S6P15.WP

EFFECTS OF MICROWAVE HEATING ON SURVIVAL OF MICROORGANISMS IN HAMBURGERS

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INTRODUCTION

The microbiological safety of microwave-heated foods is still an issue requiring discussion. Microwaves, electromagnetic waves with a frequency of 915 or 2450MHz, are generated by magnetron of a microwave oven. The electromagnetic field excites polar molecules. The mutual friction between those molecules generates heat, not only at the surface, but also inside the material being exposed to microwaves. With microwave heating the heat penetrates 10 to 20 times faster than conventional heating. The heat is generated unevenly because of the heterogeneous dielectric properties of the material, some spots being well heated while others remain relatively cool (Co and Livingston, 1969; Copson, 1962; Rosenberg and Bogl, 1987). These cold spots must be warmed by transmitted heat. It is the task of all microwave oven producers to assure that the heating of all foodstuffs is as uniform as possible, with minimal numbers of hot and cold spots. The differences in temperature after short periods of microwave heating can be reduced but cannot, at present, be totally avoided.

The temperatures of the coolest spots are of greatest importance for the hygiene safety of heat-treated foods. To determine the destruction of microorganisms in foodstuffs, only these critical points need be checked. With conventional heating, these critical points are at the greatest distance from the source of heat and they are usually situated in the middle of the product, or at the point that is best protected against heat transition. With microwave heating, the heat is not generated at and transmitted from the surface but is generated at and transmitted from heat nuclei inside the material being exposed to microwaves. Cold spots, the critical hygienic points, are then located quite irregularly and it is likely that whatever size thermometers are used these points will not be detected. Many authors who studied the destruction effects of the microwave heating on microorganisms (Aleixo *et al.*, 1985, Bengtsson *et al.*, 1970, Caroll and Lopez, 1969, Craven and Lillard, 1974, Cunningham, 1977, Cunningham, 1980, Deibel, 1986, Dreyfuss and Chipley, 1980, Goldblith and Wang, 1967, Fruin and Guthertz, 1982, Chen *et al.*, 1973, Knutson *et al.*, 1988, Khalil and Villota, 1988, Lechowich *et al.*, 1969, Ollinger-Snyder and Matthews, 1988, Spite, 1984, Teotia and Miller, 1975, Tsaka *et al.*, 1989, Wright-Rudolph *et al.*, 1986) or parasites (Carlin *et al.*, 1982, Zimmermann, 1983) measured the temperature using mercury or digital thermometers. Glass probes have also been used (Rosenberg and Sinell, 1989). Those workers found a correlation between decreasing numbers of surviving microorganisms and increasing average temperature or a correlation between the number of surviving microorganisms and the time of microwave exposure for a constant magnetron efficiency. If the average temperature is below the usual devitalization temperatures for microorganisms, the reduced viability of microorganisms exposed to a microwave field is essential to an "athermal effect", i.e., a lethal effect of microwaves other than that due to heating (Carlin *et al.*, 1982, Dreyfuss and Chipley, 1980, Khalil and Villota, 1988, Wright-Rudolph *et al.*, 1986). Many authors do not refer to this affect or they do not detect it. In a number of older studies, the effects of microwaves are attributed exclusively to the thermal effect of microwaves (Caroll and Lopez, 1969, Goldblich and Wang, 1967, Lechowich *et al.*, 1969).

MATERIALS AND METHODS

A finely chopped meat batter was prepared from fresh lean legs of pork cooled to 8°C. A freshly prepared suspension of microorganisms, 10% of water and 2% of sodium chloride were separately inoculated into the batter in the mixing machine. The strains of microorganisms are listed in Table 1. After taking from each portion samples for microbiological investigation, the batter was formed into 80g hamburgers, with a diameter of 100mm and a thickness of 10mm. The hamburgers were then frozen, in the moulds, to -18°C. After being removed from the moulds, the hamburgers were vacuum packed into bags of foil PA/PE (Svitamid, Chemosvit) and stored for one week at -18°C. Frozen hamburgers packed in foil were thawed for 5 minutes in a microwave oven (Philips Cooktronic 8915) with a frequency of 2450 MHz and a power output of 370 W. After holding the hamburger for 15 minutes at 20°C to allow the temperature of the hamburger to equilibrate, the products were exposed to microwaves for 1, 2, 3 and 4 minutes from a source of 1040 W. After that treatment, the samples were diluted in peptone broth and homogenized in sterile blender jars. Portions of the homogenates were serially diluted in 0.85% saline solution and 0.1ml portions were placed into suitable media. The microbiological methodology used is shown in Table 1. The temperatures of thawed and heated hamburgers were measured thermovisual by using an infrared camera (AGA 680, "thermovision"). The temperature differences were obtained from the thermo-photographs. As it was impossible to observe the temperature histones of hamburgers in the microwave oven, temperatures were measured just after the hamburgers were removed from the oven. The coldest and warmest spots on the hamburgers were particularly noted. These temperatures were plotted on a diagram.

RESULTS AND DISCUSSION

Temperature measurement

The temperature histories of hot and cold spots are shown in Diagram 1. It is obvious that there are two phases of the temperature histories, thawing and heat treatment. During the first phase the temperature at hot spots increased rapidly to a maximum of 50°C. The temperature of cold spots rose gradually, because of heat transmission out of hot spots. After the microwave thawing ceased the temperature of the hot spots went gradually down. Within 15 minutes the temperatures had equilibrated, to give a maximum difference between temperatures of 8°C. During the second phase, heat treatment, the temperature again increased rapidly at the hot spots of hamburgers. There was also a rapid increase in the temperature of cold spots. Between one and three minutes, temperature differences of up to 28°C occurred. However as the treatment time increased the temperature difference declined, and after four minutes the temperature was the same at all spots within 2°C.

The temperatures measured inside the hamburger revealed that after short-time microwave exposure, only low average temperatures were reached. The differences in temperature at different spots were so high that in small hot spots, that could be within the cells of microorganisms, the temperatures would be sufficient to rapidly kill microorganisms. Near these heat micronuclei there may however be spots of much lower temperature. The thermophotographs showed that relatively large hot and cold spots, differing in temperature by 20 to 30°C were located close to each other. Observations of microorganism devitalization in environment without dipolar molecules such as plastics, where heat generation outside of microorganisms is excluded, should the effect of heat of generation inside the microorganism cells (Tsaka *et al.*, 1989). In such a case, the destructive effect of microwaves is the same as if the microorganisms were warmed by heating of the environment. Evidently there is sufficient water and minerals in cells of microorganisms to provide an ideal medium for microwave heating. Thus, hot mininuclei of a temperature sufficient to denature proteins are generated by microwaves within microbial cells.

Because of the small size of these hot micro-nuclei, it is not possible to detect them using common thermometers. They can be detected only when the nucleus has enlarged to a sufficient size. The enlargement of hot nuclei, until they are homogenous, is indicated in Figure 1.

With regard to this theory, based on the generation of small, hot micronuclei and larger hot and cold spots, it may be supposed that the "athermal effect" (Carlin *et al.*, 1982; Drezfuss and Chiplez, 1980; Khalil and Villota, 1988;

Zimmermann, 1983) represented solely the direct thermal effect of microwaves on microorganisms. Any other "athermal effect" of microwaves on microorganisms is excluded.

Microbial inactivitation

There were declines in the numbers of most tested bacteria strains of about one order of magnitude during the thawing process. Only with *campylobacter jejuni* was there a greater decrease, of about two orders of magnitude. The reason for that may be the susceptibility of *C.jejuni* not only to high temperature, but also to oxygen and to freezing temperatures (Tomancova *et al.*, 1987). There were, according to the heat diagrams, hot spots in hamburgers during the thawing process which reached temperatures of up to 50°C. It is therefore probable that the temperature of micronuclei in hamburgers was up to 55°C, which is a temperature that is rapidly lethal for *campylobacter*.

Figures 2 to 7 show the falls in microbial counts with the time of microwave heating. The large dispersal of results does not allow a simple straight line to represent the average decrease. Therefore, the effect of microwave heating is described by the area between the two straight lines that characterize the extreme situations in hot and cold spots in hamburgers. It was presumed that microorganisms are not affected by only one temperature during microwave heating, but by the whole range of temperatures because of the nonhomogenous distribution of heat during microwave heating.

It is certain that the safe heating time with respect to microorganism devitalization is determined by the point of intersection of the plot for cold spots with the x-axis. The temperatures in these cold spots, which were obtained from Figure 1 and the data on the times of exposure may be found in Table 2.

The intersection of the straight line for hot spots with the x-axis indicates the time during which all cells of corresponding bacteria are killed if they are found in hot spots. These points on the x-axis are called the minimal time for total devitalization. In Figure 1, the exposure time can be compared with the temperature that was generated in the hot spots. The temperature data are also shown in Table 2. In all cases, they correspond to the devitalization temperature for designated microorganisms (Aprai and Bartl, 1977; Brandshow *et al.*, 1985).

Table 1. Bacterial strains and recovery methods used in this study.

Bacterial strain	Medium	Incubation
Bacillus cereus CCM 2010	yolk agar (Arpai *et al.*, 1977)	48h at 37°C
C.jejuni CCM 6191	blood agar with supplement (Tomancova *et al.*, 1987)	48h at 42°C
Clostridium perfrigens CCM 5872	blood agar with neomycin (Neubauer *et al.*, 1974)	48h at 37°C
Escherichia coli CCM 5872	Endo agar (Imuna)	24h at 37°C
Listeria monocytogenes CCM 5583, 5579	tryptic soy agar (Brandshaw *et al.*, 1985)	48h at 37°C
Salmonella enteritidis Isolate	agar with brilliant green and pheol red (Imuna)	24h at 37°C
Staphylococcus aureus CCM 6870, 559	Baird-Parker agar (Imuna)	24h at 37°C

Table 2. Minimuim and safe times of microwave heating of hamburgers for total devitalization of microorganisms in cold and hot spots.

Bacteria strain	Hot spots max. time (min)	Hot spots max. temp. (°C)	Cold spots max. time (min)	Cold spots max. temp. (°C)
Bacillus cereus	1.5	79.5	2.5	73.5
Clostridium perfringens	1.0	72.5	2.4	70.0
Staphylococcus aureus	1.2	75.5	2.5	73.5
Listeria monocytogenes	1.0	72.5	1.9	60.5
Escherichia coli	1.0	72.5	1.7	58.5
Salmonella enteritidis	0.9	71.5	1.7	58.5
Campylobacter jejuni	0.5	58.0	1.6	57.5