August 1, 1969

To the Graduate Council:

I am submitting herewith a thesis written by Sze-chin Chen entitled "Blanching of Small White Potatoes by Combinations of Microwave Energy and Boiling Water." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Technology.

Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Chancellor for
Graduate Studies and Research

BLANCHING OF SMALL WHITE POTATOES BY COMBINATIONS OF MICROWAVE ENERGY AND BOILING WATER

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Sze-chin Chen

August 1969

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ABSTRACT

The objective of this study was to determine the effect of hot water followed by microwave energy and microwave energy followed by boiling water on the heating, inactivation rate of peroxidase and the firmness of small whole potatoes.

In experiment one, lots of potatoes receiving the hot water followed by microwave energy treatments were held first in hot water for 1, 3, and 5 min. periods. At each of these periods samples of potatoes were subjected to microwave energy for 0, 1, 2, 3, 4, and 5 min. This design which permitted 18 treatments was replicated 3 times.

Under the conditions of this experiment the following results were found:

1. The minimum period of time for treatment found to completely inactivate peroxidase were as follows: 1 min. hot water followed by 4 min. microwave energy, and 3 min. hot water followed by 3.1 min. microwave energy and 5 min. hot water followed by 2.15 min. microwave energy.

2. The heat gradient was from the periphery to the core.

3. Temperature for inactivation of peroxidase at 1.5 cm. depth was higher than at 0.75 cm. This was due to the longer heating period required at the depth of 1.5 cm.

4. Firmness of potatoes at the point when peroxidase was just inactivated were: 95 lb., 1 min. hot water followed by 4 min. microwave energy; 150 lb., 3 min. hot water followed by 3.1 min. microwave energy; and 160 lb., 5 min. hot water followed by 2.15 min. microwave energy.

In experiment two, treatments consisted of heating samples for 0.5, 1.0, 1.5, and 2 min. by microwaves. Samples from each of the microwave treatments were heated subsequently in boiling water for periods of 0, 1, 2, 3, 4, and 5 min. This design which permitted 24 treatments was replicated 3 times.

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

1. When the potatoes were heated by microwaves a heat gradient developed from the core toward the periphery.

2. Because of the heat gradient of the potatoes, the temperature at a 1.5 cm. depth was higher than that at 0.75 cm. This heating phenomenon was different from the finding of experiment one.

3. Due to the heat patterns produced by microwaves followed by boiling water, there were two zones of enzyme inactivation prior to complete inactivation. These zones of inactivation occurred initially at the core and periphery.

4. The minimum treatment time found to completely inactivate peroxidase and the firmness values after these

treatments were as follows: 119 lb., 1.5 min. microwave energy followed by 3 min. boiling water and 124 lb., 2 min. microwave energy followed by 2 min. boiling water.

5. When the procedure of experiment one was followed, a longer period of time was required to inactivate peroxidase in the whole potato than when the procedure of experiment two was utilized. However, the firmness of tubers from experiment one was higher than the firmness of potatoes from experiment two.

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CHAPTER I

INTRODUCTION

The potato, with a present total production in excess of 10 billion bushels, is one of the major food crops in the world. Because they yield heavily, are relatively inexpensive, and can be grown in a wide variety of soils and climates, protatoes are the main item in the diet of people in many parts of the world (37).*

One of the most spectacular developments in the potato industry today is the growth of the processing phase for food uses. The blanching operation of potatoes is a preliminary procedure to freezing storage or canning. The objective of the blanching operation is to heat the potatoes to a certain temperature until the enzyme systems are inactivated. The conventional hot water or steam blanching methods are relative slow and result in the loss of some of the fresh potato characteristics.

Microwave blanching can be used to heat a product to any desired degree of doneness. As long as the dimensions of the item are appropriate for the wavelength, heat will be produced at the center. Heating is accomplished without contact with water or steam. The other advantages of

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*The numbers in parenthesis represent similarily numbered references in the Bibliography.

microwave blanching are: faster speed, higher efficiency, greater yield, and higher quality results (10).

In this study, experiments were conducted to determine the effect of blanching potatoes by hot water followed by microwave energy and microwave energy followed by boiling water on the heat penetration, inactivation rate of peroxidase and the firmness of the potatoes.

CHAPTER II

REVIEW OF LITERATURE

I. HEAT TRANSFER

Heat is transferred in three ways: by conduction, convection, and radiation (14). Conduction is the transfer of heat by molecular activity through one substance to another. Convection involves the transfer of heat by the movement of groups of molecules in a fluid. The transfer of heat by conduction is very much slower than transfer by convection (12, 14).

According to Dickerson and Read (13), the rate of heating of food products in containers is a function of the geometry of the container, physical properties of the food product and heat transfer characteristics of the container.

Nelson et al. (25) studied the heat transfer in commercial cuts of meat. Commercial cuts of meat have anomalous shapes, are heterogeneous in composition, and often exhibit anisotropic thermal properties. The authors presented a method of geometric analysis. The anomalous shape was replaced by an equivalent ellipsoidal model. The geometry of the ellipsoid was represented by an index "G" described by the following equation:

$$G = 1/4 + 3/8A^2 + 3/8B^2$$

Where A and B are semi-major axes of ellipses forming the ellipsoid in units of the semi-minor axis common to the ellipses.

II. MICROWAVE ENERGY

The ability of high frequency electrical fields to heat or affect biological systems has been known since 1893. Heating and cooking foods with microwaves was pioneered in the 1940's, but it was not until the early 1950's that a feasible microwave oven was developed. Microwaves are a by-product of radar development of that time (27).

There are three types of electronic heating commonly encountered: Induction, dielectric, and microwave. Induction heating operates, as the name implies, by inducing a current in material with the help of an alternating current in a coil surrounding the material, just as in the action of a transformer when a current in the primary induces a current in the secondary. The coupling of energy is through the magnetic fields and not by electrical or mechanical contact (magnetic coupling). The frequencies range from 960 cycles to 1,000,000 cycles per second. The power output may range into the thousands of kilowatts.

Dielectric heating on the other hand involves the heating of poor electrical conductors which tend to be, generally, poor thermal conductors as well. It is also

characterized by freedom from electrical and mechanical contact, and may be carried out with the material to be heated positioned between electrode plates. It is the rapid reversal of polarity on the plates which influences the particles making up the load. This, in turn, gives the frequency effect, and operation is usually within the range of from 1 to 150 megahertz (MHz). Power output from dielectric heaters ranges into the hundreds of kilowatts (10).

Microwaves are electromagnetic waves which differ from the more familiar light waves and radio waves only in frequency and wavelength. Microwave energy has wavelengths of about 1 to 30 in. and frequencies of 400 to 20,000 MHz or megacycles per second. The frequency bands for microwave heating come under the rules of the Federal Communications Commission which provide certain frequencies for industrial, scientific, and medical (ISM) uses. Among those frequencies allowed two are of importance today: 915 and 2450 MHz (10, 21).

All matter is composed of electrically charged particles, both positive and negative. In normal, undistributed matter there are equal numbers of positively and negatively charged particles. Thus, most materials are electrically neutral. If the material is nonconducting, i.e., a dielectric, and is placed in an electromagnetic

field, the charged asymetric molecules, of which the dielectric (such as a foodstuff) is composed, are driven first one way and then another. Each of the asymmetric molecules attempts to align itself with the rapidly changing field of alternating current. In this field, the molecules act as miniature dipoles and, while oscillating around their axes in an attempt to go to the proper positive and negative poles, intermolecular friction is created and is manifested as a heating effect. At the frequency of 915 MHz the molecules oscillate back and forth 915 million times per second (18).

Cathcart (6) and Cathcart et al. (7) reported that growth of mold in wrapped sliced bread of all types, including Boston brown and whole wheat bread, can be prevented by thorough heating with high frequency current. Bread should be wrapped in a moisture vapor-proof wrapper that will not lose its effectiveness during heating or subsequent storage. Bartholomen et al. (2) showed that heating by an induction coil was relatively rapid, and the heating effect was largely confined to the surface where it was most needed. However, heating in a dielectric field produced a slower, but more penetrating type of heat. More recent work has been done by Olsen (26) on use of microwaves to inhibit bread mold. Viable spores were greatly reduced in number by exposure to microwave energy, thereby

prolonging shelf life and enhancing product quality.

Early work on the blanching of foods was done by Moyer and Stotz (23), Moyer and Holgate (22), and others (1). Electronic blanching of vegetables has an advantage over the conventional hot water or steam methods in that it possesses a favorable retention of nutrients. More recent work has been done by Eheart (15) on the effect of microwave vs. water blanching on nutrients in broccoli. The results of their work confirmed those of earlier workers.

Cathcart (5) studied frozen foods defrosted by electronic heat. He found through that the application of dielectric heat, frozen eggs could be defrosted as they were needed and without an increase in bacterial count. Frozen fruits were thawed in only a few minutes without loss of quality and without discoloration due to enzymatic activity.

Smith (34) reported that microwave processing of potato chips was a firmly established commercial process for controlling color and moisture in chips. Because of the selective absorption of microwave energy by water, the chips were dried rapidly and effectively without attaining excessive temperatures. Huxsoll (20) studied the use of microwaves in producing large potato dice. Microwaves could be used conceivably to improve both drying and rehydration of the large potato pieces.

Olsen (27) described the current microwave

applications in the food and pharmaceutical industries which included cooking, baking, blanching, thawing, pasteurizing, puff drying, and various combinations. The advantages of microwave cooking include rapid heating, uniform heating throughout the mass, and selective heating of water and other polar molecules.

III. ENZYMES OF POTATOES

According to Smith (35), the following enzyme systems are present in potatoes: amylase, tyrosinase, phosphorylase, catalase, aldehydrase, polyphenol oxidase, phosphatase, peroxidase, glyoxalase, dehydrogenase, sistoamylase, and zymohexase.

Feinberg (17) studied the enzymes of the potato. He found that polyphenol oxidases are a complex of several enzymes which together are responsible for the darkening of potatoes after they are peeled or cut. In a series of enzymatic oxidative reactions, the monophenolic amino acid, tyrosine, is first converted to a diphenol and eventually to the black pigment, plant melanin. Clark et al. (8) reported that polyphenol oxidase activity increased with increasing maturity of tubers of Pontiac and Ontario varieties.

Muneta and Walradt (24) showed that cystein could not inhibit oxidation in the presence of tyrosine plus cholrogenic acid from potatoes. According to Talburt and

Smith (37), there are other methods which prevent this type of discoloration; they include the use of heat, acid, low temperatures and organic solvents.

Heisler et al. (19) reported that commercial amylases convert potato starch to sugars rapidly. Maltose is the principal sugar formed together with a varying amount of oligosaccharides. Pressey (29) indicated that invertase in potato increased at low temperature and decreased at warm temperature in a reversible manner. The changes in the presence of invertase are usually parallel to the changes in occurrence of reducing sugars. Pressey and Shaw (30) studied enzymes and sugar changes in potatoes during storage. Invertase is the final enzyme in the metabolic scheme of hexose accumulation in potato tubers. The invertase system consisting of the enzyme and its inhibitor appears to regulate sugar accumulation.

IV. THE INACTIVATION OF PEROXIDASE BY BLANCHING

Peroxidases (E.C. 1.11.1.7) are defined as enxymes catalyzing the following general reaction:

$$ROOH + AH_2 = H_2O + ROH + A$$

Peroxidase appears to be the most heat-stable enzyme in plants (31). The effectiveness of the blanching of vegetables and the effect of residual peroxidase on the

keeping quality of vegetables have been determined for corn (39), peas (28), green beans and turnips (40).

Collins and McCarty (9) studies the comparison of microwave energy with boiling water for blanching whole potatoes. In tubers with a mean radius of 2.27 cm,, peroxidase was inactivated completely in 13 min. by boiling water and in 4.7 min. by microwaves. The temperature of inactivation for peroxidase by boiling water decreased from 190°F at depth of 0.5 cm. to 178°F at 2 cm. The enzyme was inactivated at about 175°F at 1 and 2 cm. depth when the tubers were heated in the microwave oven. According to Cruess (11), for the inactivation of peroxidase of apples by steam for 4 to 7 min. were needed.

Peroxidase regenerates in some instances after blanching by heat. Pinsent (28) reported that the peroxidase of peas could be completely inactivated by blanching for 60 sec„ but regeneration occurred. Even immediate freezing of the peas and storage at -18°C permitted regeneration of a detectable amount of peroxidase within 2 months. Desrosier (12) found that the same thing happened in the turnip and cabbage. Esselen and Anderson (16) studied thermal destruction of peroxidase in vegetables at high temperature. The degree of heat required to prevent regeneration of peroxidase during subsequent storage was two to

four times greater than that required to inactivate the enzyme immediately after blanching.

V. EFFECT OF HEAT ON FIRMNESS AND TEXTURE OF POTATOES

Softening and textural changes of the potato tissue are caused by heat. Unrau and Nylund (38) suggested that the properties of starch of the raw tuber and the changes that these properties undergo during cooking, such as mealiness, consistency, sloughing and lack of sogginess should be considered in attempting to explain variations in texture. According to Roberts and Proctor (33), when the temperature of a potato is raised to above 122°F, water passes from the non-starchy parts of the cell into the starch granule, which starts to swell. The starch will begin to gelatinize in the range of 147 to 160°F. This results in the rounding off of cells and in cell separation or in sogginess of the tissue. Bettelheim and Sterling (3) reported that the starch content of boiled potato tissue is lower than that of the corresponding fresh tissue. This may be due in part to swelling of the starch resulting in cell rupture and leaching.

Sterling (36) reported that the hemicellulose and cellulose components are relatively resistant to the heat effects of normal cooking; the cell walls usually retain their integrity during this event. But according to Reeve (32), upon prolonged heating of potatoes these

substances undergo some breakdown due to gelatinized starch.

According to Collins and McCarty (9) in the blanching of whole potatoes, microwave energy produced softening comparable to that produced by boiling water but microwaves required only about one-third the time.

CHAPTER III

MATERIALS AND METHODS

I. SOURCE AND PREPARATION OF POTATOES

The white potatoes were supplied by the Winter Garden Freezer Co., Bells, Tennessee. The potatoes were the Katahdin variety, New York strain and they were raised in Alabama. The Creamer 90 size was utilized.

The potatoes were graded for uniformity of size; those utilized has a mean diameter of 3.9 cm. and a mean weight of 29 g.

Before utilization, the potatoes were stored at 45°F. Samples were removed from storage, washed under tap water and drained for 5 min. The potatoes were not peeled prior to the heating studies.

II. EXPERIMENTAL DESIGN

Experiment One: Blanching Potatoes by Hot Water Followed by Microwave Energy

The heating was accomplished in a pyrex casserole dish (9.5 in. I.D. and 4 in. high) with a lid. The dish was modified to possess an inlet and outlet tube in the side wall of the dish. The inlet port was 5/8 in. I.D. and the outlet port was 3/4 in. I.D. The dish was used by placing

it in a Tappan electronic range (model R-2000, frequency 2450 MHz, fixed power output of 1.0 Kw). The oven door was modified to permit one to connect tygon tubes from outside the oven to the side tubes on the dish. With this adaptation, hot water could be circulated through the dish at a constant temperature. The water (about 35 gal.) was heated to boiling in a steam jacketed kettle. The boiling water was circulated from the kettle through the dish by using a Manostat varistaltic pump. The length of the tubes was held to a minimum: the inlet tube was 90 in. and the outlet tube, 70 in. The pump was adjusted to permit a flow rate of around 1,300 cc. per min. The pyrex dish contained about 2 liters of water which was maintained at this level.

During the heating operation, the temperature of the water in the center of the dish was 205°F (without application of microwave energy). The water at the discharge tubing outlet was 200°F.

Initially, water was pumped from the kettle into the dish and when the temperature of the water at the center of the dish equilibrated at 205°F, five potatoes were placed into the dish. The hot water completely covered the potatoes. Hot water was continually pumped from the kettle into the dish for a designated period of time. Then the flow of water was discontinued and microwave energy was applied for

a designated period of time. During microwave heating the water level remained constant.

Samples of potatoes receiving the hot water followed by microwave energy heating treatments were held first in hot water for 1, 3, and 5 min. periods. At each of these periods a sample of potatoes received microwave energy for 0, 1, 2, 3, 4, and 5 min. This design which permitted 18 treatments was replicated three times.

Immediately after each blanching treatment, four of the five potatoes were placed in tap water to cool. The four potatoes were used for peroxidase assay and firmness measurement. The remaining potato was used for the heat penetration study.

For the heat penetration study, temperature measurements were made at two depths, 0.75 and 1.5 cm. At each depth, for each heat treatment there were four replications for temperature measurement (each consisting of one potato). From each potato, three observations were taken. By using this procedure, a total of eight tubers were required for temperature measurement at the two depths. Since only three tubers were available, additional potatoes were prepared under conditions similar to those previously described.

For the peroxidase inactivation study, there were three replications for each heat treatment. Each replication consisted of four tubers from which four observations

were made from each tuber. The potato was cut longitudinally through the central part to obtain a slice (about 0.4-0.5 mm. thick) for the peroxidase inactivation assay. Measurements were made in each quadrant on the flat surface of the slice. The colorless zone of the radius was considered for enzyme inactivation. The remaining part of the potatoes were utilized for firmness measurements.

For the firmness study, there were three replications for each heat treatment. From each replication two samples were prepared for shear measurement. These samples consisted of the tissue remaining after the slice was removed for peroxidase activity assay.

Experiment Two: Blanching Potatoes by Microwave Energy Followed by Boiling Water

Samples of five potatoes were placed in the Tappan electronic range on the fiberglass tray and were heated for designated periods. The potatoes were not submerged in water. Immediately after microwave heating, the potatoes were removed and placed in a wire basket and immersed under boiling water which was heated in a steam jacketed kettle.

Microwave treatments consisted of heating samples for 0.5, 1.0, 1.5, and 2 min. Samples from each of the microwave treatments were heated subsequently in boiling water for periods of 0, 1, 2, 3, 4, and 5 min. This design which permitted 24 treatments was replicated three times.

Immediately after each completed heat treatment, one of the five potatoes was used for the heat penetration study; the other four were removed and immersed under cold water. After cooling, these four potatoes were used for peroxidase assay and firmness measurement.

Temperature measurements were made at two depths, 0.75 and 1.5 cm. Four potatoes were utilized and three measurements were taken from each potato. One potato was used for the determination of temperature of one depth only, therefore, in order to provide a sufficient number of potatoes for measurement of both depths, additional potatoes were heated under conditions similar to those presented for experiment one.

The experimental design for peroxidase inactivation study was similar to that of experiment one, with one exception. In this case the zone of peroxidase inactivation across the diameter was measured. The zone consisted of that portion of the diameter which was colorless. Two readings were made, one at a 90° direction from the other.

The experimental procedure for the firmness study was similar to that of experiment one.

III. METHODOLOGY AND INSTRUMENTATION

Temperature Measurement by Thermocouples

Immediately after each heating operation, one potato

was selected at random from the sample of five tubers for temperature measurements at predetermined depths. An implant thermocouple was inserted into the tuber to the designated depth and the temperature was read from a potentiometer. The temperature was measured at three loci on the equatorial area of the potato. A period of about 35 sec. was required to obtain the three observations.

Peroxidase Inactivation Assay

After each heating operation, four potatoes of the sample of five were placed immediately into cold water. After cooling for about 10 min., each potato was cut longitudinally through the central part to obtain a slice (about 0.4-0.5 mm. thick) which was used for peroxidase inactivation assay. The remaining tissue was utilized for firmness determination.

The following procedure was used to determine the peroxidase inactivation:

1. Four drops of 0.5 percent quaiacol in a 50 percent alcohol solution were applied to one of the surfaces of the potato slice. The solution was spread over the surface.

2. Following, four drops of 0.05 percent H_2O_2 solution were added to the potato surface in like manner.

3. The slice was allowed to stand for 3 min. By the

end of this time, the active enzyme would have reacted with the added substances to produce a reddish-brown coloration.

4. In experiment one, that portion of the radius (colorless area) was used to indicate the depth to which the enzymes were inactivated. Measurements were made on the flat surface in each quadrant of the slice. For experiment two, measurements of the colorless zones were made across the diameter in two directions, one at a 90° direction from the other.

Firmness of Potatoes Measured by Allo-Kramer Shear Press

An Allo-Kramer shear press, model SP-12, was used to determine the firmness of potatoes after the heating treatment. The 1,000-lb. proving ring was employed and a 28-sec. thrust was used. The maximum force required to shear the sample was recorded; firmness was expressed in pounds of force.

The shear samples consisted of 50 g of diced potato tissue. With the exception of the slice removed from the mid-section for peroxidase measurement, the whole tuber was used in preparing the sample. Two shear samples were prepared from each heat treatment. Samples were placed into the standard shear-compression cell.

Statistical Analyses

The ANOVAR program adapted for the IBM model 7040

computer at the University Computing Center was used to perform the analysis of variance calculations (4). The data of heat penetration measurement, peroxidase inactivation assay, and firmness determination were analyzed. The data were analyzed as a factorial arrangement of a completely randomized design. Factors were tested for significance by the snalysis of variance.

Duncan's New Multiple Range Test was used to determine significant differences among means.

CHAPTER IV

RESULTS AND DISCUSSION

I. EXPERIMENT ONE

Inactivation of Peroxidase

The summary of the analysis of variance for the effect of hot water followed by microwave energy on inactivation of peroxidase in potatoes is shown in Table I. The factors and the interactions were significant at 0.01 level of probability.

The inactivation of peroxidase in the tubers increased as the heating time by hot water and by microwaves was increased (Table II).

The depths at which peroxidase was inactivated at the different times in hot water and microwaves are presented in Figure 1. For inactivation of peroxidase to a depth of 0.75 cm., the following heat treatment was required: 1 min. hot water followed by 2.6 min. microwave energy, 3 min. hot water followed by 1.9 min. microwave energy, and 5 min. hot water followed by 1.15 min. microwave energy. Treatments which inactivated peroxidase to 1.5 cm. were the following: 1 min. hot water followed by 3.5 min. microwave energy,

TABLE I

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF HOT WATER FOLLOWED BY MICROWAVE ENERGY ON INACTIVATION OF PEROXIDASE IN WHOLE WHITE POTATOES*

Source of Variance	D.F.	Mean Squares
Water	2	4.7921**
Microwaves	5	23.0930**
Water x Microwaves	10	1.0856**
Replication	2	0.0037
Residual Error	196	0.0125

*Mean radius, 1.95 cm.

**Significant at 0.01 level of probability.

TABLE II

EFFECT OF HOT WATER FOLLOWED BY MICROWAVE ENERGY ON INACTIVATION OF PEROXIDASE* IN WHOLE WHITE POTATOES**

Hot Water		Microwave Energy	
Min.	Mean***	Min.	Mean****
1	0.89 p	0	0.13 f
		1	0.34 e
		2	0.96 d
3	1.16 n		
		3	1.60 c
		4	1.94 b
5	1.41 m	5	1.95 a

*Inactivation of peroxidase is expressed in cm.

**Potato mean radius was 1.95 cm.

***Each value is the mean of 72 observations.

****Each value is the mean of 36 observations.

Note: Within each column, means followed by the same letter are not significantly different at the 0.01 level of probability.

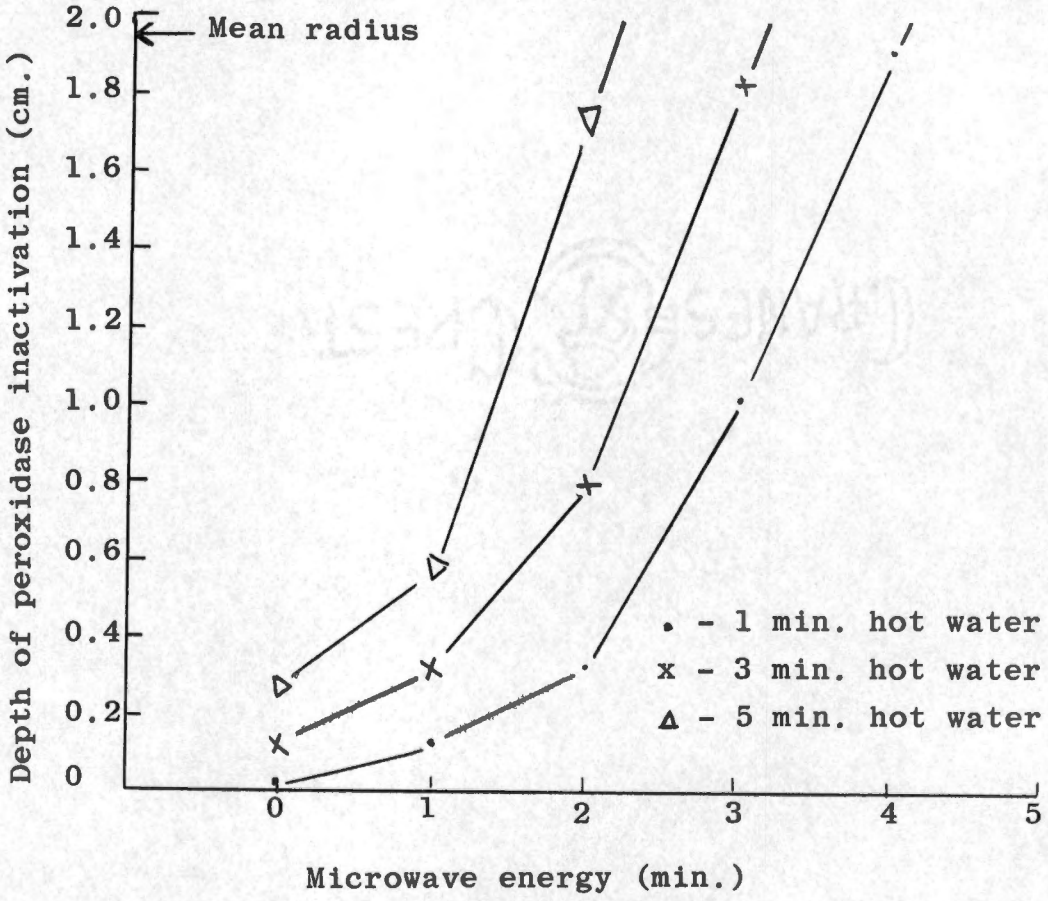


Figure 1. Inactivation of peroxidase in potatoes heated in hot water followed by microwave energy. Mean radius potato, 1.95 cm.

3 min. hot water followed by 2.7 min. microwave energy, and 5 min. hot water followed by 1.8 min. microwave energy. To completely inactivate peroxidase in the tubers (1.95 cm., mean radius), the following treatments were effective: 1 min. hot water followed by 4 min. microwave energy, 3 min. hot water followed by 3.1 min. microwave energy, and 5 min. hot water followed by 2.15 min. microwave energy.

Heat Penetration Pattern of Potatoes

The summary of the analysis of variance for the effect of hot water followed by microwave energy on heat penetration into the potatoes is shown in Table III. The factors and the interactions among the factors were significant at 0.01 level of probability except the interaction depth x water.

The tissue at the depth of 0.75 cm. was heated faster than the tissue at 1.5 cm. (Table IV). This indicates that the heat penetrated from the periphery toward the center of the tuber. The rate of temperature rise in the tubers in the first two min. of heating was more rapid than it was in the last two min. This phenomenon is due to the fact that the innermost tissue is at a greater distance from the source of heat. The means of the microwave energy factor show that the heat penetration into the tubers increased as the heating time was increased. After a certain period of time, the temperature reached a maximum. When the maximum

TABLE III

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF HOT WATER FOLLOWED BY MICROWAVE ENERGY ON HEAT PENETRATION INTO WHOLE WHITE POTATOES*

Source of Variance	D.F.	Mean Squares
Depth	1	2015.0**
Water	2	25883.1**
Microwaves	5	104904.3**
Depth x Water	2	60.9
Depth x Microwaves	5	2352.8**
Water x Microwaves	10	3999.7**
Depth x Water x Microwaves	10	213.9**
Replication	3	38.3
Residual Error	393	33.2

*Mean radius, 1.95 cm.

**Significant at 0.01 level of probability.

TABLE IV

EFFECT OF HOT WATER FOLLOWED BY MICROWAVE ENERGY ON HEAT PENETRATION* INTO WHOLE WHITE POTATOES

Depth		Hot Water		Microwave Energy	
Cm.	Mean**	Min.	Mean***	Min.	Mean****
0.75	179 x	1	162 p	0	117 e
				1	146 d
				2	175 c
1.50	174 y	3	180 n		
				3	202 b
				4	211 a
		5	188 m	5	209 a

*Heat is expressed as degree of Fahrenheit.

**Each value is the mean of 216 observations.

***Each value is the mean of 144 observations.

****Each value is the mean of 72 observations.

Note: Within each column, means followed by the same letter are not significantly different at the 0.01 level of probability.

temperature was reached, there was small but insignificant decrease in temperature with further heating.

The rates of temperature rise in the tuber at the depth of 0.75 cm. are shown in Figure 2. The heating time required to inactivate peroxidase (Figure 1, p. 24) and the temperature at a depth of 0.75 cm. this depth were estimated as follows: 1 min. hot water followed by 2.6 min. microwave energy, 174°F; 3 min. hot water followed by 1.9 min. microwave energy, 179°F; 5 min. hot water followed by 1.15 min. microwave energy, 178.5°F.

The rates of temperature rise in the tuber at the depth of 1.5 cm. are shown in Figure 3. The heating time required to completely inactivate peroxidase (Figure 1) and the temperature at this depth was estimated as follows: 1 min. hot water followed by 3.5 min. microwave energy, 205°F; 3 min. hot water followed by 2.7 min. microwave energy, 196°F; 5 min. hot water followed by 1.8 min. microwave energy, 184°F.

Firmness of Potatoes

The summary of the analysis of variance for the effect of hot water followed by microwave energy on firmness of potatoes is shown in Table V. The factors and the interaction for each test were significant at the 0.01 level of probability.

In Table VI the means of the hot water factor show

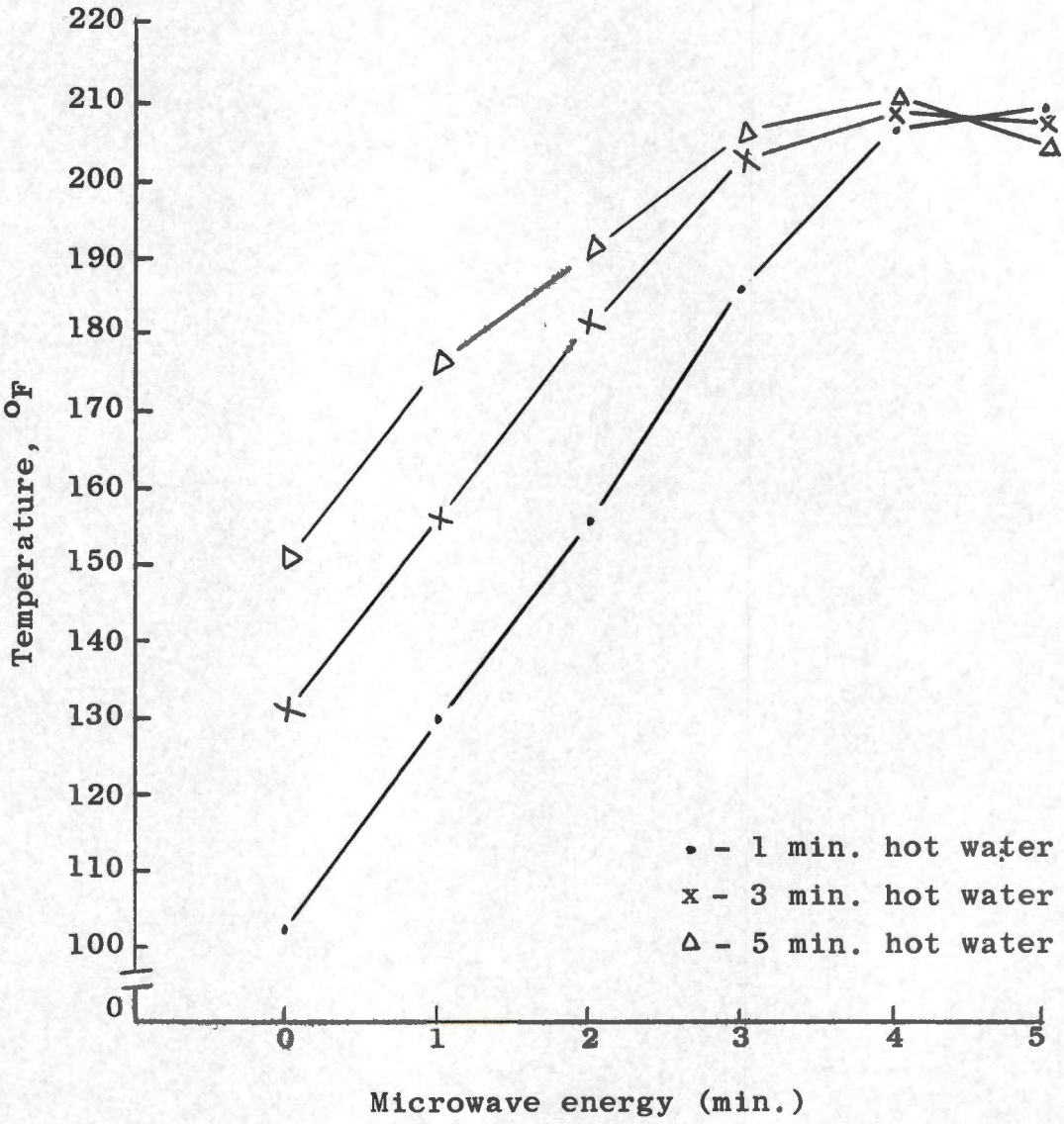


Figure 2. Penetration of heat to 0.75 cm. by heating potatoes in hot water followed by microwave energy. Mean radius potato, 1.95 cm.

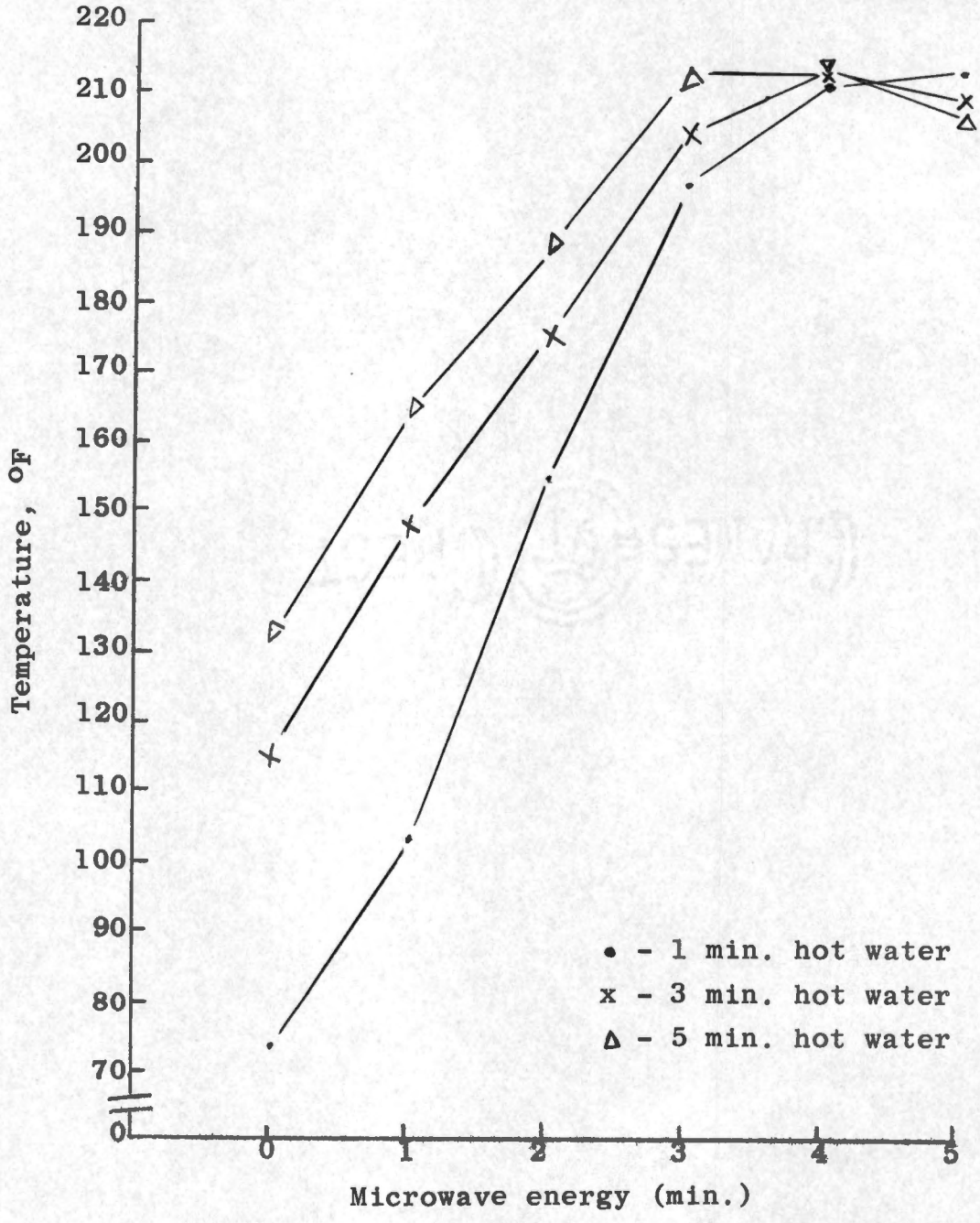


Figure 3. Penetration of heat at 1.5 cm. by heating potatoes in hot water followed by microwave energy. Mean radius potato, 1.95 cm.

TABLE V

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF HOT WATER FOLLOWED BY MICROWAVE ENERGY ON FIRMNESS OF WHOLE WHITE POTATOES*

Source of Variance	D.F.	Mean Squares
Water	2	96915.0**
Microwaves	5	588547.7**
Water x Microwaves	10	9681.5**
Replication	2	3.3
Residual Error	88	66.0

*Mean diameter, 3.9 cm.

**Significant at 0.01 level of probability.

TABLE VI

EFFECT OF HOT WATER FOLLOWED BY MICROWAVE ENERGY ON FIRMNESS* OF WHOLE WHITE POTATOES**

Hot Water		Microwave Energy	
Min.	Mean***	Min.	Mean****
1	287 m	0	496 a
		1	393 b
		2	285 c
3	249 n		
		3	145 d
		4	72 e
5	185 p	5	52 f

*Firmness was measured by shear press and was expressed as pounds force.

**Mean diameter, 3.9 cm.

***Each value is the mean of 36 observations.

****Each value is the mean of 18 observations.

Note: Within each column, means followed by the same letter are not significantly different at the 0.01 level of probability.

that the firmness of potatoes decreased as the heating time was increased. The means of the microwave energy factor show a similar relationship. Within each variable all means were significantly different from the others at the 0.01 level of probability.

Figure 4 shows the rates of softening when the potatoes were held in hot water at the different time followed by microwaves. The firmness of the potatoes at the end of the period required to inactivate peroxidase (Figure 1, p. 24) were estimated to be: 95 lb., 1 min. hot water followed by 4 min. microwave energy; 150 lb., 3 min. hot water followed by 3.1 min. microwave energy; 160 lb., 5 min. hot water followed by 2.15 min. microwave energy. The use of microwave energy would probably cost more than the use of steam or hot water, but its use could shorten the blanching time. From this experiment, when firmness, inactivation of peroxidase, and rate of heat penetration are considered heating potatoes for 5 min. in hot water followed by 2.15 min. microwave energy seemed to be more desirable than the other treatments.

II. EXPERIMENT TWO

Heat Penetration Pattern of Potatoes

The summary of the analysis of variance for the effect of microwave energy followed by boiling water on heat

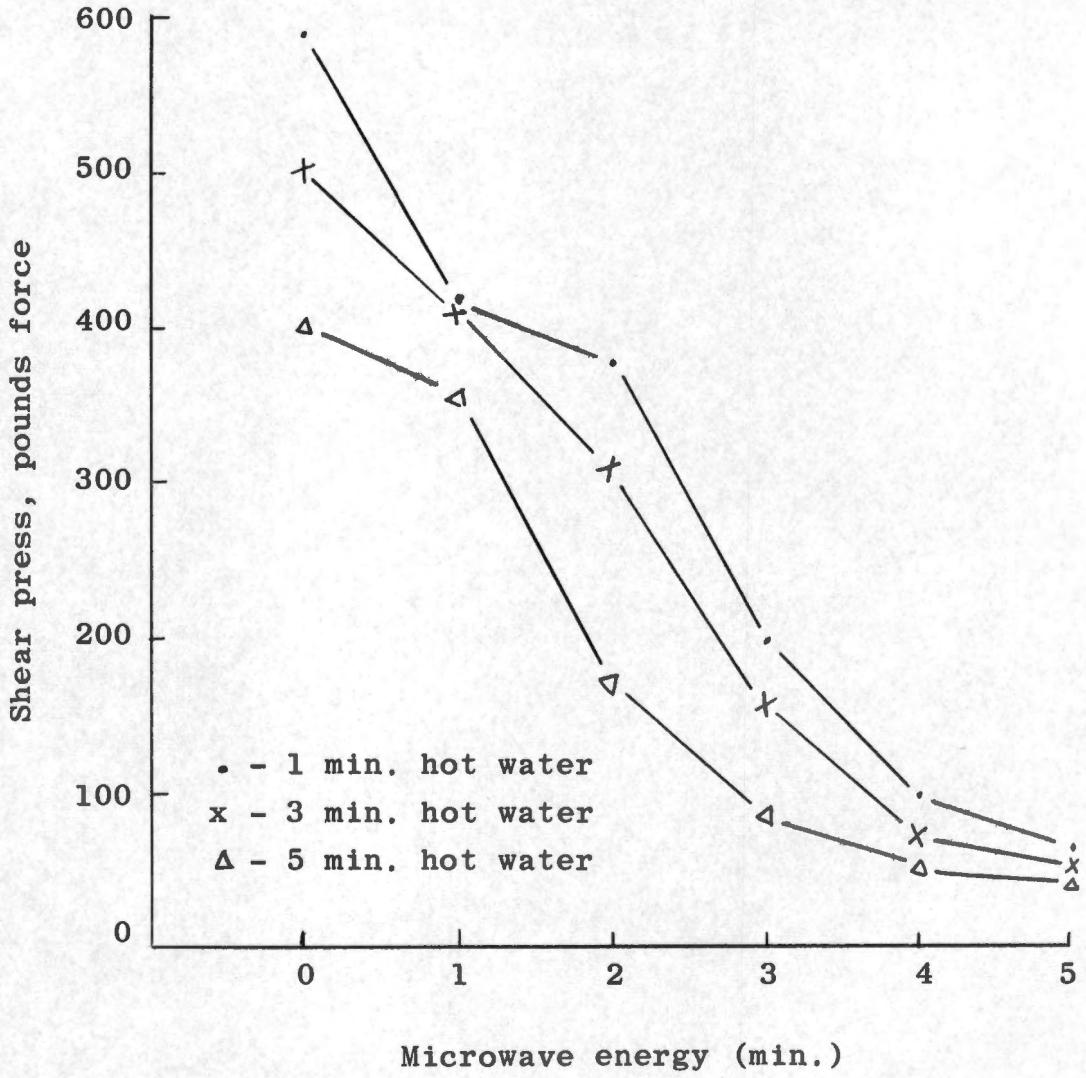


Figure 4. Firmness of potatoes heated in hot water followed by microwave energy. Potato mean diameter, 3.9 cm.

penetration is presented in Table VII. All factors and interactions of the factors are significant at the 0.01 level of probability. Replication is significant because there is a non-uniform heating pattern in the center and there is a delay in temperature measurement.

Results for the effect of microwave energy and boiling water on heat development in the potatoes are presented in Table VIII. Significant differences were found between the mean temperatures of the two depths. The temperature at 1.5 cm. was higher than that at 0.75 cm. There were significant differences among the temperature means resulting from the different periods of time of microwave heating up to 1.5 min. This indicates that the rate of heating resulting from microwave energy increased as the heating time was extended. The temperature means resulting from the different periods of time of boiling water heating show that the heat moved from the periphery toward the core of the potato.

The rates of temperature change at the depth of 0.75 cm. at 0.5 min. intervals of heating by microwave followed one minute-intervals of heating by boiling water are shown in Figure 5. These curves show the characteristic of this blanching method. The rates of temperature change at a depth of 1.5 cm. at 0.5 min. intervals of heating by microwave followed one minute-intervals of heating by boiling

TABLE VII

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF MICROWAVE ENERGY FOLLOWED BY BOILING WATER ON HEAT PENETRATION INTO WHOLE WHITE POTATOES*

Source of Variance	D.F.	Mean Squares
Depth	1	6420.0**
Microwaves	3	41932.6**
Water	5	1275.0**
Depth x Microwaves	3	901.6**
Depth x Water	5	1513.1**
Microwaves x Water	15	634.2**
Depth x Microwaves x Water	15	1119.0**
Replication	3	219.8**
Residual Error	525	26.9

*Mean diameter, 3.9 cm.

**Significant at 0.01 level of probability.

TABLE VIII

EFFECT OF MICROWAVE ENERGY FOLLOWED BY BOILING WATER ON HEAT PENETRATION* INTO WHOLE WHITE POTATOES

Depth		Microwave Energy		Boiling Water	
Cm.	Mean**	Min.	Mean***	Min.	Mean****
0.75	187 y	0.5	166 p	0	192 b
				1	187 c
		1.0	191 n		
				2	186 c
1.50	194 x				
				3	190 b
		1.5	202 m		
				4	191 b
		2.0	202 m	5	196 a

*Heat is expressed as degree of Fahrenheit.

**Each value is the mean of 288 observations.

***Each value is the mean of 144 observations.

****Each value is the mean of 96 observations.

Note: Within each column, means followed by the same letter are not significantly different at the 0.01 level of probability.

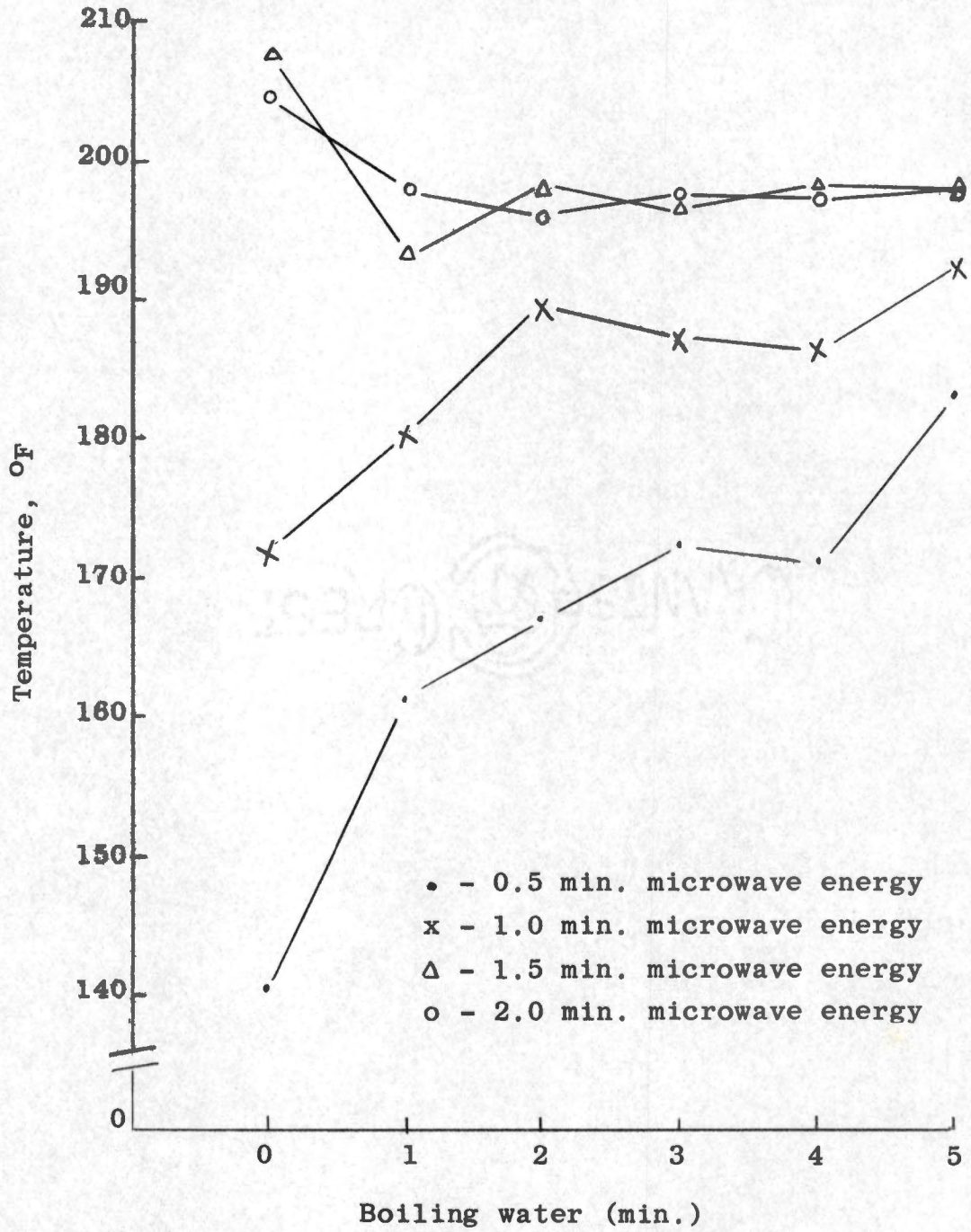


Figure 5. Temperature at 0.75 cm. by heating potatoes in microwave energy followed by boiling water. Potato mean radius, 1.95 cm.

water are shown in Figure 6. The means show that there was rapid heating initially within the potato (by microwaves). When the potatoes were placed in water after the microwave treatment the temperature at the internal points dropped at first, then temperature began to rise again after heating in water was begun. The heating phenomenon was unlike that found in experiment one. In this experiment, the potatoes were heated first by microwaves without being covered with water. Then they were placed in boiling water. It was found that potatoes heated by microwaves only became hotter first at the core. Also, the rate of heating of tubers by microwaves was more rapid than heating by hot water.

Inactivation of Peroxidase

The summary of the analysis of variance for the effect of microwave energy and boiling water on inactivation of peroxidase is presented in Table IX. All factors were significant at the 0.01 level of probability.

The means for peroxidase inactivation as affected by microwaves followed by boiling water are presented in Table X. The longer the period in which microwaves were applied, the greater the inactivated of peroxidase. The same trend was found when the potatoes were held for progressively longer period of time in boiling water.

Due to the heat patterns produced by microwaves

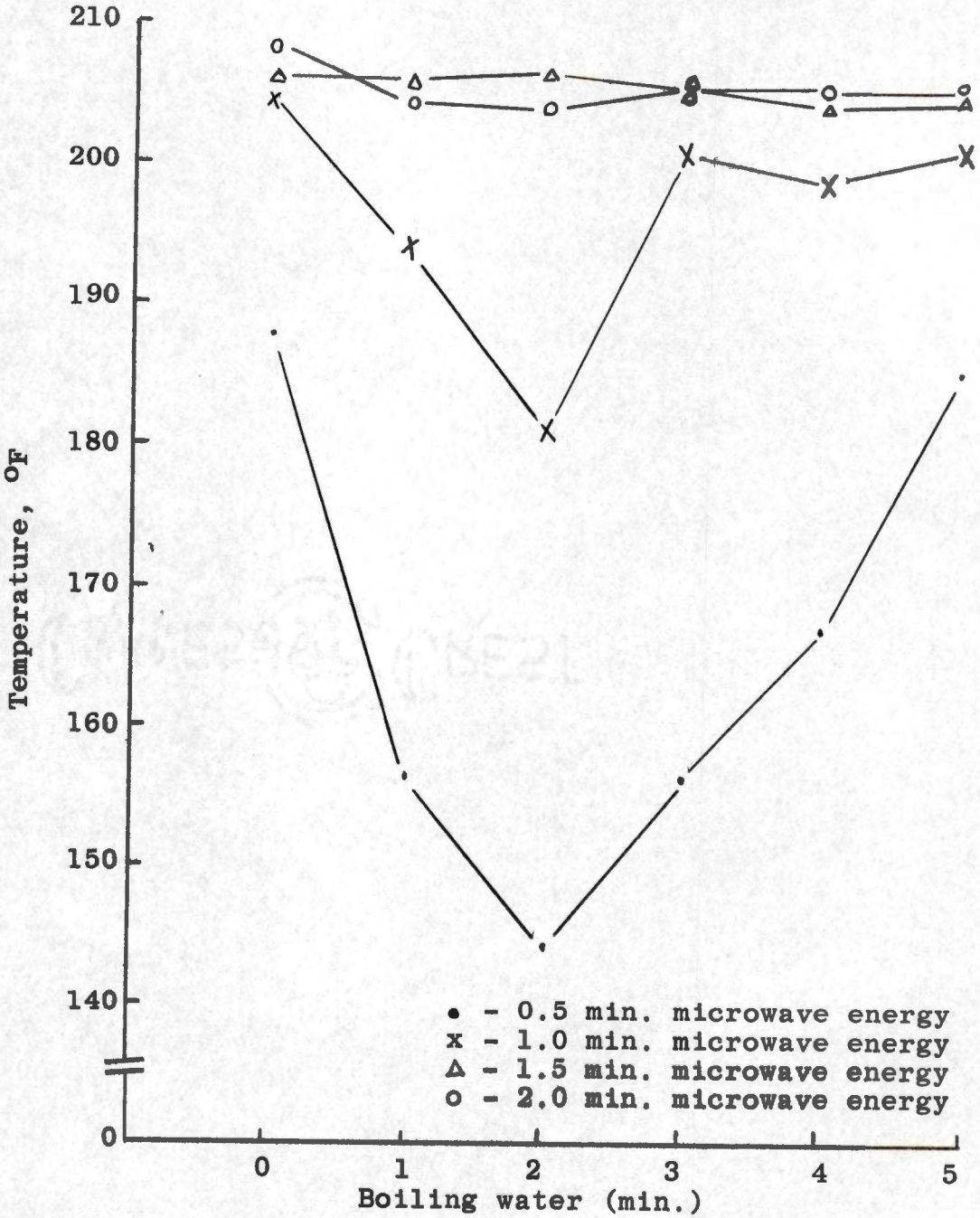


Figure 6. Temperature at 1.5 cm. by heating potatoes in microwave energy followed by boiling water. Potato mean radius, 1.95 cm.

TABLE IX

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF MICROWAVE ENERGY FOLLOWED BY BOILING WATER ON INACTIVATION OF PEROXIDASE IN WHOLE WHITE POTATOES*

Source of Variance	D.F.	Mean Squares
Microwaves	3	90.0205**
Water	5	4.8215**
Microwaves x Water	15	0.3335**
Replication	2	0.0479
Residual Error	262	0.1197

*Mean diameter, 3.9 cm.

**Significant at 0.01 level of probability.

TABLE X

EFFECT OF MICROWAVE ENERGY FOLLOWED BY BOILING WATER ON INACTIVATION OF PEROXIDASE* IN WHOLE WHITE POTATOES**

Microwave Energy		Boiling Water	
Min.	Mean***	Min.	Mean****
0.5	1.43 q	0	2.35 d
		1	2.60 c
1.0	2.48 p		
		2	2.86 b
		3	3.00 ab
1.5	3.66 n		
		4	3.10 a
2.0	3.82 m	5	3.17 a

*Inactivation of peroxidase is expressed as cm of the diameter.

**Mean diameter, 3.9 cm.

***Each value is the mean of 72 observations.

****Each value is the mean of 48 observations.

Note: Within each column, means followed by the same letter are not significantly different at the 0.01 level of probability.

followed by boiling water, there were two zones where the enzyme was inactivated prior to complete inactivation. These zones of inactivation occurred intially at the core and periphery. Table XI shows the extent of inactivation by the two methods of heating. The minimum treatments found to completely inactivate peroxidase were as follows: 1.5 min. microwaves followed by 3 min. boiling water and 2 min. microwaves followed by 2 min. in boiling water.

The total cross-section of the diameter in which peroxidase was inactivated under the different heating treatments is shown in Figure 7. Values at the complete inactivation (mean diameter) were estimated: 1.5 min. microwave energy followed by 3 min. boiling water; 2 min. microwave energy followed by 2 min. boiling water. Peroxidase was not completely inactivated at microwave treatments of 1.0 min. and less with the subsequent treatments in boiling water.

Firmness of Potatoes

The summary of the analysis variance for the effect of microwave energy followed by boiling water on firmness of potatoes is presented in Table XII. The factors and the interaction of the factors were significant at 0.01 level of probability. The firmness means of potatoes heated by the two methods are presented in Table XIII. A softening of the tubers occurred when both types of heat were applied.

TABLE XI

MICROWAVE ENERGY FOLLOWED BY BOILING WATER HEATING OPERATION PRODUCED TWO ZONES WHERE THE PEROXIDASE WAS INACTIVATION PRIOR TO COMPLETE INACTIVATION

Heat Sources		Inactivation of Peroxidase		
Microwave (min.)	Boiling Water (min.)	Center (cm.)	Periphery (cm.)	Total (cm.)
0.5	0	0.94	0.00	0.94
0.5	1	1.22	0.00	1.22
0.5	2	0.99	0.33	1.32
0.5	3	0.93	0.59	1.52
0.5	4	0.82	0.93	1.75
0.5	5	0.66	1.16	1.82
1.0	0	1.73	0.00	1.73
1.0	1	2.05	0.00	2.05
1.0	2	2.13	0.40	2.53
1.0	3	2.15	0.54	2.69
1.0	4	2.04	0.81	2.85
1.0	5	2.07	0.98	3.05

TABLE XI (continued)

Heat Sources		Inactivation of Peroxidase		
Microwave (min.)	Boiling Water (min.)	Center (cm.)	Periphery (cm.)	Total (cm.)
1.5	0	3.14	0.00	3.14
1.5	1	3.39	0.00	3.39
1.5	2	3.39	0.31	3.70
1.5	3	CIP*	CIP	3.90
1.5	4	CIP	CIP	3.90
1.5	5	CIP	CIP	3.90
2.0	0	3.58	0.00	3.58
2.0	1	3.73	0.00	3.73
2.0	2	CIP	CIP	3.90
2.0	4	CIP	CIP	3.90
2.0	5	CIP	CIP	3.90

*Complete inactivation of peroxidase (3.9 cm.).

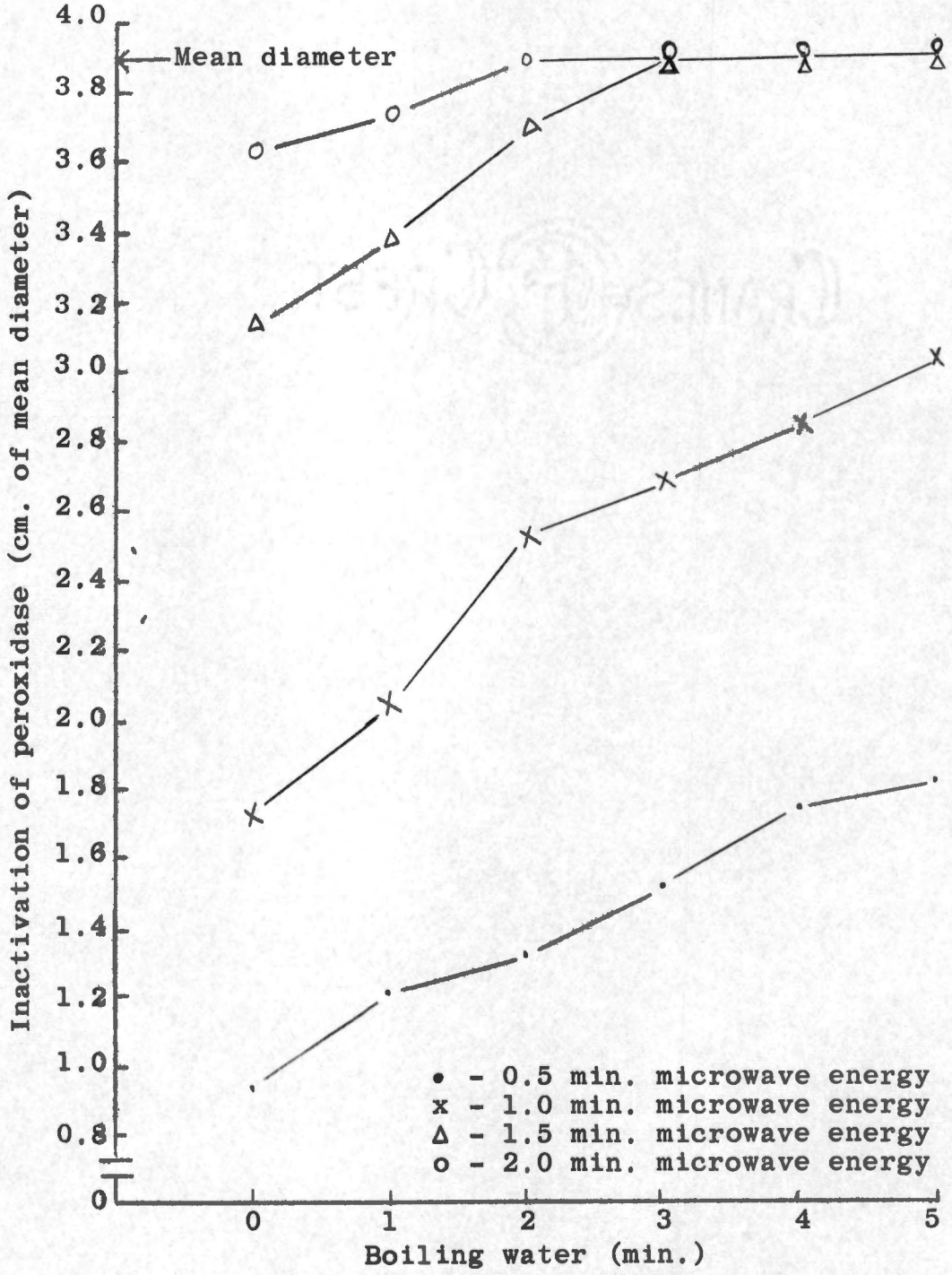


Figure 7. Inactivation of peroxidase in potatoes heated in microwave energy followed by boiling water. Potato mean diameter, 3.9 cm.

TABLE XII

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF MICROWAVE ENERGY FOLLOWED BY BOILING WATER ON FIRMNESS OF WHOLE WHITE POTATOES*

Source of Variance	D.F.	Mean Squares
Microwaves	3	530227.2**
Water	5	335620.7**
Microwaves x Water	15	11026.9**
Replication	2	182.6
Residual Error	118	173.2

*Mean diameter, 3.9 cm.

**Significant at 0.01 level of probability.

TABLE XIII

EFFECT OF MICROWAVE ENERGY FOLLOWED BY BOILING WATER ON FIRMNESS* OF WHOLE WHITE POTATOES**

Microwave Energy		Boiling Water	
Min.	Mean***	Min.	Mean****
0.5	407 m	0	457 a
		1	312 b
1.0	285 n	2	242 c
		3	196 d
1.5	180 p	4	165 e
2.0	134 q	5	137 f

*Firmness was measured by shear press and was expressed as pounds force.

**Mean diameter, 3.9 cm.

***Each value is the mean of 36 observations.

****Each value is the mean of 24 observations.

Note: Within each column, means followed by the same letter are not significantly different at the 0.01 level of probability.

The effect of heating treatments on the firmness of potatoes is shown in Figure 8. The firmness of potatoes at the minimum time that peroxidase was completely inactivated (Figure 7, p. 46) were estimated as follows: 119 lb., 1.5 min. microwave energy followed by 3 min. boiling water; 124 lb., 2.0 min. microwave energy followed by 2 min. boiling water. Observation of the blanched potatoes indicated that they were partially cooked. Therefore, processors of frozen whole potatoes may not desire to heat the potatoes to this degree. A heating treatment at some point short of complete inactivation may be more desirable.

III. COMPARISON OF TWO EXPERIMENTAL METHODS

Comparison of firmness of the potatoes where peroxidase just completely was inactivated is presented in Table XIV. Both methods would shorten the blanching time when compared with conventional methods. When the procedure of experiment one was followed, a longer period of time was required to inactivate peroxidase than when the procedures of experiment two were utilized. However, potatoes from experiment one were firmer than those of experiment two. The potatoes from experiment one heated at 3 and 5 min. in hot water showed only a 10 lb. difference in firmness. Firmness of potatoes by the treatments in experiment two were only different by 5 lbs. of force.

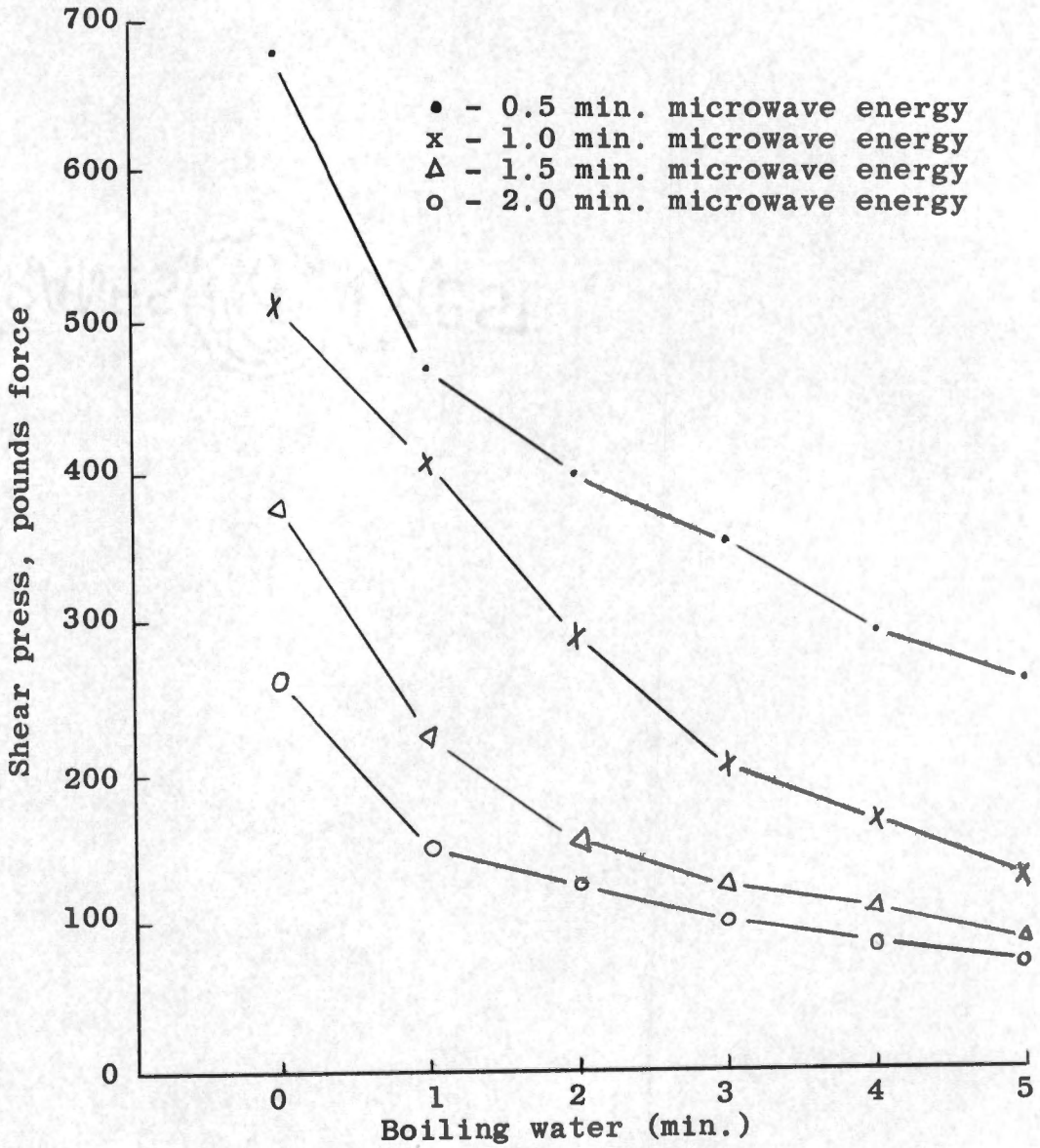


Figure 8. Firmness of potatoes heated by microwave energy followed by boiling water. Potato mean diameter, 3.9 cm.

TABLE XIV

COMPARISON OF FIRMNESS OF THE POTATOES WITH TWO EXPERIMENT METHODS WHERE PEROXIDASE WAS JUST INACTIVATED

Experiment One			Experiment Two		
Hot Water (min.)	Microwave Energy (min.)	Firmness (lb.)	Microwave Energy (min.)	Boiling Water (min.)	Firmness (lb.)
1	4.0	95	1.5	3	119
3	3.1	150	2.0	2	124
5	2.15	160			

CHAPTER V

SUMMARY

In this study, experiments were conducted to determine the effect of heating by microwaves and hot water on the heat penetration, inactivation rate of peroxidase, and the firmness of whole white potatoes.

The first experiment was conducted to determine the effectiveness of hot water followed by microwave energy for blanching the potatoes.

The following results were found from experiment one:

1. The minimum treatments found to completely inactivate peroxidase were as follows: 1 min. hot water followed by 4 min. microwave energy, and 3 min. hot water followed by 3.1 min. microwave energy and 5 min. hot water followed by 2.15 min. microwave energy.

2. The heat gradient was from the periphery to the core.

3. Temperature of inactivation of peroxidase at 1.5 cm. depth was higher than at 0.75 cm.

4. Firmness of potatoes at the point when peroxidase was just inactivated were: 95 lb., 1 min. hot water followed by 4 min. microwave energy; 150 lb., 3 min. hot

water followed by 3.1 min. microwave energy; and 160 lb., 5 min. hot water followed by 2.15 min. microwave energy.

The second experiment was conducted to determine the effect of blanching potatoes by microwave energy followed by boiling water.

From this study the following results were found:

1. When the potatoes were heated by microwaves a heat gradient developed from the core toward the periphery.

2. Because of the heat gradient of the potatoes, the temperature at a 1.5 cm. depth was higher than that at 0.75 cm. This heating phenomenon was different from the finding of experiment one.

3. Due to the heat patterns produced by microwaves followed by boiling water, there were two zones of enzyme inactivation prior to complete inactivation. These zones of inactivation occurred initially at the core and periphery.

4. The minimum treatment time found to completely inactivate peroxidase and the firmness values after these treatments were as follows: 119 lb., 1.5 min. microwave energy followed by 3 min. boiling water and 124 lb., 2 min. microwave energy followed by 2 min. boiling water.

5. When the procedure of experiment one was followed, a longer period of time was required to inactivate peroxidase in the whole potato than when the procedures of

experiment two were utilized. However, the firmness of tubers from experiment one was higher than the firmness of potatoes from experiment two.

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LITERATURE CITED

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