**
150 vs. 165	1	2.183	14.58**
CM x T	3	0.042	0.28
Error	21	0.150	
Total	31		
	Side core		
Replication	3	0.495	6.20**
Cooking method (CM)	1	0.602	7.55
Final temperature (T)	3	2.029	25.43**
120 vs. 135	1	0.221	2.77
135 vs. 150	1	1.870	23.43**
150 vs. 165	1	0.043	0.54
CM x T	3	0.054	0.67
Error	21	0.080	
Total	31		

**Significant at the 0.01 level.

Table 41. Raw weight, cooking time and rate of temperature rise for top round roasts cooked by three methods to 150°F, Experiment III, Studies A and B[a]

Cooking method[b]	Raw weight		Cooking time		Min/ lb		Temperature rise/min	
	A lb	B lb	A min	B min	A	B	A °F	B °F
CP	5.0	4.0	314	289	62.8	72.4	0.35	0.38
	4.6	4.2	283	292	61.5	68.8	0.40	0.39
	4.2	4.6	283	308	67.4	66.4	0.39	0.35
	3.8	4.2	257	323	67.6	76.8	0.42	0.34
Av	4.4	4.3	284	303	64.8	71.1	0.39	0.36
LO	4.8	4.4	316	255	65.8	57.2	0.36	0.44
	4.6	4.4	335	255	72.8	58.0	0.32	0.43
	4.5	4.9	355	253	78.9	51.5	0.32	0.46
	-[c]	3.9	-	221	-	56.2	-	0.49
Av	4.6	4.4	335	246	72.5	55.7	0.33	0.46
MO	4.6	4.4	132	93	28.7	21.0	0.84	1.19
	4.8	4.6	118	110	24.9	23.9	0.93	1.04
	3.8	4.6	115	100	30.3	22.9	0.96	1.10
	4.0	4.2	118	108	29.5	25.6	0.95	1.03
Av	4.3	4.4	121	103	28.4	23.4	0.92	1.09

[a]A = May 1973, General Electric range model J349001DC; B = February 1975, General Electric range model J390003HT.

[b]CP = crockery pot, low; LO = oven, 200°F; MO = oven, 350°F.

[c]- = missing data.

Table 42. Analysis of variance for total cooking time for top round roasts (4.4 lb) cooked to 150°F by three methods, Experiment III, Studies A and B

Source of variation	df	MS	F value
		Study A	
Replication	3	342.08	0.92
Cooking method	2	48492.33	131.06**
Error	5	370.00	
Total	10		
		Study B	
Replication	3	36.75	0.13
Cooking method	2	42579.75	154.79**
Error	6	275.08	
Total	11		

**Significant at the 0.01 level.

Table 43. Average[a] temperature of air in 4 1/2-qt crockery pot during cooking of 4.4-lb top round roasts from 38° to 150°F, Experiment III

Elapsed cooking time (hr)	Study A (°F)	Study B (°F)
0	63	63
1/2	108	105
1	132	126
1 1/2	147	138
2	157	150
2 1/2	166	160
3	171	168
3 1/2	178	174
4	183	176
4 1/2	185	179
5	-[b]	179

[a]Average for 4 cooking periods.

[b]Cooking ended.

Table 44. Total, volatile and drip losses for top round roasts (4.4 lb) cooked to 150°F by three methods, Experiment III, Studies A and B[a]

Cooking method[b]	Cooking losses					
	Total		Volatile		Drip	
	A %	B %	A %	B %	A %	B %
CP	21.9	27.4	2.6	2.9	19.3	24.5
	22.6	27.5	2.6	2.6	19.9	24.8
	23.3	23.6	4.3	2.4	19.0	21.3
	23.3	21.3	2.4	4.2	20.8	17.0
Av	22.8	24.9	3.0	3.0	19.8	21.9
LO	16.2	20.7	11.3	6.5	4.8	14.2
	19.7	20.8	11.1	7.7	8.6	13.1
	15.6	19.8	11.7	7.3	3.9	12.6
	-[c]	20.9	-	7.9	-	13.0
Av	17.2	20.5	11.4	7.3	5.8	13.2
MO	24.7	24.0	20.6	15.3	4.1	8.7
	24.9	27.4	19.8	18.9	5.1	8.5
	21.6	24.5	19.3	16.8	2.3	7.7
	23.2	25.8	20.7	18.2	2.6	7.5
Av	23.6	25.4	20.1	17.3	3.5	8.1

[a]A = May 1973, General Electric range model J349001DC; B = February 1975, General Electric range model J390003HT.

[b]CP = crockery pot, low; LO = oven, 200°F; MO = oven, 350°F.

[c]- = missing data.

Table 45. Analysis of variance for percent total, volatile and drip losses for top round roasts (4.4 lb) cooked to 150°F by three methods, Experiment III, Studies A and B

Source of variation	Study A			Study B		
	df	MS	F value	df	MS	F value
			Total losses			
Replication	3	2.58	1.23	3	4.54	1.28
Cooking method	2	48.88	23.32**	2	28.74	8.10
Error	5	2.09		6	3.55	
Total	10			11		
			Volatile losses			
Replication	3	0.18	0.27	3	2.25	3.29
Cooking method	2	293.30	437.57**	2	214.63	313.87**
Error	5	0.67		6	0.68	
Total	10			11		
			Drip losses			
Replication	3	4.03	2.72	3	6.93	1.97
Cooking method	2	309.07	208.41**	2	195.06	55.41**
Error	5	1.48		6	3.52	
Total	10			11		

**Significant at the 0.01 level.