The Effect of Microwaves on Nutrient Value of Foods

by

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1. INTRODUCTION

A. Microwave Energy

Microwaves are high frequency radiations with 1 m to 0.1 mm wavelengths in air. This type of radiation is expressed in millions of cycles/second or mega Hertz (MHz) with frequencies ranging from 300 to 30,000 MHz. Microwave radiation represents only one part of the electromagnetic radiation spectrum. Other entities of the spectrum include gamma rays, ($\lambda \sim 10^{-11}$ to 10^{-16} m), x-rays ($\lambda \sim 10^{-8}$ to 10^{-11} m), ultraviolet ($\lambda \sim 10^{-7}$ m), visible ($\lambda \sim 10^{-6}$ m), and short and long radio waves ($\lambda \sim 10^{-4}$ to 10^{-8} m). X-rays and gamma rays are electromagnetic radiation arising from the shift of energy of orbital electrons and nuclear particles, respectively. They differ from the rest of the spectrum by their ability to ionize other compounds. These high energy radiations separate electrons from molecules encountered along their paths thus creating charged ions. The resultant electrically charged ions are capable of causing chemical changes in surrounding matters with little or no temperature rise. These processes occur in fluorescent lightbulbs, X-ray machines, γ- radiation chambers, or in matter exposed to β particles. Much research on the biological effects of ionizing radiation has been conducted and reported (71). A brief summary of research data on these effects is included in Chapter 3.

Ultraviolet, infrared, microwaves and radio waves have longer wavelengths than ionizing radiation and are classified as non-ionizing because they do not possess enough energy to ionize other compounds.

Radiation can be considered as a combination of electric and magnetic waves traveling through space, or as a compact moving uncharged particle. This particle, the photon, represents a bundle of energy and has been described as possessing mass only by virtue of its motion (73). The choice of model — wave or particle — depends on the process under study. Irrespective of its origin, all radiation is characterized by its energy or frequency. This is related to speed and wavelength as illustrated in Figure 1. Non-ionizing waves are characterized by frequencies ranging between 10^1 and 10^{16} cycles/second and wavelengths between 10^{-7} and 10^7 m.

Figure 1. Radiant waves characterized by wavelength and frequency of vibration, where wavelength (λ) x frequency (v) = speed of light (c).

Adapted from Microwave Energy Applications Newsletter (5).

The Federal Communications Commission (38) designated 915 ± 25 MHz, 2450 MHz ± 50 MHz, 5800 MHz ± 75 MHz and 22,125 MHz ± 125 MHz for industrial scientific and medical applications. The microwave frequencies of 915 MHz and 2450 MHz are used for industrial heating equipment and domestic food preparation, respectively, whereas 5800 MHz and 22,125 MHz are reserved for research and industrial applications.

The main difference between equipment utilizing these megacycles is the power output of the magnetron tube which functions like a generator to convert electrical power to microwaves. The 915 MHz wavelength is available only in combination microwave - conventional ranges produced by one American manufacturer. All other domestic appliances use the 2450 MHz frequency.

B. Microwave Heating Mechanism

In conventional cooking, heat is applied to the outside of food by convection, as in baking; by radiation, as in broiling; or by conduction, as in frying. Then the heat is conducted to the interior of the food. In contrast, food cooked by microwave engages heat generated from within the food through a series of molecular vibrations.

Goldblith (41) described the heating principle as an attempt by asymmetric dielectric molecules to align themselves with the rapidly changing alternating electrical field. The molecules in the microwave paths oscillate around their axes in response to reversing or flipping occurring at 915 or 2,450 million times/second. This oscillation creates intermolecular friction which results in the generation of heat.

Such materials as polarized food or water exhibit a high degree of intermolecular motion. They are characterized as "lossy." The amount of "lossiness" varies depending upon the radiation frequency, temperature and nature of the material. Consequently, the increased "lossiness" of a material can be directly related to increased absorption of microwave energy and hence, heat production (41). Water serves as a good example of a lossy material which is responsible for heat production.

There are several factors which affect microwave heating of food. As in conventional heating, the higher the initial temperature, the faster the food will be heated by microwaves. Cooking food from the frozen state in a microwave oven is not recommended (74). Differing absorption rates between ice and water cause an uneven rate of heating in frozen foods. Thus, foods will have some hot areas while other parts remain partially frozen. Napleton (74) recommended a two-step sequence for successful heating of frozen foods: heating to allow surface layer warming, a withdrawal from the oven allowing heat conduction, followed by a return to the oven for heat completion. This method utilizes the oven first as a defroster.

Density and consistency can also affect heating. The denser the food, the longer it takes to cook. Thus food with an open, porous texture is very easily penetrated by microwaves. A more homogenous nature also contributes to greater absorption and less cooking time.

Microwaves are capable of penetrating food from 2.4 to 2.9 inches. Irregularly shaped foods such as roasts require additional time for microwave penetration and may result in uneven cooking.

An increased amount of food increases cooking time. A linear relationship exists between the quantity of food prepared and cooking time. Napleton (74) suggested every additional food item or relative increase in weight added one-half the time required to heat one item to the overall heating time.

C. Energy and time savings

The microwave oven has a high thermal efficiency when compared to conventional gas and electric ovens. In contrast to conventional ovens which heat the air surrounding the food, the microwave oven generates heat from within the food. Unlike conventional ovens, little energy escapes from the microwave oven to the outside air.

The power efficiency of the microwave oven has been calculated and compared to conventional cooking systems. Efficiency designates the amount of energy utilized by the appliance for providing heat (93). The National Bureau of Standards concluded microwave ovens are approximately 40% efficient, compared to 14% and 7% for standard electric and gas ovens, respectively (90). One manufacturer reported a series of tests conducted to determine savings in kilowatt hours using microwave (Thermador), conventional electric surface heating and electric oven heating (90). Savings in kilowatt hours ranged from a 22% for thawing frozen spinach to 94% for reheating coffeecake. The Department of Energy, however, estimated that an average household will save only $10 per year due to microwave oven efficiency (90), which does not justify the purchase of a microwave oven.

When time savings is considered in the cost justification, the purchase of a microwave oven is enhanced. The most outstanding advantage of using any microwave oven is its time saving feature — both in preparation and clean-up. Most microwave ovens require only 20% of the time used by conventional heating systems. Various sources have reported a time savings of 10 - 90% (3, 68, 70, 93, 97).

Results of a survey conducted for American Can Company, Greenwich, Connecticut, indicated that 82% of those sampled reported quickness as the major advantage of the microwave oven (47). Other responses included convenience (31%), easy clean-up (25%) and reduced energy expenditure (17%).

D. Utilization and Application of Microwave Energy

Microwave ovens for home use were first marketed in 1955 by Tappan, under license to Raytheon Company. These ovens, like the General Electric ovens introduced in the early 1960's, were combination microwave/conventional ranges and cost as much as $1500 (68).

The appearance of the countertop or portable microwave oven in 1967 increased unit sales. Amana Refrigeration, Inc. manufactured the first countertop microwave oven which retailed under $500. Other manufacturers challenged the Amana design with improved countertop ovens. Among these are domestic (U.S.) companies, General Electric, Litton, Magic Chef, Tappan and Thermador, as well as Japanese manufacturers Hayakawa (Sharp), Matsushita (Panasonic), Mitsubishi (MGA) and Sanyo. Oven sales prior to 1973 were less than 500,000 units, with Japanese companies controlling 48% share of the market.

By 1975, Japanese sales declined to an estimated 26% but U.S. sales had soared to 2.5 million, with 4% of U.S. homes owning microwave ovens. Present oven sales in 1980 have surpassed 4 million representing close to 20% ownership in American homes. Decareau estimated a six million unit market in 1985 when one in every two households is expected to own a microwave oven (31).

Over the past several decades, extensive efforts to develop devices and techniques for commercial applications of microwave energy have been made. One of the early uses of microwave energy in the food industry was for frozen food defrosting. Various studies reported uneven heating (14, 27, 72), but some suggested uses and advantages of defrosting by microwave energy (30, 49). Applications of microwave thawing of precooked frozen meals for hospitals and foodservice institutions were made (18, 29, 46, 56, 58). This microwave method, known as the "cook-chill" or "ready foods" system provided a fundamental break-through in traditional hospital foodservice. The improved quality of meals with decreased food and labor costs have been documented (28, 78). This effective and efficient concept, while nearly 20 years old, now has been implemented successfully in hotel and restaurant systems (85, 95).

Wide experimentation with microwave energy in food processing has been documented. Numerous studies investigated vegetable blanching with some reporting nutrient and pigment retention due to less water leakage (32, 35, 36, 80). Microwaves were utilized to speed the freeze-drying process (41) and for a variety of microwave baking (7, 84, 91) applications.

The microwave finish drying of potato chips was recognized as economically and practically feasible by Goldblith in 1966 (40). "Puffing" of food pieces to aid rehydration and microwave drying of pasta goods have been implemented with varying success in industry (28). Other uses of microwave energy with food applications include dough proofing, tempering of meat, dehydration of fat and oils and the pasteurization of solids. A recent review indicates microwave heating results in the destruction of microorganisms in various food systems (39).

From its beginnings in radar and communications during World War II to the present, technology has developed and advanced microwave energy applications. Not only can it provide a rapid method to cook food, microwaves relay network and public television, permit safer air traffic control and serve as an integral component of national defense intelligence (87). Even with these incredible advances, the microwave industry remains dynamic and anticipates new applications.

2. EFFECTS OF MICROWAVES ON NUTRIENT VALUE OF FOODS

Consumers in this enlightened society demand foods that are not only good to look at and taste, safe to eat and hunger satisfying, but also nutritious. Thus, the food industry is rising to meet the demands of the consumer for nutrition labeling of food products. Governmental agencies in 1973 have reinforced this demand with legislation that required a food processor who chose to reveal any nutritional information regarding his product to make a full declaration (45).

While nutrition labeling on food containers has increased the awareness of food values, these data do not and cannot reveal the nutritional value of the food as consumed. With the exception of foods consumed directly from the container, most products undergo further processing by the consumer.

The method of heating and cooking, duration and delay prior to serving, all affect the nutrition inherent in foods (31). Public concern has arisen over these factors and their effects on products served in commercial foodservice establishments. The literature contains various studies (17, 56) which investigated nutrient losses in institutional feeding. A direct relationship between service delay and nutrient loss was shown.

The development of microwave ovens for domestic use started 30 years ago. A great deal of early research work was devoted to studying nutrient retention of food cooked in a microwave oven. Studies as early as 1948 reported an increased retention of nutrients in microwave applications compared to conventional cooking. More recent studies (8, 24, 43) showed that nutrient retention was greater with electronic heating compared with conventional cooking and attributed this to less water-to-product ratio, and consequent reduced leaching out. Other studies (36, 88) of nutrients reported higher moisture losses when cooking with microwave energy, and as a consequence decreased nutrient retention.

Because of these conflicting data, this chapter reviews and reports on changes in the nutrient value of foods due to microwave processing. The effects of microwaves have been reported here in the six main nutrient categories: water, protein, carbohydrate, lipid, minerals and vitamins.

A. Moisture

The effect of cooking methods on moisture content has been studied almost exclusively in meat products. Early research studies (18, 62) indicated that microwave prepared meat products had greater cooking losses than that cooked conventionally.

Marshall (67) found significantly more moisture was lost in top rounds of beef cooked by microwave to an internal temperature of 80^{o} C compared to companion top rounds roasted by a conventional method. Apgar et al. (6) showed that pork patties cooked by microwave had more moisture losses compared to conventional treatment. In the same study, pork roasts cooked conventionally retained considerably more moisture compared to their microwave treated counterparts.

Electronic cooking of beef patties studied by Janicki and Appledorf (50), produced greatest moisture losses due to electronic cooking as shown in Table 1. Likewise, significantly lower moisture losses were reported by

TABLE 1

Effect of Cooking Method on Content of Beef Patties

Treatment	Cooking Time	Moisture (g)
Raw	---	67.6 $\pm$ 2.3 a
Broiled	50 sec.	42.5 $\pm$ 4.1 b
Grill frying	4 min.	42.4 $\pm$ 3.4 b
Microwave	90 sec.	36.2 $\pm$ 2.2 c

Values followed by the same letter are not significantly different ($P \leq 0.05$).

Adapted from Janicki and Appledorf (50).

Kylen et al. (62) in conventionally heated beef and pork roasts. Moisture losses for beef and ham loaves were approximately the same with both conventional and microwave cooking methods. These results are shown below in Table 2.

TABLE 2

Moisture Content of Raw and Cooked Meat

Products and Methods of Cooking	Raw meat Moisture %	Cooked meat Moisture %
Beef roasts		
Conventional gas oven	68.3 ± 0.74	58.2 ± 0.71
Microwave oven	67.0 ± 1.52	49.0 ± 0.96**
Pork roasts		
Conventional electric oven	67.3 ± 1.30	52.9 ± 1.47
Microwave oven	66.6 ± 1.06	49.6 ± 0.86*
Beef loaves		
Conventional gas oven	67.4 ± 1.85	63.5 ± 0.51
Microwave oven	67.4 ± 1.85	63.5 ± 0.58
Ham loaves		
Conventional gas oven	64.4 ± 0.62	60.7 ± 0.55
Microwave oven	64.4 ± 0.62	56.6 ± 0.71**

* Significantly lower than the corresponding mean ($P < 0.05$)

** Significantly lower than the corresponding mean ($P < 0.01$)

Adapted from Kylen (62).

These results were in agreement with others (15, 18, 67) who reported greater cooking losses in beef roasts cooked in an electronic range but differs with Apgar et al. (6) who found no significant difference in pork roasts due to cooking method.

Cooking losses in beef and beef-soy loaves were compared by Ziprin and Carlin (101). Loaves cooked electronically had consistently higher losses than those cooked conventionally. Substitution of 15% soy reduced cooking losses more in loaves cooked in conventional than in microwave ovens.

Paired legs of lamb, boned and rolled were prepared by conventional and electronic methods by Headley and Jacobson (48). Although the paired roasts reached the same internal temperature, those cooked electronically experienced greater cooking losses.

Further evidence that cooking losses were greater after microwave treatment was found by Wing and Alexander (98). Chicken breasts cooked in a microwave oven lost more moisture compared to those conventionally prepared.

One exception was reported by Korschgen and Baldwin (61) who studied round roasts of beef cooked by moist heat microwave and conventional oven braising. No significant differences in cooking or moisture losses were revealed in meat cooked by the two methods.

Studies designed to compare water content of vegetables before or after microwave cooking yielded little significant data (63). Differences in water content of vegetables were relatively small. A 1951 study (63) of five cooking methods (2 conventional ovens, surface heating, boil-in-bag and microwave) and their effects on frozen cooked vegetables (green beans, Swiss chard, broccoli, carrots, beets, potatoes) showed the greatest weight loss in products heated by microwave. Mean losses ranged from 9% of the total weight reported in baked stuffed potatoes to 22% in cut green beans. Eheart and Gott (36) compared conventional cooking methods to microwave cooking for five vegetables (broccoli, spinach, peas, green beans and potatoes) prepared without water. Microwave cooking of vegetables without the addition of boiling tap water resulted in greater weight losses when compared to those incurred through conventional cooking.

A variety of reasons were postulated for the greater losses in moisture in microwave cooked products. Apgar et al. (6) suggested that increased losses may be attributed to a greater rise in post oven temperature, thus causing more dehydration through evaporation, and increased shrinking. Van Zante (92) showed that presence of bone affected heating results, causing a rapid cooking in meat closest to bone. This direct microwave penetration resulted in increased moisture losses in areas near the bone.

The amount of water added varied considerably in microwave versus conventionally cooked vegetables. Thus, increased leaching of nutrients may have been a result of greater water to vegetable ratio, rather than the superiority of microwave applications.

It is important to note that very few studies provided data on water content of foods prior to and following microwave cooking. Conclusions are difficult to make on existing data, although higher moisture losses by microwave cooking have been indicated in nearly all research to date.

B. Protein of Animal Origin

The effect of heat on the utilization of dietary protein has been the subject of much research. While there were many studies involving meat, an excellent source of dietary protein, very few have investigated protein changes in microwave cooked meat.

Effects of temperature on relative percentage of crude myofibrillar protein were compared in conventional and microwave heating by Roberts and Lawrie (81). Beef longissimus dorsi muscle was exposed to conventional heating for 0 - 70 minutes at temperatures ranging from 45° C - 90° C and to microwaves for 0 - 10 seconds. Protein denaturation was determined through measurements of nitrogen distribution between sarcoplasmic and crude myofibrillar fractions. Muscle damage increased with heat and length of exposure. Values for insoluble protein increased sharply in conventionally heated muscle at temperatures between 50 and 70° C, whereas microwave-heated muscle exhibited a more gradual increase. Thus, microwave heating may aid in retention of total protein in foods.

Baldwin and Tettambel compared cooking losses and nitrogen content of rib-eye steaks cooked (66° C) by microwaves and by a conventional method (9). Significantly more nitrogen was reported in the microwave heated steaks; the drip values showed significantly less nitrogen for microwave cooked steaks compared with those from conventionally prepared samples. Kierebinski also reported higher nitrogen values in microwave-heated samples of longissimus dorsi muscle (60).

In a 1976 study Baldwin et al. (10) determined nitrogen and free amino acid content in raw and cooked (70^{o} C) longissimus muscle of beef and pork and deboned legs of lamb. Nitrogen content and free amino acids were determined by macro-Kjeldahl and amino acid analyzer methods, respectively. Free amino acid content tended to be greater in conventionally cooked meat when compared to that cooked by microwaves. This trend for significantly greater amounts in the conventionally cooked meat occurred for valine and leucine in all three species, but other differences varied with the species of the meat. Protein content of microwave cooked meat was greater than in the conventionally cooked meat, as seen in Table 3, but was statistically significant only between beef cooked by 115 V

TABLE 3

Mean Percent Protein Content of Roasts Cooked By Microwave and Conventional Methods

	Cooked meat [a]			Drippings [a]		
	Microwave			Microwave		
Species	220 V	115 V	Conv.	220 V	115 V	Conv.
Beef[1]						
Protein	30.8 ab	31.5 a	28.5 b	13.1 b	11.9 b	19.4 a
Pork[2]						
Protein	33.2	33.6	33.4	16.9 b	12.2 c	26.7 a
Lamb[3]						
Protein	32.2	31.5	27.5	16.8 b	12.1 c	21.4 a

[a] N = 5. Where letters differ within a constituent for cooked meat or dripping within a species, means differ significantly ($P < 0.05$) from each other.

[1] Raw beef: 21.3% protein.

[2] Raw pork: 22.7% protein.

[3] Raw lamb: 21.1% protein.

Adapted from Baldwin et al. (10).

microwaves and the conventional method. Again, drippings from conventionally cooked meats contained more protein than those from both microwave sets of roasts; and those from 115 V microwave meats had the least protein.

Six beef and pork samples were evaluated for protein quality after various cooking (fried, boiled, microwave heated) methods (37). Protein quality, determined by a *Tetrahymena pyriformis* W growth assay, was highest in boiled meat samples, with 46.9% total essential amino acids in total protein, followed by microwave treated meat (46.1%) and fried samples (45.4%). This study has limited application as boiling of beef and pork is not a common cooking practice.

Free amino acid content differed little in round roasts of beef and pork cooked (98^{o} C) by moist-heat microwave and conventional oven braising (61). Korschgen and Baldwin (61) reported no significant differences in protein fractions of the two treated roasts. Similarly, in studies using paired legs of lamb, Johnson *et al*. found no alterations in amino acid and nucleotide concentrations (52).

Two studies investigated effects of heating methods on protein nutritional value in frozen prepared foods (17, 76). Penner and Bowers (76) compared freshly cooked (77^{o} C) by microwave and conventionally re-heated (55^{o} C) pork loins. Protein content in three fractions (low ionic strength; soluble and a denatured fibrillar protein nitrogen fraction; sarcoplasmic and a nonprotein nitrogen fraction) was determined by micro-Kjeldahl. Results of their study showed amounts of protein in the various tissue extracts were not significantly affected by method of heating.

Lyophilized samples of instant mashed potatoes, peas with onions, beans with frankfurters, beef pot roast with gravy and breaded fish portions were evaluated for changes in protein following treatment simulating institutional and convenience food system handling procedures (17). For the five products studied, amino acid composition did not vary markedly with treatment. Rat bioassays were conducted to detect decreases in selected amino acids, but the differences observed were not consistently related to treatment. Bodwell and Womack (17) concluded neither conventional nor convenience food system handling procedures significantly decrease protein nutritive values of the products studied.

Protein digestibility was investigated in cod fillets by Kadaner <u>et al</u>. (55). Microwave heating did not alter the susceptibility of fish proteins <u>in vitro</u> to proteolytic enzyme attack.

Microwave thawing of fish showed reduced protein losses in a study by Bezanson <u>et al</u>. (16). Two varieties (Louisiana brown, Columbia white) of raw headless shrimp were defrosted by a conventional method (submersion of frozen fish in water, 18^{o} C) and microwave energy (915 MHz) application. Samples analyzed for protein showed significantly higher protein percentages in microwave defrosted shrimp. Moisture/protein ratios were higher in the water-defrosted samples indicating a loss of protein due to leaching occurred more in the conventional method. As shown by the data in Table 4, microwave thawing of fish can reduce protein losses significantly. While it is doubtful that these data will change current industry practices, the use of high frequency energy below the microwave range has also been

TABLE 4

Proximate Composition of Microwave vs. Water Defrosted Raw, Headless Shrimp

	Louisiana brown	Columbia white
% protein (water defrosted)	16.57	16.68
% protein (microwave defrosted)	18.66	17.49
Protein difference (% of total weight)	2.09	0.81
Moisture/protein ratio (water defrosted)	4.97	4.93
Moisture/protein ratio (microwave defrosted)	4.28	4.65

Adapted from Bezanson *et al*. (16).

implemented to speed defrosting with varying success (51).

Overall, the nutritional effects of microwaves on animal proteins appear minor. Variability in procedures and products prevent any additional conclusions from the research data.

C. Protein of Non-Animal Origin

While much of the data regarding changes in protein have concentrated on proteins of animal origin, some studies have included protein of non-animal origin.

One such study (89) investigated the effects of various home cooking methods on the proximate composition of four potato varieties (Katahdin, Norchip, Pontiac and Russet Burbank). The methods of preparation included boiled, both peeled and unpeeled for 30 minutes, oven baked at 218^{0} C for 60 minutes and microwave cooked for 30 minutes. No significant changes in protein content were found in Katahdin tubers regardless of cooking method used. With Norchip and Pontiac varieties, there were significant decreases in protein content with boiled, unpeeled potatoes and oven baked treatments. In the Norchip tuber a decrease in protein was shown with microwave application. Cooking methods did not affect protein content of Russet Burbank potatoes except when subjected to microwave, where there was a significant increase in protein constituent. In summary, microwave treatement favored protein retention over the other three methods of preparation investigated.

Legumes are a known source of moderately-high protein. In particular, the nutritive value of soybeans has been observed after various heat treatments. White reported (96) that in 1917 Osborne and Mendel observed that heated soybean was more effective in promoting growth or rats than raw soybean. Thus, they concluded that heating had in some way made the soy protein more readily utilized.

White (96) also reported that Kunitz in 1946 demonstrated the presence of a trypsin inhibitor in raw soybean which apparently interfered with the digestion of the protein and the availability of methionine - the most limiting amino acid in soybean.

In 1971, it was reported that a 30-35% increase in nutritive value of soybeans was observed after radiofrequency dielectric heating for one minute. When beans were raised to a temperature of 137^{0} C, the trypsin and erepsin inhibitors intrinsic to soybeans were inactivated. This increase in availability of soy protein has been validated by animal feeding tests (4).

In a Canadian study (99) the value of processing unextracted, or full fat, soybeans was examined. The optimum heating required to produce beans of good nutritive quality was determined and found to be in the range of two to three minutes of microwave treatment. Legumes processed under 2450 MHz, at 1250 W were then compared with beans processed by boiling for the ability to support rat growth. Microwave-processed beans were found to have higher nutritive value than those processed by conventional heat treatment.

Borchers et al. (19) also reported a rapid improvement in nutritional quality of soybeans treated with microwaves. Raw, air-dried whole soybeans were exposed to microwave treatment and showed full nutritive development in less than two minutes. The nutritive value was assayed by rat feeding tests. The indices of heat treatment of soybeans showed the usual decrease in protein solubility, inactivation of urease and inactivation of trypsin inhibitor activity.

These studies indicated favorable changes in the protein fraction of food exposed to microwave compared with conventional cooking. While no deleterious effects on nutritive value were reported in the literature, susceptibility to heat processing has been observed with protein foods containing significant amounts of carbohydrates. It is generally accepted that interactions between functional groups with the protein chain or between the protein chain and other food constituents during heating lead to cross linkages. These cross linkages are resistant to the normal digestive processes (96).

D. Carbohydrate

An extensive search of the research literature revealed no report on the effects of microwaves on the carbohydrate fraction in foods. However, microwave heating has been shown to affect carbohydrates in the drying of herbage. Carlier and Hee (25) utilized microwave energy to dry lucerne and grass samples; no specific data regarding carbohydrate was cited. Jones and Griffith (53) utilized a slightly modified commercial microwave oven to dry fresh herbage. When compared to conventionally dried samples, the carbohydrate contents of the microwave dried samples were significantly higher.

This represents the only reported data relating to carbohydrate composition in foodstuffs exposed to microwave energy. Much work needs to be done in this area.

E. Lipid Oxidation and Total Fats

Many factors are known to catalyze autoxidation of lipids. Among these are heat, light and ionizing radiation. As microwaves are a lower form of electromagnetic radiation, they might also act as a catalytic agent in autoxidation.

Little research has been directed to the investigation of microwave radiation on lipid composition in foods. The effects of heat treatment, as generated in conventional systems and in microwave ovens, on the degree of lipid oxidation, total fat losses and fatty acid composition have been studied. Any effects of microwaves on the lipid fraction in foods appeared minor.

Only small differences existed in total fat and fatty acid composition, and the literature did not suggest that these differences were microwave induced.

The term autoxidation is used to describe the chemical degradative reactions which cause oxidative rancidity. The rate of autoxidation is enhanced by the presence of prooxidants, such as heat and exposure to UV light. Thiobarbituric acid (TBA) values have been determined to measure lipid oxidation.

Microwave-reheated turkey breast muscle was analyzed using the TBA test to determine the extent of oxidation (21). TBA values were compared with raw, freshly cooked and conventionally reheated turkey breasts. TBA values for all samples were fairly low (1.60 for freshly cooked, 1.54 in microwave reheated, 1.71 for conventionally reheated samples) and did not differ statistically for the three heated samples but were higher than values reported for the raw muscle tissue (0.33). Flavor scores could not be related to TBA values in this study.

In a 1973 study by Penner and Bowers (76) freshly cooked boneless pork loins were compared with conventionally reheated and microwave reheated samples. TBA values, determined as a measure of fat oxidation, differed significantly as seen in Table 5. TBA values were highest for pork exposed the longest total heating time (precooked and conventionally reheated), intermediate for microwave reheated pork, and lowest for freshly cooked loins. The data suggested that those portions of pork exposed to the longest heat treatment had the largest TBA values. Heat, rather than microwave application contributed to the oxidative reactions observed.

TABLE 5

Mean Values of Thiobarbituric Acid (TBA) Numbers of Heated Pork

	Freshly cooked	Conventionally reheated	Microwave reheated
TBA value [b]	3.31	4.97	4.01

[b] mg malonaldehyde/1000 g tissue

Adapted from Penner and Bowers (76).

Fifty g. samples of egg yolk with and without added linoleic acid were cooked (80^o C) by a conventional oven and two microwave ovens (915 MHz, 2450 MHz) in a study by Schiller et al. (83). Lipid changes in cakes baked with these egg yolks were also determined by TBA numbers. Conventionally heated egg yolks showed significantly greater TBA values than those of raw and microwave cooked yolks. Uncooked batter samples showed the lowest TBA values than those raw and microwave cooked yolks. Uncooked batter samples showed the lowest TBA value when compared to other treatments as shown in Table 6; however no significant differences in TBA numbers were reported in compared microwave frequencies. Schiller et al. agreed with an earlier review in 1972 by Rosen (82) which suggested thermal effects of microwaves accounted for these differences.

Fat losses in microwave heated pork patties, roasts and chops were investigated by Apgar et al. (6). All meat was cooked to an internal temperature of 87.8^o C and analyzed. The longissimus dorsi muscle of pork

TABLE 6

Thiobarbituric Acid Numbers for Cakes

Treatment	Heating time	TBA number *
	min.	
Microwave oven, 2,450 MHz	2.75	0.560 bc
Microwave oven, 915 MHz	4.0	0.614 c
Conventional oven, 173°C	22.0	0.497 b
Uncooked sample	--	0.173 a

* Means with different superscripts are significantly ($P < 0.05$) different.

Adapted from Schiller et al. (83).

roasts cooked conventionally had a significant lower fat content than those cooked by microwaves. All pork samples cooked electronically exhibited a slightly higher, but not significant, percentage of total fat and fat retention when compared with conventional oven cooking.

Kylen et al. (62) investigated fat losses in boneless beef rib and pork loin roasts prepared in a gas oven and in an electronic range. Roasts were cooked to approximately the same mean internal temperature. Comparisons of the data obtained on the products cooked by the two methods showed that fat content was approximately the same. In the same study, beef loaves preapred by conventional treatment exhibited a slightly greater percentage total fat loss than those given microwave treatment.

Values for crude fat and cholesterol levels in ground beef patties were determined for three cooking methods by Janicki and Appledorf (50). Cooking procedure affected both the values for crude fat and cholesterol, as seen in Table 7. Broiled and grill fried patties exhibited similar

TABLE 7

Effect of Heating Treatment on Crude Fat and Cholesterol Levels in Beef Patties

	Cooking time	Crude fat (g)	Cholesterol (mg)
Raw		18.1 ± 3.0 a	77 ± 11 a
Broiled	50 sec	10.0 ± 1.0 bc	63 ± 12 b
Grill Frying	4 min	10.5 ± 1.2 b	62 ± 14 b
Microwave	90 sec	8.0 ± 1.0 d	70 ± 17 ab

Values in each column followed by the same letter are not significantly different ($P < 0.05$).

Adapted from Janicki and Appledorf (50).

losses, while microwave cooked beef patties showed larger losses of crude fat. When compared to raw patties decreases in total cholesterol content were observed in all cooking treatments except the microwave. The study suggested a nutritional advantage existed in terms of crude fat losses in patties prepared by microwave heating.

Variation in total fat content between these studies have been attributed to differing procedures, conditions and products used (65). No general statement can be made regarding total fat in microwave versus conventionally prepared food products from the research published to date.

F. Minerals

It has been generally regarded that the mineral composition of foodstuffs is not altered significantly by exposure to radio frequency energy. Limited research data was found concerning specific effects of microwaves on mineral composition.

Beef, pork and lamb roasts cooked conventionally and in two microwave ovens operating at varying voltage (115 V, 22 V) were compared (10). Only one significant difference in mineral content was reported. Sodium content of lamb cooked conventionally was 10% greater than in lamb cooked by the two microwave methods. On a percent retention basis there was a trend toward increased mineral retention in the conventionally cooked meat.

As seen in Table 8, significant differences were shown for phosphorus and iron retention in conventionally prepared beef, and iron retention in pork and lamb cooked conventionally compared to microwave treated foods. Mineral determinations for meat drippings showed significant differences for sodium, chloride, phosphorus and iron content of drippings from oven roasted pork: this trend was evidenced in phosphorus and iron content from beef and lamb drippings as well. Baldwin et al. (10) suggested this greater concentration of minerals in the drippings from the conventionally cooked roasts could be related to the lower moisture content of the drippings.

In a follow-up study, Korschgen and Baldwin (61) found no significant differences in mineral content in round roasts of beef cooked by moist-heat microwave and by conventional oven braising. Sodium and iron contents of

TABLE 8

Mean Mineral Content ($\mu g/g$) and Percent Retention in Roasts Cooked by Microwave and Conventional Methods.

Species and Mineral	Cooked meat			% retention			Drippings		
	Microwave			Microwave			Microwave		
	220V	115V	Conv.	220V	115V	Conv.	220V	115V	Conv.
Beef[b]									
Sodium	398	375	432	68	72	89	1461	1590	2090
Chloride	377	401	339	78	84	87	1426	1178	1616
Phosphorus	2162	2096	2006	75 b	79 b	98 a	4923 b	4738 b	6890 a
Iron	21	20	19	70 b	85 ab	98 a	25 b	24 b	34 a
Pork[c]									
Sodium	396	346	447	68	62	73	1157 b	934 b	2267 a
Chloride	422	387	420	74	68	70	1193 b	870 b	2148 a
Phosphorus	2368	2412	2589	74	70	76	5088 b	3964 b	9042 a
Iron	8	6	9	87	65	100	8 b	9 b	20 a
Lamb[d]									
Sodium	508 b	549 b	658 a	65	64	74	3281	2225	3105
Chloride	583	548	630	64	60	67	2280 b	1182 c	2655 a
Phosphorus	2286	2152	2279	77	78	92	6082ab	5110 b	6888 a
Iron	21	20	24	73 b	79 b	110 a	30 b	20 b	61 a

[a] N=5, except N=4, for drippings of conventional method for lamb and pork. Where letters differ within a mineral for cooked meat or for drippings within a species, means differ significantly ($P < 0.05$).

[b] Raw beef: 379 $\mu g/g$ sodium, 337 $\mu g/g$ chloride, 1889 $\mu g/g$ phosphorus, 19 $\mu g/g$ iron. N=15.

[c] Raw pork: 381 $\mu g/g$ sodium, 378 $\mu g/g$ chloride, 2188 $\mu g/g$ phosphorus, 7 $\mu g/g$ iron. N=15.

[d] Raw lamb: 581 $\mu g/g$ sodium, 618 $\mu g/g$ chloride, 1835 $\mu g/g$ phosphorus, 17 $\mu g/g$ iron. N=15.

From Baldwin et al. (10).

meat cooked by the two methods compared favorably. Potassium retention was found significantly higher in meat cooked by microwaves than in those roasts cooked conventionally.

The softening of vegetables during the cooking process was investigated by Barbiroli et al. (11). Five types of vegetables (carrots, fennel, french cut beans, marrows, asparagus) were analyzed for composition and then cooked by two surface applications, oven heat treatment (165^{o} C) at varying times and temperatures, and in a microwave oven. Analysis following cooking of vegetables revealed a negligible loss of water and minerals regardless of cooking method. The microwave method was suggested superior over the other four heat treatments since less nutrients were lost.

Ash represents the incombustible mineral residue that remains when a substance is incinerated. It serves as a measure of the inorganic salts that were present in the original material (12). Ordinarily, these salts consist chiefly of sodium, potassium, calcium, chloride, magnesium and iron. The literature indicated one study which measured ash content in microwave and conventionally treated food.

Toma et al. (89) studied changes in proximate composition of four potato varieties (Katahdin, Norchip, Pontiac, Russell Burbank) prepared by various home cooking methods. Unpeeled potatoes boiled for 30 minutes did not show a significant change in the ash content, whereas those boiled without the peelings for 30 minutes resulted in significant losses of ash. None of the potato varieties exposed to 30 minutes of microwave power exhibited an alteration in ash content. These findings suggested that microwave cooking enhanced macronutrient retention.

G. Vitamins

a. Fat-soluble

The effects of microwave energy on the retention of vitamins in foods has been widely studied. Data for fat-soluble vitamins are practically non-existent in the literature, although Vitamin A determinations have been made in some studies (1, 54). Aldor reported no significant losses of Vitamin A in microwave cooked or microwave/infrared irradiated meat when compared with conventional cooking values (1). No other data on fat-soluble vitamins was available.

b. Water-soluble

Vitamin B complex (11 compounds) and Vitamin C have been grouped together as the water-soluble vitamins. Virtually no direct relationship exists between these vitamins except they all are water-soluble and most function as coenzymes in metabolic reactions. Deficiency symptoms often develop rapidly without these essential nutrients, thus explaining the interest and study of these vitamins. Of the 10 B-complex vitamins isolated, thiamine, riboflavin, niacin, pyridoxine and folacin have been studied following microwave exposure.

Thiamine. Thiamine is a sulfur-containing substance easily destroyed by heat or oxidation, particularly in the presence of alkali. Since it is water-soluble, it will leach out of a product in proportion to the amount of water available, the extent to which it is agitated and the surface area of the food exposed to water (45). The combined effects of heat, water and rapid boiling in conventional cooking of vegetables suggested that electronic cooking could be less destructive to thiamine. The data from various sources proved inconclusive, as some reports indicated no differences between microwave and conventional heating while other data showed decreased and increased retention with microwaves.

The thiamine content in buffered solutions treated in microwave and conventional ovens was investigated by Van Zante and Johnson (94). A buffered solution of thiamine hydrochloride was prepared using 0.02 M citrate buffer. A pH of 5.7 was selected to represent similar conditions in post-mortem pork. Two concentrations of thiamine hydrochloride (8 mg/l,) 40 mg/l) were exposed to microwaves and conventional oven heating and measured for thiamine retention. Results obtained from microbiologic assay and spectrophotometric analysis indicated thiamine retention was slightly lower as compared to conventional cooking in both concentrations following microwave treatment. The study indicated thiamine retention was significantly different with varying endpoint temperatrues, but no cooking method emerged as superior.

Destruction rate of thiamine hydrochloride in a pH 6.8 phosphate buffer was studied by Goldblith et al.using conventional heat and microwave energy (42). Temperatures were maintained (0, 33, 102.8° C) and percent thiamine determined at 10 minute intervals. Based on their findings, Goldblith et al. (42) concluded that thiamine destruction was solely attributable to effects of accelerated temperatures in both conventional and microwave heating systems.

Meat and meat products represent a good source of dietary thiamine. Thomas et al. (88) cooked beef patties, pork patties and beef roasts to internal temperatures of approximately 73.5° C in a microwave and conventional oven. There was an 11% loss of thiamine in beef patties cooked by microwave and a significant retention of thiamine in the electronically cooked roasts. There was much variability in the data reported, and Thomas et al. suggested prolonged cooking to reach appropriate end temperatures may be responsible for the apparent thiamine lost in microwave heated meat.

A study in 1964 by Kylen et al. (62) investigated thiamine content of raw and cooked beef roasts and loaves and pork roasts and loaves. Mean percentage retentions of thiamine in beef roasts cooked by microwave were significantly lower, as seen in Table 9, while thiamine retentions in pork

TABLE 9

Thiamine Content of Cooked Meat

Products and Methods of Cooking	Mean Thiamine Retention Raw Weight Basis		
	Cooked meat	Drippings	Total
	%	%	%
Beef roasts, Series 1			
Conventional gas oven	80 ± 3.7	2 ± 0.7	81 ± 3.5
Microwave oven	58** ± 2.8	13** ± 0.8	70 ± 3.0
Beef roasts, Series 2			
Conventional electric oven	86 ± 4.8	1* ± 0.4	86 ± 4.8
Microwave oven	67* ± 3.4	14* ± 1.3	80 ± 3.2
Pork Roasts			
Conventional electric oven	61 ± 1.0	19 ± 1.0	80 ± 1.2
Microwave oven	60 ± 1.5	31* ± 3.5	91* ± 3.7
Beef loaves			
Conventional gas oven	76 ± 1.1	---	---
Microwave oven	80 ± 3.0	---	---
Ham loaves			
Conventional gas oven	91 ± 2.7	---	---
Microwave oven	87 ± 2.4	---	---

* Significantly different from the corresponding mean at ($P < 0.05$).

** Significantly different from the corresponding mean at ($P < 0.01$).

Adapted from Kylen <u>et al</u>. (62).

roasts, beef and ham loaves were similar after both microwave and conventional methods of cooking. Thiamine content in all meat drippings was significantly higher after microwave heating.

Pork patties, roasts, and chops were cooked electronically and conventionally (to 88° C), and thiamine was measured by a modification of the Conner and Straub thiochrome method (6). Small differences (0.2 - 0.4 mg/100 gm) were noted as thiamine retention of microwave cooked chops appeared higher, but there were not practically important. Apgar <u>et al</u>. (6) suggested more rapid heat rise in microwave cooking might be responsible for more rapid heat destruction; however, their data showed no greater total destruction of thiamine in microwave than in conventional cooking.

Noble and Gomez (75) compared lamb roast cooked in conventional and microwave ovens. There was no trend for differences in retention of thiamine when cooking methods were compared.

Mean contents (μg/g) and percent retention of thiamine in beef and pork roasts and deboned legs of lamb were studied by Baldwin (10). Thiamine content of beef cooked (70° C) by a 115 V microwave oven was significantly less than that of the conventionally cooked products. Thiamine contents of microwave cooked pork and lamb showed no significant differences in percent retention.

Analysis of thiamine in other studies involving meats (lamb legs and loin chops; beef, top round roasts) reported similar thiamine retention with microwave and conventional heat treatments (52).

Two studies indicated microwave heating to be less destructive to the thiamine content in foods (44, 56). Various precooked and chilled dinners (fried chicken, salisbury steak, beef and chicken pies) showed no losses of thiamine when cooked in a microwave oven after being stored at -30° C, and some slight increases in thiamine values were reported (44).

Kahn and Livingston (56) found microwave reheating of pre-cooked frozen foods provided the highest as compared to what percent retention. Beef stew, chicken a la king, shrimp Newburg and creamed peas prepared by four methods showed highest retention (Table 10) in small batch preparation and with no delay prior to service. While these results were not

TABLE 10

Effect of Heating Method on Thiamine Content of Pre-cooked Frozen Food Products

Heating Method	Thiamine retention (%)
Microwave	93.5
Infra red	90.4
Immersion	86.0
Freshly prepared and held on steam table	
1 hour	78.2
2 hours	73.9
3 hours	67.4

Adapted from Kahn and Livingston (56).

surprising, this study reinforced the general concept that cook-chill systems have nutritional benefits, provided rapid reheating is employed.

In a study by Thomas <u>et al</u>. (88) retention of nutrients in vegetables was dependent upon both cooking time and amount of water utilized. In general, greater losses of water-soluble nutrients occurred through leaching into boiling water, however in microwave cooking, decreased cooking time employed by this method increased nutrient retention. While cooking methods affected thiamine values for broccoli and cabbage, no significant differences in thiamine retention for different cooking methods were observed in carrots or potatoes. Decreased cooking time showed less effect on retention of thiamine than amount of cooking water. Therefore, a pressure-cooking method favored thiamine retention over the other methods employed.

Variability in data prevented any conclusions in a study of baked products by Bender (13). Retention of thiamine ranging from 80 - 100% with microwave treatments was compared with 50 - 90% retention in gas oven baked products. Lorenz (65) suggested that these differences may be related to differing internal end temperatures.

The results of these reported studies indicated that destruction of thiamine in food systems is related to heat, rather than exposure to microwaves.

Riboflavin and Niacin. Riboflavin and niacin are relatively stable vitamins, resistant to the effects of acid, heat and oxidation. Riboflavin is unstable in the presence of alkali and light. As both are slightly soluble in water, some losses may occur from leaching; however, niacin losses are not common in food processing and preparation. Due to the stable nature of these vitamins, the number of research studies reporting riboflavin and niacin retention in microwave cooked foods is significantly less than for thiamine.

Data for riboflavin and niacin retentions in beef and pork patties and beef roasts were given by Thomas et al. (88) There were no appreciable differences in the retention of riboflavin or niacin when beef and pork patties were cooked (79.5° C) by microwaves or on a grill. Riboflavin retention for both methods was approximately 100%. The niacin retention was 90% and 85% in beef and pork patties, respectively. Nutrient retention varied in beef rib roasts. While the retention of riboflavin in the roasts was approximately the same (85%) for both methods, niacin retention was higher in the beef roasts cooked conventionally. Roasts prepared conventionally (73.5° C) retained an average of 81% of the niacin in contrast to microwave roasts which retained 73% niacin. Differences in end internal temperatures and procedures do not permit conclusions on this data.

In another study (75) riboflavin retention in lamb roasts was about the same (80%), in compared microwave and conventional heating methods. A trend in this data correlated with results by Thomas et al. (88).

On a percent retention basis, riboflavin and niacin retention did not significantly differ in beef, pork and lamb cooked conventionally and by microwave. Baldwin et al.(10) reported that these findings (Table 11) were significant, as it suggested vitamin retention was not related solely to length of time exposed to high temperatures. While trends in this study were similar to those reported earlier (75, 82, 88), thiamine and niacin retentions were higher.

In a 1978 study Korschgen and Baldwin (61) indicated no significant differences in niacin retention in beef round roasts cooked conventionally and by microwaves to an internal temperature of 98° C (61). Thiamine and riboflavin retentions were significantly higher in microwave cooked roasts.

TABLE 11

Mean Contents (μg/g) and Percent Retention of Vitamins in Roasts Cooked by Microwave and Conventional Methods

Species and vitamin	Cooked meat[a] Microwave 220 V	Cooked meat[a] Microwave 115 V	Cooked meat[a] Conv	Retention[a] Microwave 220 V	Retention[a] Microwave 115 V	Retention[a] Conv
Beef[b]						
Thiamine	0.89 a	0.74 b	0.92 a	61 a	49 b	69 a
Riboflavin	2.00	1.73	1.79	98 ab	83 b	99 a
Niacin	46.54	43.44	43.94	94 ab	86 b	104 b
Pork[c]						
Thiamine	14.78	14.48	17.51	73	67	72
Riboflavin	2.32	2.52	2.97	81	82	96
Niacin	41.31	59.06	46.01	87 ab	79 b	101 a
Lamb[d]						
Thiamine	1.96	2.10	1.93	52	49	52
Riboflavin	3.78	3.24	4.03	88	73	98
Niacin	44.56	36.67	43.14	71	64	86

[a] N=5. Where letters differ within a vitamin for a species, means differ significantly ($P < 0.05$) from each other (Duncan, 1965).

[b] Raw beef: 1.06 μg/g thiamine, 1.45 μg/g riboflavin, 34.83 μg/g niacin. N = 15.

[c] Raw pork: 14.44 μg/g thiamine, 1.98 μg/g riboflavin, 37.13 μg/g niacin. N = 15.

[d] Raw lamb: 2.61 μg/g thiamine, 2.82 μg/g riboflavin, 37.21 μg/g niacin. N = 15.

Adapted from Baldwin *et al*. (10).

The effect of roasting by conventional and microwave methods of thiamine and riboflavin retention in selected retail meat products (turkey, beef and pork) was studied by McMullen (69). Nutrient retention did not vary significantly with either heat treatment or in the presence of oven film during cooking.

Beef psoas major and longissimus dorsi muscles were compared by Maljutin (66) using microwave and conventional heating. The data reported no significant differences in pH but higher riboflavin and niacin contents in beef cooked by microwaves.

In contrast Bender (12) cited less riboflavin retention (87%) in microwave heated fish compared to that heated conventionally (92%). Incomplete procedures prevent comparison of this research with data of others.

Analysis of riboflavin and niacin in paired legs of lamb resulted in only small and generally insignificant variations when conventional and microwave cooking methods were compared (52).

The contribution of vegetables to the riboflavin and niacin content in the diet is minimal. Therefore, few studies investigated microwave effects on these dietary components. Thomas et al. (88) compared three cooking methods (boiling by surface heat, microwave heating and pressure cooking) and determined their effects on riboflavin retention. Pressure-cooked samples of broccoli, cabbage, carrots and potatoes all yielded high riboflavin retention. Microwave heating yielded medium retentions (ranging from 62% in cabbage to 93% in carrots), while saucepan boiling yielded least riboflavin retention. Importantly, Thomas et al. noted riboflavin retention percentages increased up to 100% of the original amount when cooking water was included in the analyses. Thus, utilization of cooking water recovered those nutrients leached during heating.

Riboflavin retention in a buffered solution heated conventionally and by microwaves was investigated by Van Zante and Johnson (94). Slightly higher values for riboflavin were reported when the buffered solution was heated conventionally; however, the researchers concluded differences were not significant. It was suggested that complete food systems may enhance riboflavin retention more than a buffered solution.

Pyridoxine. This substance is widely distributed in nature, most prevalently in animal tissues. Pyridoxine is relatively stable to heat and acid, but labile to alkali, oxidation and UV light. While it serves numerous functions in the human system, it is seldom a manifested deficiency. In view of this, retention of this vitamin has not been widely studied.

Bowers et al. (22) compared pyridoxine values in turkey breasts cooked (75^{o}, 85^{o} C) by microwaves and a conventional oven. Results indicated that pyridoxine values were significantly higher in those samples cooked by microwaves and evaluated on the basis of cooked weight. No statistical differences were reported in pyridoxine values calculated on the basis of dry weight. Differing pyridoxine values were attributed to differences in moisture content, rather than exposure to microwaves. Conversely, in a later study in 1974 using similar conditions with pork muscle, Bowers et al. (23) reported pyridoxine values were higher on the basis of dry weight and not statistically different when calculated on a cooked weight basis.

Variations in products and temperatures did not permit correlations between these studies.

Microwave cooked chicken breasts showed significantly higher pyridoxine values in a study by Wing and Alexander (98). Internal temperature of microwave processed chicken was 96° C, whereas oven baked breasts were cooked to 88° C. Wing and Alexander suggested time, rather than temperature accounted for the increased values reported for microwave heated chicken. When amounts of pyridoxine retained in the meat and drippings were combined and compared for both cooking methods, retention was 92.5% in microwave heated chicken and 88.4% in conventionally cooked breasts.

While losses of pyridoxine are not normally associated with heating, the findings of these two studies indicated microwave applications do not result in any increased losses.

Folacin. Losses of this water-soluble vitamin in processing and cooking may range as high as 50 to 90% and even 100% when high temperatures and large volumes of water are employed (45). Although folic acid deficiences are not usually attributed to inadequate intake, losses are common in infant foods and some reheated pre-cooked foods.

A study by Klein and Van Duyne (59) investigated folacin retention in frozen spinach and peas cooked by microwave and conventional cooking. Total folacin content and retention were determined by microbiological assays using *Streptococcus faecalis* and *Lactobacillus casei*. Differences due to cooking methods were not significant, as retention reported was about 80%. Microwave cooking did not appear more destructive to folacin than conventional methods.

Ascorbic Acid. Chemically, ascorbic acid is a simple 6-carbon compound closely related to the monosaccharides. While ascorbic acid can exist in a natural or synthetic form, it is found almost exclusively in foods of plant origin. It is therefore, not surprising that most of the research data regarding ascorbic acid retention was found in studies with vegetables and citrus fruits.

There are many factors affecting ascorbic acid content in foods. It is generally regarded that ascorbic acid is stable to acid but easily destroyed by oxidation, alkali and heat. Therefore, any method of food processing or cooking that involves the application of heat is likely to result in a reduced ascorbic acid content. While many of the best sources of ascorbic acid are consumed raw, interest still has been generated to trace the fate of this water soluble vitamin in heat treated foods.

Electronic cooking of vegetables has yielded some favorable data on ascorbic acid content when compared to conventionally prepared vegetables. Several studies (8, 24, 43) have reported higher retentions of ascorbic acid in vegetables prepared by dielectric heat. In contrast, studies by Kylen et al. (63), Eddy et al. (33), Eheart and Gott (36), Thomas et al. (88) and Stevens and Fenton (86) reported no significant differences in microwave treated foods while Ang et al. (2) indicated less ascorbic acid retention after microwave heating.

Campbell et al. (24) estimated reduced and total ascorbic acid in four vegetables (fresh cabbage, fresh and frozen broccoli, frozen peas), uncooked and after cooking by conventional and microwave heating. Fresh and frozen broccoli retained more ascorbic acid after microwave treatment. Later work by Gordon and Noble (43) confirmed these findings. Trials by Campbell et al. (24) showed that for microwave cooked foods, ice presented insuperable problems as solidly frozen vegetables required additional time for defrosting and cooking. Microwave heating gave much higher ascorbic acid values when partially defrosted foods were utilized. Eddy et al. (34) suggested that deep frozen foods be thawed in a refrigerator for four hours at 0 - 4^{o} C prior to microwave exposure for best results. Waterless cooking of peas by microwave heating showed excellent retention of ascorbic acid. This indicated the use of little or no water in microwave ovens feasible and desirable in terms of nutrient retention. This supported findings by Peppler and Cremer (77) that less cooking water used with peas, beans and cabbage yielded higher ascorbic acid retention with electronic cooking.

In experiments carried out by Potacel (79), losses of ascorbic acid in potatoes cooked conventionally and by microwave heating were 24% and 6%, respectively; and for cooked cabbage, they were 63% and 55%, respectively. These data all suggested the use of microwave ovens enhanced the retention of this water soluble vitamin.

Perhaps the most complete and convincing data was presented in a comparative study by Armbruster (8). Comparisons were made of the ascorbic acid content of fruits and vegetables after microwave, conventional and convenient cooking methods were used. In 75% of the instances studies, the ascorbic acid content of the microwave cooked product was significantly higher than that observed after the conventional and convenient methods were used. Microwave cooking methods also yielded shorter cooking times in every instance except for one. This reduced cooking time, coupled with less cooking water required in a microwave heating resulted in less ascorbic acid destruction. These data are reported in Table 12.

TABLE 12

Mean Reduced Ascorbic Acid Content of Fruits and Vegetables After Cooking by Microwave, Conventional and Convenient Methods

		Mean Reduced Ascorbic Acid in mg/100 g			
Food Item	Market Form	Microwave	Conventional Boil	Conventional Bake	Convenient Conventional
FRUITS					
Apple	Fresh	16.6	--	6.7	--
Cranberry	Fresh	15.2	15.7	--	17.2
Grapefruit	Fresh	43.4	--	38.0	--
VEGETABLES					
Asparagus	Fresh	20.0	17.5	--	--
	Frozen	26.0	22.4	--	--
Broccoli	Fresh	116.6	73.2	--	77.8
	Frozen	85.6	72.9	--	69.5
Brussel sprouts	Fresh	86.5	73.5	--	--
	Frozen	59.6	55.8	--	56.0
Cabbage	Fresh	43.2	24.5	--	20.0
Cauliflower	Fresh	84.6	48.2	--	--
	Frozen	68.3	48.0	--	--
Green beans	Fresh	5.7	4.9	--	--
Kale	Fresh	81.5	58.2	--	--
Parsnips	Fresh	14.1	6.9	--	--
Pepper, bell	Fresh	109.4	--	98.0	--
Spinach	Fresh	23.9	15.0	--	--
	Frozen	16.1	8.9	--	--
Squash	Frozen	7.0	--	6.3	--
Tomato	Fresh	22.3	--	23.3	--
Turnips	Fresh	25.9	14.2	--	16.6
THERMATRONIC II					
Asparagus	Fresh	17.2	14.4	--	--
Cabbage	Fresh	51.6	35.6	--	41.4
Cauliflower	Fresh	86.6	60.1	--	58.0

Adapted from Armbruster (8).

No statistically significant differences in the retention of ascorbic acid in vegetables cooked by a conventional and microwave method were found by Kylen et al. (63). Data shown in Table 13 indicated frozen vegetables

TABLE 13

Ascorbic Acid Retention in Fresh and Frozen Vegetables after Cooking in a Conventional and Microwave Oven

Vegetable	Cooking Method	% Ascorbic acid retention: Fresh vegetable – Vegetable	Fresh vegetable – Water	Frozen vegetable – Vegetable	Frozen vegetable – Water
Broccoli	C	83	10	48	12
	M	79	11	52	9
Peas	C	73	23	--	--
	M	74	16**	--	--
Cabbage	C	69	14	--	--
	M	72	11**	--	--
Cauliflower	C	92	7	--	--
	M	87	6	--	--
Green beans	C	74	9	38	8
	M	78	7*	38	8
Spinach	C	61	5	22	10
	M	56	9	26	5

* Mean percent retention significant at ($P < 0.05$)

** Mean percent retention significant at ($P < 0.01$)

Adapted from Kylen et al. (63)

retained less ascorbic acid than fresh samples of the same vegetables. However, cooking water of fresh peas, cabbage and green beans retained significantly less ascorbic acid: mean percent retention values of only 16%, 11% and 7%, respectively. These data, when compared to those of other investigations, indicated amount of cooking water and cooking time seem to play a more significant role in ascorbic acid retention than cooking methods.

Eheart and Gott (36) found no significant differences in ascorbic acid retention in peas, spinach, broccoli and potatoes cooked with and without boiling water by microwave and by conventional methods. Ascorbic acid retention was the same with or without water for oven cooking and not significantly different from that resulting from boiling or oven cooking with the same amount of water. This study disagreed with the earlier findings by Campbell et al. (24) which suggested waterless cooking improved ascorbic acid retention.

Spinach and brussel sprouts, cooked, frozen and kept at -18° C retained 63 - 71% of the ascorbic acid of the uncooked vegetables in a study by Eddy et al. (33). Reheating by microwave resulted in a 20% further loss of the nutrient. These results compared favorably with losses incurred in domestic cooking. In a follow-up study (34) ascorbic acid content was determined in cabbage, spinach and peeled potatoes. Again retention was similar to that with conventional ovens, but more variable.

Values for ascorbic acid were determined by Thomas et al. (88) in vegetables prepared by boiling, pressure cooking and microwave heating. Significant amounts of ascorbic acid were extracted in both the boiling and microwave methods of cooking. These authors attributed this decrease in ascorbic acid content to the combined effects of leaching and heat destruction.

A recent study by Bowman et al. (20) indicated vegetables cooked by microwave and countertop heating methods did not differ significantly in amounts of reduced ascorbic acid. A slight increase in these values was observed in microwave cooked vegetables and in addition, ascorbic acid leached into the cooking liquid was less than in conventional cookery. These differences however, were not statistically significant.

Research completed by Causey and Fenton (26) and Stevens and Fenton (86) provided no significant differences in ascorbic acid retention between microwave and conventional cooking.

Six products were analyzed for ascorbic acid content before and after treatments simulating institutional handling and rapid reheating (microwave and pressure steam heating) methods (2). Losses of ascorbic acid occurred in products held at 82^{o} C, under high steam and was greatest in those microwave reheated frozen foods. Microwave heating was preferred over fresh preparation and institutional holding for three hours, however, was considered inferior in ascorbic acid retention to the high pressure steam heating (2).

Blanching of vegetables prior to freezing is necessary to destroy certain enzymes that otherwise would catalyze the destruction of ascorbic acid. In home-frozen vegetables the ascorbic acid content is likely to be less than that in commercially frozen vegetables that have been harvested at peak maturity and processed immediately. Microwave blanching resulted in enhanced ascorbic acid retention in a study by Eheart (35). Broccoli blanched in a microwave oven contained 79.2 mg of ascorbic acid, while that blanched at 100 or 77° C yielded only 60.8 and 55.6 mg per 100 g, respectively. This study suggested that microwave blanching could be successfully implemented in home processing to yield comparable ascorbic acid values found in commercially blanched foods.

A non-conventional method of sterilizing glass containers of orange segments was investigated by Lin and Li (64) using microwave energy. Conventional water bath processing to 87° C was compared to microwave exposure for 130, 140 and 150 seconds. End temperatures were regulated in the two procedures as closely as possible. The data showed microwave exposure for 140 seconds was not only sufficient in attaining the necessary temperature for sterilization but also yielded better ascorbic acid retention than conventional sterilization.

From the results of the studies cited here, it can be concluded that no appreciable losses in ascorbic acid are derived from microwave heating when compared to conventional heating methods. However, any increased retention of ascorbic acid in microwave cooked foods cannot be attributed entirely to the dielectric heating. A combination of factors including ratio of water to vegetable, cooking length and variability of cooking loads may account for the varying data reported.

3. SUMMARY AND CONCLUSIONS

A. Problems with Microwave Data

While an abundance of promotional literature exists in support of the microwave oven, research studies involving microwave energy in cooking processes have yielded limited data. Studies prior to 1970 showed widely variable data, but generally indicated microwave heating of foods was less harmful to nutrients than conventional methods. Early studies reported marked moisture losses and undesirable flavor changes in microwave treated food systems. It is significant to note these studies were conducted using relatively small quantities of foods and with incomplete understanding of microwave cooking. Other failures may be related to the technical differences in early microwave ovens. Changes in oven magnetrons and cavity/feed/stirrer design have shown improvement in reliability and consequently cooking performances.

Research procedures have not been uniform or well standardized for use in different research laboratories. Many studies failed to include temperature measurements, considered one of the few tools for comparison in microwave versus conventionally treated products. These failures were due more to the inavailability of oven-proof thermometers than to oversight by researchers. Currently thermometers made of polysulfone have been introduced for microwave usage and may provide more accurate temperature readings. Temperature showed the highest variability in studies; however, size of cooking load, sample number, length of cooking and ratio of water to product accounted for varying data. Marked differences existing in products and purchase lots of raw food were factors cited in only a few studies (8). Many of the reports did not present data on a dry weight basis of foods, thus making comparisons difficult.

A great deal of the microwave research findings have been published in a variety of non-research oriented publications. Many of these sources (newsletters, trade journals, promotional literature) were not widely circulated or placed in research libraries. Consequently data were difficult to obtain and often impossible to review. No doubt private studies by manufacturers have yielded data that have not been released for public information. As is frequently the case with new techniques and innovations, microwaves, too, have been given remarkable properties and effects by those promoting this new technology (65). Any results from these private studies implying deleterious effects of microwaves to nutrients may remain unpublished.

B. Conclusions

1. Microwave ovens have been proven to be safe when properly used by the consumer. In 1968 the Radiation Control for Health and Safety Act passed by Congress established radiation standards for public protection (5). Under these standards, radiation leakage from microwave ovens cannot exceed one milliwatt per square centimeter (mW/cm^2) measured two inches from the oven prior to factory release, and five (mW/cm^2) thereafter (5). Concern has been raised over potential dangers from door leakage. Incidents

reporting harmful radiation exposure to humans have been isolated and poorly documented (57, 71) but have justified modification of safety-seal door design (68).

2. Microwave energy represents a good method of modern cookery, especially when considering the efficiency of operation, energy savings and reduced cooking time. Current microwave oven sales are indicative of consumer demand and the growing popularity of microwave cooking.

3. While microwave cooking is not totally understood, the industry and the consumer alike are experimenting with its use. Due to modifications and improvements in oven design, current microwave ovens are more reliable. These modifications have led to a better final product.

4. No significant nutritional differences exist between foods prepared by conventional and microwave methods. Any differences reported in the literature are minimal.

5. The microwave oven has a bright future and numerous applications. Efforts to develop devices and techniques for commercial application have been initiated (100). Industrial and domestic microwave usage can no longer be sharply separated. The microwave industry has maximized the growing popularity and interest in microwave cooking and allowed new ideas to cross the once-rigid technical boundaries.

C. RECOMMENDATIONS

The future success of the microwave oven depands upon the continued improvement of oven engineering and research advances in areas of food technology, packaging and consumer marketing. An industrial effort should be made to educate consumers by providing more detailed cooking instructions on packages, standardizing basic recipes and improving methods for cooking complete meals.

Further research on microwave effects on nutrients is needed, with research emphasis on moisture, protein, carbohydrate and water soluble vitamin retention. A concerted effort in standardizing experimental procedures by microwave researchers would be highly desirable to minimize variability.

BIBLIOGRAPHY

1. Aldor, T. 1964. The behavior of foods in the high frequency range. Nutr. Abstr. 34:

2. Ang, C.Y.W., C.M. Change and G.E. Livingston. 1975. Effects of heating methods on vitamin retention in six fresh or frozen prepared food products. J. Food Sci. 40:997-1003.

3. Annis, P.J. 1980. Design and use of domestic microwave ovens. J. Food Prot. 43:629-632.

4. Anonymous. 1971. Quick-cooked soybeans. Agricultural Research 19:16-17.

5. Anonymous. 1974. The abc's of microwave cooking. Microwave Energy Applications Newsletter, Amherst, NH, 1:26.

6. Apgar, J., I. Downey and F. Fenton. 1959. Cooking pork electronically. J. Am. Dietet. Assoc. 35:1260-1269.

7. Aref, M.M., J.G. Noel and H. Miller. 1972. Inactivation of α-amylase in wheat flour with microwaves. J. Microwave Power 7:215-221.

8. Armbruster, F. 1978. Comparison of reduced ascorbic acid content of microwave and conventional cooked fruits and vegetables final report. Thermador/Waste King pamphlet, MHS-1.

9. Baldwin, R.E. and J.E. Tettambel. 1974. Nitrogen content of rib eye steaks heated by microwaves and a conventional method. Microwave Energy Applications Newsletter, Amherst, NH, 7:3.

10. Baldwin, R.E., B.M. Korschgen, M.S. Russell and L. Mabesa. 1976. Proximate analysis, free amino acids, vitamin and mineral content of microwave cooked meat. J. Food Sci. 41:762-765.

11. Barbiroli, G., M.A. Garutti and P. Mazzaracchio. 1972. Causes and effects of softening of vegetable products after different methods of cooking. Rassenga Chimica 24:361-366.

12. Bender, A.E. 1960. Dictionary of Nutrition and Food Technology, Butterworth Publications LTD, London, 1960:12, 83.

13. Bender, A.E. 1960. Nutritive effects of food processing. Rev. Nutr. Food Sci. 13:6.

14. Bengtsson, N. 1963. Electronic defrosting of meat and fish at 915 and 2450 MHz - a laboratory comparison. Food Technol. 17:97-100.

15. Berger, L.R. 1958. An experiment in the electronic cookery of meat, Food News and Views (Swift and Co.), Bulletin No. 147.

16. Bezanson, A., R. Learson, and W. Teich. 1973. Defrosting shrimp with microwaves. Microwave Energy Applications Newsletter 6:3.

17. Bodwell, C.E. and M. Womack. 1978. Effects of heating methods on protein nutritional value of 5 fresh or frozen prepared food products. J. Food Sci. 43:1543-1549.

18. Bollman, M.C. 1948. Applications of electronic cooking to large scale feeding. J. Am. Dietet. Assoc. 24:1041-1048.

19. Borchers, R., L.D. Manage, S.O. Nelson, and L.E. Stetson. 1972. Rapid improvements in nutritional quality of soybeans by dielectric heating. J. Food Sci. 37:333-334.

20. Bowman, F., E.P. Berg, A.L. Chuang, M.W. Gunther, D.C. Trump and K. Lorenz. 1975. Vegetables cooked by microwave versus conventional methods. Retention of reduced ascorbic acid and chlorophylls. Microwave Energy Applications Newsletter 8:3.

21. Bowers, J.A. 1972. Eating quality, sulfhydryl content and TBA values of turkey breast muscle. J. Agr. Food Chem. 20:706-708.

22. Bowers, J.A., B.A. Fryer and P. Engler. 1974. Vitamin B_6 in turkey breast muscles cooked in microwave and conventional ovens. Poultry Sci. 53:844.

23. Bowers, J.A., B.A. Fryer and P. Engler. 1974. Vitamin B_6 in pork muscle cooked in microwave and conventional ovens. J. Food Sci. 39: 426.

24. Campbell, C.L., T.Y. Lin and B.E. Proctor. 1958. Microwaves versus conventional cooking. I. Reduced and total ascorbic acid in vegetables. J. Am. Dietet. Assoc. 34:

25. Carlier, L.A. and L.P. van Hee. 1971. Microwave drying of lucerne and grass samples. Nutr. Abstr. 42:74.

26. Causey, K. and F. Fenton. 1951. Effect of reheating on palatability, nutritive value and bacterial count of frozen cooked foods. J. Am. Dietet. Assoc. 27:390-395.

27. Cathcart, W.H. 1946. Frozen foods defrosted by electronic heat. Food Ind. 18:1524-1525.

28. Copson, D.A. 1975. Microwave Heating. 2nd ed. AVI Publishing Co., Westport, Connecticut. 1975:374-377.

29. Copson, D.A., B.R. Neumann and A.L. Brody. 1955. High frequency cooking, browning methods in microwave cooking. J. Agr. Food Chem. 3:424-427.

30. Decareau, R.V. 1964. Microwave defrosting and heating. Cornell Hotel Rest. Adm. Quart. 5:76-78.

31. Decareau, R.V. 1979. Microwaves and nutrition. The Professional Nutritionist 11:9-10.

32. Dietrich, W.C., C.C. Huxsoll, and D.G. Guadagni. 1970. Comparison of microwave, conventional and combination blanching of brussell sprouts for frozen storage. Food Technol. 24:613-617.

33. Eddy, T.P., A.L. Nicholson, and E.T. Wheeler. 1968. Pre-cooked frozen foods: the effects of heating on vitamin C. Nutrition 22: 122-128.

34. Eddy, T.P., A.L. Nicholson, and E.T. Wheeler. 1969. Pre-cooked frozen foods: the use of microwave ovens. Nutrition 23:14-22.

35. Eheart, M.S. 1967. Effect of microwave versus water blanching on nutrients in broccoli. Chlorophylls, ascorbic acid, pH and total acids. J. Am. Dietet. Assoc. 50:207.

36. Eheart, M.S. and C. Gott. 1964. Conventional and microwave cooking of vegetables. J. Am. Dietet. Assoc. 44:116-119.

37. Evans, E., S.C. Carruthers and R. Witty. 1980. Effects of cooking methods on the protein quality of meats as determined using a Tetrahymena pyriformis W growth assay. J. Food Sci. 44:1678-1680.

38. Federal Communications Commission, Part 18, Jan. 1964.

39. Fung, D.Y.C. and F.E. Cunningham. 1980. Effects of microwaves on microorganisms in foods. J. Food Prot. 43:547-550.

40. Goldblith, S.A. 1966. Applications of microwaves in food processing. Microwave J. 1966:120.

41. Goldblith, S.A. 1966. Basic principles of microwaves and recent developments. Adv. Food Res. 15:277-301.

42. Goldblith, S.A., S.R. Tannebaum and D.I.C. Wang. 1968. Thermal and 2450 MHz microwave energy effect on the destruction of thiamine. Food Technol. 22:1266.

43. Gordon, J. and I. Noble. 1959. Effects of blanching, freezing, freezing-storage and cooking on ascorbic acid retention of vegetables. J. Home Econ. 51:867.

44. Graham, D.C. 1977. The nutritional quality of frozen convenient foods. Unpublished research, Cornell University, Ithaca, New York.

45. Guthrie, H.A. 1975. Introductory Nutrition. 3rd ed., C.V. Mosby Co., St. Louis, Missouri.

46. Hancock, D.A. 1973. Planning the change to convenience foods for a hospital. J. Am. Dietet. Assoc. 63:418-422.

47. Harrison, D.L. 1980. Microwave versus conventional cooking methods; effects on food quality attributes. J. Food Prot. 43:633-637.

48. Headley, M.E. and M. Jacobson. 1960. Electronic and conventional cookery of lamb roasts. Cooking losses and palatability. J. Am. Dietet. Assoc. 36:337.

49. Heisig, C.G. and K.A. Kobe. 1958. Selective melting of frozen solutions with radio-frequency power. Ind. Eng. Chem. 50:1517-1524.

50. Janicki, L.J. and H. Appledorf. 1974. Effect of broiling, grill frying and microwave cooking on moisture, some lipid components and total fatty acids of ground beef. J. Food Sci. 39:715-717.

51. Jason, A.C. and H.R. Sanders. 1962. Dielectric thawing of fish. Food Technol. 16:101.

52. Johnson, W.A., L. Guild, and D. Deethardt. 1976. Chemical composition, nutritional value, palatability and consumer acceptance of lamb meat. FSTA Computer Search, File 51.

53. Jones, D.I.H. and G. Griffith. 1969. Microwave drying of herbage. Nutr. Abstr. 39:369.

54. Joseph, R.V. 1976. Vitamin A retention in time-temperature tolerance and heat treated frozen convenience meals. Unpublished M.S. thesis, Cornell University, Ithaca, New York.

55. Kadaner, J., S.V. Pantjuhina, and E.I. Elovoj. 1968. Susceptibility of meat and fish proteins to proteolytic enzyme attack in vitro after ultra-high frequency heating. Nutr. Abstr. 39:741.

56. Kahn, L.N. and G.E. Livingston. 1970. Effect of heating methods on thiamine retention in fresh and frozen prepared foods. J. Food Sci. 35:349-351.

57. Kalafat, S.R. and M. Korger. 1973. Microwave heating of food - use and safety considerations. CRC Crit. Rev. Food Technol. 4:141-151.

58. Keefe, R.T. and S.A. Goldblith. 1973. Hospital feeding via microwave kitchenettes - a cost analysis. Food Technol. 27:16.

59. Klein B.P. And F.O. Van Duyne. 1979. Effects of food preparation practices on nutrient content and food quality. FSTA Computer Search, File 51.

60. Kierebinski, C. 1968. Cutting resistance and changes in collagen of meat after microwave or conventional heating. Przem. Spozyw. 22:301.

61. Korschgen, B.M. and R.E. Baldwin. 1978. Moist heat microwave and conventional cooking of round roasts of beef. J. Microwave Power 13:257-262.

62. Kylen, A.M., B.H. McGrath, E.L. Hallmark, and F.O. Van Duyne. 1964. Microwave and conventional cooking of meat. J. Am. Dietet. Assoc. 39:139-145.

63. Kylen, A.M., V.R. Charles, B.H. McGrath, J.M. West and F.O. Van Duyne. 1961. Microwave cooking of vegetables. J. Am. Dietet. Assoc. 39:321.

64. Lin, C.C. and Li, C.F. 1971. Microwave sterilization of oranges in glass-pack. J. Microwave Power 6:45.

65. Lorenz, K. 1976. Microwave heating of foods - changes in nutrient and chemical composition. CRC Crit. Rev. in Food Sci. and Nutr. 2:339-366.

66. Maljutin, A.F. 1968. Changes in some indices of the nutritive value of meat after ultra-frequency cooking. Vopr. Pitan. 27:79.

67. Marshall, N. 1960. Electronic cookery of top round of beef. J. Home Econ. 52:31.

68. McConnell, D.R. 1975. The consumer microwave oven. Microwave J. 18:37-40.

69. McMullen, E.A. 1974. A comparison of the weight loss, tenderness and nutrient retention of selected microwave products cooked uncovered and in oven film. Dissert. Abstr. Intl. 35:1979.

70. Moore, L.J., A.D. Dayton and D.L. Harrison. 1980. Differences among top round steaks cooked by dry or moist heat in a conventional or a microwave oven. J. Food Sci. 45:777.

71. Morgan, K.Z., and J.E. Turner. 1967. Principles of Radiation Protection. John Wiley and Sons, Inc., New York.

72. Morse, P.W., and H.E. Revercomb. 1947. U.H.F. heating of frozen foods. Electronics 20:85-89.

73. Murray, R.L. 1975. Nuclear Energy: an introduction to the concepts, systems and applications of nuclear processes. Pergamon Press, Inc., New York.

74. Napleton, L. 1967. A Guide to Microwave Catering. Northwood Publ., Ltd., London.

75. Noble, T. and L. Gomez. 1962. Vitamin retention in meat cooked electronically. J. Am. Dietet. Assoc. 41:217.

76. Penner, K.K. and J. A. Bowers. 1973. Flavor and chemical characteristics of conventionally and microwave reheated pork. J. Food Sci. 38:553-555.

77. Peppler, E. and H.D. Cremer. 1960. Retention of vitamins B1 and C during high frequency cooking of vegetables. Nutr. Abstr. 31:469.

78. Pinkert, M.S. 1973. The Ready Foods System for Health Care Facilities. Inst. Vol. Feeding Mag., Chicago, Illinois. 1973:1-6.

79. Potacel, J. 1978. Effect of microwave heating of food quality. Vyziva Lidu. 33:18-19.

80. Proctor, B.E. and S.A. Goldblith. 1948. Radar energy for rapid food cooking and blanching and its effect on vitamin content. Food Technol. 2:95-104.

81. Roberts, P.C.B. and R.A. Lawrie. 1974. Effects on bovine l. dorsi muscles of conventional and microwave heating. J. Food Technol. 9:345.

82. Rosen, C.G. 1972. Effects of microwaves on food and related material. Food Technol. 26:36-55.

83. Schiller, E.A., D.E. Pratt, and E. Reber. 1973. Lipid changes in egg yolks and cakes baked in microwave ovens. J. Am. Dietet. Assoc. 62:529-533.

84. Seiler, K. 1978. High-frequency baking - present aspects. Intl. Rev. for Sugar and Conf. 31:109-113.

85. Smith, L.L.W. 1963. Progress abroad in microwave cooking. Cornell Hotel and Rest. Adm. Quart. 4:75-78.

86. Stevens, H.B. and F. Fenton. 1951. Dielectric versus stewpan cookery. Comparison of palatability and vitamin retention in frozen peas. J. An. Dietet. Assoc. 27:32

87. Thielen, L.R. 1980. The first thirty years. Microwave J. 23:14-16.

88. Thomas, M.H., S. Brenner, A. Eaton and V. Craig. 1949. Effect of electronic cooking on nutritive value of foods. J. Am. Dietet. Assoc. 25:39-44.

89. Toma, R.B., J. Augustin, P.H. Orr, R.H. True, J.M. Hogan and R.L. Shaw. 1978. Changes in nutrient composition of potatoes during home preparation. I. Proximate composition. Amer. Potato J. 55:639-645.

90. Traub, L. 1979. Microwave ovens: who's using them and why. Natl. Food Rev. Winter 1979:24-25.

91. Tsen, C.C. 1980. Microwave energy for bread baking and its effect on the nutritive value of bread: A review. J. Food Prot. 43:638-640.

92. Van Zante, H.J. 1968. Some effects of microwave cooking power upon certain basic food components. Microwave Energy Applications Newsletter 1:3.

93. Van Zante, H.J. 1973. The Microwave Oven. Houghton Mifflin Co., Boston, Massachusetts. 1973:50, 139-143.

94. Van Zante, H.J. and S.K. Johnson. 1970. Effect of electronic cookery on thiamine and riboflavin in buffered solutions. J. Am. Dietet. Assoc. 56:133.

95. West, B.B., L. Wood, V. Harger and G. Shugart. 1977. Food Service in Institutions. 5th ed. John Wiley & Sons, Inc., New York. 1977: 308-316.

96. White, P.L. and D.C. Fletcher. 1974. American Medical Association Nutrients in Processed Foods - Proteins. Publishing Sciences Group, Inc., Acton, Massachusetts. 1974:140.

97. Wilson, P. 1976. Household Equipment: Selection and Management, Houghton Mifflin Co. 1976:133-143.

98. Wing, R.W. and J.C. Alexander. 1972. Effect of microwave heating on vitamin B_6 retention in chicken. J. Am. Dietet. Assoc. 61;661.

99. Wing, R.W. and J.C. Alexander. 1975. The value of microwave radiations in the processing of full-fat soybeans. Canadian Inst. Food Sci. and Tech. J. 8:16-18.

100. Wyslouzil, W. 1975. Commercial Applications of Microwave Energy: the Canadian effort. Microwave J. 5:51-54.

101. Ziprin, Y.A. and A.F. Carlin. 1976. Microwave and conventional cooking in relation to quality and nutrient value of beef and beef-soy loaves. J. Food Sci. 44:4-8.

The Effect of Microwaves on Nutrient Value of Foods

by

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Microwaves are non-ionizing radiations with frequencies between 300 and 300,000 MHz. The Federal Communications Commission has designated 915 $\pm$ 25 MHz, 2450 $\pm$ 50 MHz, 5800 $\pm$ 75 MHz and 22,125 $\pm$ 125 MHz for industrial, scientific and medical applications. Two frequencies, 2450 MHz and 915 MHz, have been allocated for microwave cooking appliances, however the 915 MHz wavelength is utilized by only one manufacturer.

When food or other cellular substances are placed in a microwave field they heat due to absorbed energy from the microwaves. Heat is generated within the food by friction resulting from asymmetric dielectric molecular vibrations occurring at 915 or 2,450 million times/second. Heating rate is influenced by the degree of lossiness, temperature and mass of the food.

The method of heating and cooking, duration and delay prior to serving all affect the nutrition inherent in foods. While nutritional labeling on food containers has increased awareness of food values, these data do not and cannot reveal the nutritional value of the food as consumed. The development of the microwave oven for domestic use initiated numerous studies on nutrient retention of foods prepared by microwave heating.

While it is difficult to compare heating times and temperatures between conventional and microwave treatments, nearly every study reported higher moisture losses under microwave cooking. Effects of cooking methods on moisture content was studied almost exclusively in meat products, and reported increased dripping losses, dehydration and shrinking. Studies designed to compare water content of vegetables before or after microwave cooking yielded little significant data.

Many research studies investigated changes in meat, however very few investigated protein changes. Microwave heated beef retained more nitrogen than beef conventionally cooked. Studies involving pork found no significant changes in protein fractions. Limited research has been reported on vegetable and seed proteins. Trypsin inhibitors present in soybeans were inactivated after brief microwave exposure. Microwave processing yielded beans of high nutritive value which compared favorably to beans conventionally processed.

The effects of heat treatment on fat losses, fatty acid composition and degree of lipid oxidation have been studied. Any effects of microwaves on the lipid fraction in foods appeared minor.

Mineral composition following microwave treatment has been determined. It is generally regarded that minerals in foods are not altered by microwave treatment.

The water soluble B-complex vitamins, riboflavin, niacin, and particularly thiamine, have been studied in foods treated with microwaves to determine any favorable nutrient retention. Heat labile ascorbic acid measured in studies was significantly higher in microwave treated foods than those conventionally prepared. Studies indicated higher retention of all water soluble vitamins, but this was attributed to a combination of factors including microwave exposure. Results have indicated that microwave energy in blanching, cooking and baking may result in vitamin conservation.

Research data which consider the effects of microwaves on the carbohydrate or fat soluble vitamin content in foods during food preparation are non-existent. An investigation of the possible changes in these fractions would make worthwhile research projects.

Microwave energy represents a good, safe method of modern cooking, especially when considering the efficiency of operation, energy savings and reduced cooking time. While microwave cooking is not totally understood, the industry and consumer both are experimenting with its use, reporting favorable results.

Following a search of the literature, no significant nutritional differences exist between foods prepared by conventional and microwave methods. Any reported differences are minimal.

Despite problems in locating and interpreting microwave data, studies indicate that the microwave oven has a bright future and numerous applications.