
Irradiation and Other Physically Based Control Strategies for Foodborne Pathogens

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I. INTRODUCTION

The ubiquity of potentially life-threatening pathogens in our environment and their contamination of our foods is an enormous problem. The ability of some of these pathogens to survive and/or proliferate under refrigeration and in reduced oxygen atmospheres and, for some of them, the low number necessary for food-poisoning outbreaks indicate a potential public health hazard. Moreover, microorganisms, previously unknown or not known to be causes of foodborne disease, have recently been linked with documented outbreaks of illness. The U.S. Public Health Service has estimated that foodborne diseases caused by pathogenic bacteria such as *Salmonella*, *Campylobacter*, *Escherichia coli*, and *Vibrio*, as well as *Toxoplasma gondii* and other parasites, may cause as many as 9000 deaths and 6.5 million to 81 million cases of diarrheal diseases in the U.S. annually.¹ The annual economic losses in relation to medical costs, loss of productivity, loss of business, and possible legal action associated with foodborne diseases may be as large as \$5 billion to \$6 billion.² These food-safety concerns are magnified because of consumer preferences for high quality and minimally processed convenient meals that require minimal preparation time. Accordingly, the need for better control of foodborne pathogens has become paramount in recent years.

Strategies for control of foodborne pathogens include established physical microbiocidal treatments such as ionizing radiation and heating. Microorganisms can also be destroyed by the emerging methods of new non-thermal treatments, such as the application of high hydrostatic pressure, high-intensity pulsed electric fields, oscillating magnetic fields, intense light pulses, or a combination of physical processes such as heat-irradiation, or heat-high hydrostatic pressure. Each of the non-thermal technologies has specific applications in terms of the types of food that can be processed. Mechanical removal of microorganisms from food can be accomplished by centrifugation, filtration, trimming, and washing. Cleaning and sanitation strategies can be used for minimizing the access of microorganisms to foods. This chapter deals with a variety of conventional and newly developed physical treatments for controlling foodborne pathogens and enhancing the safety and shelf-life of foods.

II. IRRADIATION OF FOOD

Food irradiation improves the safety of meat, poultry, and other foods by destroying indigenous microflora and thereby extending the shelf-life of these products during refrigerated storage. Sources of ionizing radiation include X-rays with a maximum energy of 5 million electron volts (MeV), electrons with a maximum energy of 10 MeV, and gamma rays emitted by the radioisotopes cobalt-60 or cesium-137. The food is exposed to doses of ionizing radiation sufficient to create positive and negative charges leading to the death of bacteria and other pathogens in foods. It is the rapidly growing cells of pathogenic and spoilage bacteria or parasites that are killed when food is irradiated. Ionizing radiation affects organisms by damaging the genetic material, such as DNA base damage, single-strand and double-strand DNA breaks, and cross-linking between bases. As a consequence of this damage,

TABLE 12.1
Ionizing Radiation Dose Requirements for
Various Applications of Food Irradiation

Application	Dose Requirement (kGy)
Inhibition of sprouting potatoes and onions	0.03–0.12
Insect disinfestation of seed products, flours, fresh and dried fruits, etc.	0.2–0.8
Parasite disinfestation of meats and other foods	0.1–3.0
Radurization of perishable food items (fruits, vegetables, meat, poultry, fish)	0.5–10
Radacidation of frozen meat, poultry, eggs, and other foods and feeds	3.0–10
Reduction or elimination of microbial populations in dry food ingredients (spices, starch, enzyme preparations, etc.)	3.0–2.0
Radappertization of meat, poultry, and fish products	25–60

Source: Adapted from Farkas.⁴¹

microorganisms are unable to replicate DNA and reproduce, leading to their death. In addition to DNA damage, ionizing radiation may damage bacterial membranes and cause other changes leading to sublethal injury.³

A. ABSORBED DOSES

There are several terms that must be known with regard to the application of radiation to foods. These terms include:

1. *Curie:* Quantity of radioactive substance in which 3.7×10^{10} radioactive disintegrations occur per second.
2. *Rad:* As used in the past is a unit equivalent to the absorption of 100 ergs energy/g of irradiated material.
3. *Gray (Gy):* Currently used unit of absorbed dose; one Gy is an energy absorption of one joule per kilogram (1 Gy = 100 rads = 1 joule/kg; 1 kGy = 10^5 rads; 1 joule = 10^7 ergs).

Depending upon the dose, a variety of desirable effects can be achieved (Table 12.1). Like all processing technologies, excessive doses can produce adverse effects. Sudar-madji and Urbain⁴ estimated threshold doses of irradiation (5 to 10°C) for an organoleptically detectable “off-flavor” in foods of animal origin (Table 12.2). Higher doses can be used without adverse effects by exclusion of oxygen and or by irradiation with the product in the frozen state. Goresline et al.⁵ devised the following terms to describe the applications of irradiation in food processing:

1. *Radacidation:* Considered as equivalent to pasteurization of milk and accordingly referred as “irradiation pasteurization.” It is intended to

TABLE 12.2
Threshold Doses of
Irradiation at 5 to 10°C
for Foods of Animal
Origin for an
Organoleptically
Detectable "Off-Flavor"

Food	Threshold Dose (kGy)
Beef	2.5
Chicken	2.5
Turkey	1.5
Lamb	6.25
Pork	1.75
Shrimp	2.5

Source: Adapted from Sudarmadji and Urbain.⁴

reduce the number of specific, viable, non-spore-forming pathogens, including parasites other than viruses, to non-detectable levels as determined by any standard method (<10 kGy dose).

2. *Radurization*: May be considered as equivalent to pasteurization. It is intended to considerably reduce the population densities of specific, viable, spoilage microbes with an aim to extend the shelf-life of foods (<10 kGy dose).
3. *Radappertization*: Considered as equivalent to sterilization or rendering the food "commercially sterile," as it is known in the canning industry (>10 kGy dose). If the food has been enzyme inactivated and has been irradiated while hard-frozen *in vacuo*, it will be shelf-stable and of excellent quality.

B. SAFETY

Food exposed to ionizing radiation is never in contact with any radioactive material. None of the sources of radiation, such as gamma rays, X-rays, or electrons can render the food radioactive. There is little effect on the food itself, as the cells in the food are not multiplying. Extensive research using animal models has provided sufficient evidence that ingestion of irradiated foods is completely safe and that the nutritive value remains essentially unchanged.²

Some vitamins (e.g., Vitamins B₁ and C), however, are sensitive to radiation. Factors affecting the amount of vitamin loss include dose, temperature, presence of oxygen, and the type of food. Packaging of foods in the absence of oxygen and exposing them to radiations at low temperatures minimize any vitamin loss, and

further loss can be prevented by storage at low temperatures in sealed packages.⁶ It has been estimated that only 2.3% of vitamin B₁ in the American diet would be lost if all the pork in the U.S. were to be irradiated.² Also, irradiation causes a small amount of ascorbic acid in fruits to be converted (oxidized) to dehydro-ascorbic acid. This compound is as biologically active as its reduced form and is converted back to the reduced form during storage of the fruits or vegetables.

When molecules absorb ionizing energy, they become reactive and form ions or free radicals that react to form stable radiolytic products.⁷ The Council for Agricultural Science and Technology (CAST)⁸ estimated that a dose of 1 kGy will break fewer than 10 chemical bonds for every 10 million such bonds present (cooking produces similar changes in chemical bonds). Researchers have developed methodologies to detect irradiated foods and have identified alkylcyclobutones in some irradiated foods that were not detected in unirradiated foods; however, Crawford and Ruff⁹ reported that no radiolytic product of toxicological significance have been found in irradiated foods. The committee on the wholesomeness of irradiated foods convened by the Food and Agriculture Organization of the United Nations, the World Health Organization, and the International Atomic Energy Agency concluded, based on decades of research, that irradiated foods are safe and wholesome at any radiation dose.¹⁰

C. RADIATION SUSCEPTIBILITY OF MICROORGANISMS

Several factors influence the survival of microbial cells when exposed to ionizing radiation. First, the higher the dose of ionizing radiation, the greater is the destruction of microorganisms; however, the microbiocidal efficacy of irradiation is lower under anaerobic conditions than in the presence of oxygen. This effect is attributed to the slower rate of oxidizing reactions, such as the formation of radicals due to the interaction of ionizing energy with water molecules.

Second, food-processing treatments such as curing, high hydrostatic pressure, temperature, decreased pH, and added preservatives (sodium benzoate, potassium sorbate, sodium salt of methyl, propyl esters of parahydroxy benzoic acid, etc.) increase the efficiency of the ionizing radiation by decreasing the number of surviving organisms. However, the reduction of water activity or a decrease in the moisture content, a common preservation method, exhibits a protective effect against the lethal effect of ionizing radiation as a result of reduced free radical formation due to lower moisture content.¹¹ Similarly, freezing causes a substantial increase in the resistance of vegetative cells, due to reduced availability of reactive water molecules; the radical formation is practically inhibited. Microbial radiation resistance in frozen foods is about two- to threefold higher than at ambient temperature. The composition of the food, in addition to its thickness and particle size, also plays an important role in determining the survival of microorganisms and the extent of the dose required to achieve the desired microbiological lethal effect. Bacterial cells are more protected against the lethal effects of irradiation in solid foods than in phosphate buffer. This is because of greater competition of the medium components in food matrix for the free radicals formed from water and activated molecules, thereby protecting the microorganisms. Accordingly, it is not advisable to predict the dose required to kill the microorganism in one food based on the dose quantified in other foods.

TABLE 12.3

Some D₁₀ Values of Foodborne Pathogens

Organism	Product	Irradiation Temperature (°C)	D ₁₀ (kGy)	Ref.
<i>Aeromonas hydrophila</i>	Ground beef	2	0.04–0.90	Palumbo et al. ⁴²
<i>Campylobacter jejuni</i>	Ground beef	18–20	0.14–0.16	Tarkowski et al. ⁴³
<i>Escherichia coli</i> O157:H7	Beef	2–4	0.24	Clavero et al. ¹⁴
<i>Listeria monocytogenes</i>	Chicken	2–4	0.45	Hutanen et al. ⁴⁴
<i>Salmonella</i> spp.	Chicken	2	0.38–0.77	Thayer et al. ⁴⁵
<i>Shigella dysenteriae</i>	Oysters	5	0.40	Quinn et al. ⁴⁶
<i>Staphylococcus aureus</i>	Chicken	0	0.40–0.46	Thayer et al. ⁴⁷
<i>Vibrio parahaemolyticus</i>	Crab meat	24	0.053–0.357	Matches and Liston ⁴⁸
<i>Yersinia enterocolitica</i>	Ground beef	18–20	0.10–0.21	Tarkowski et al. ⁴³

Finally, microorganisms vary considerably in their sensitivity to ionizing radiation. In general, the simpler the organism, the more resistant it is to the effects of ionizing radiation. For example, viruses are more resistant than bacteria, which are more resistant than yeasts, which are more resistant than molds. Within bacteria, Gram-negative cells are more sensitive than Gram-positive bacteria, and rods are more sensitive than cocci. Spores are very resistant to irradiation because of their low water content.

D. REDUCTION/ELIMINATION OF MICROORGANISMS

Foodborne pathogens and food spoilage microflora can be destroyed by irradiation. The D₁₀ value is the radiation dose required to destroy 90% of a bacterial population. Of the Gram-negative bacterial pathogens of public health significance, such as *Escherichia coli*, *Yersinia enterocolitica*, *Aeromonas hydrophila*, and *Campylobacter* species, *Salmonella* is the most resistant to irradiation, with a D value of 0.6 kGy. Recommended doses for reduction of the most resistant serotype of *Salmonella* by about 3 log-cycles (99.9%) to 5 logs (99.999%) are 3 to 5 kGy for frozen poultry, and 1.5 to 2.5 kGy for chilled poultry.¹² Irradiation doses designed to eliminate *Salmonella* will also render the food product safe from other Gram-negative bacterial pathogens (Table 12.3). For *E. coli* O157:H7, elimination of 90% of the viable cells in mechanically deboned chicken meat was achieved using 0.27 kGy at 5°C.¹³ Clavero et al.¹⁴ reported D₁₀ values of 0.241 to 0.307 kGy for *E. coli* O157:H7 in ground beef. Thus, irradiation at a dose levels of <2 kGy can effectively eliminate at least 6 logs of *E. coli* O157:H7 in ground beef.

Both Gram-positive and Gram-negative spoilage bacteria are easily destroyed by irradiation pasteurization doses. Irradiation doses to 2.5 kGy reduced the levels of aerobic and anaerobic bacteria by 4 and 5 log₁₀, respectively, in chilled ground beef.¹⁵ In an earlier study, Niemand et al.¹⁶ reported that the shelf-life of vacuum-

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packaged beef was increased by 6 weeks after irradiation at 2 kGy (shelf-life of 4 weeks for non-irradiated product vs. 10 weeks for irradiated product). Lefebvre et al.¹⁷ reported that ground beef irradiated at doses of 2.5 kGy exhibited a 3- \log_{10} reduction in psychrotrophic aerobic bacteria, with a shelf-life extension of 9 days. Fish fillets treated with 1 kGy ionizing radiation had a refrigerated shelf-life 15 days longer than non-irradiated fillets.^{18,19} Novak et al.²⁰ reported that oysters, when irradiated with 2 kGy, had a shelf-life of 23 days compared to non-irradiated oysters that began to spoil after 7 days.

E. PARASITE DISINFESTATION

Doses of 0.15 to 0.30 kGy are required to eliminate the risk of contamination by *Trichinella spiralis*, a pork parasite. Ionizing radiations act by rendering the parasite sexually sterile and blocking the maturation of ingested larvae in the host's gut.²¹ The U.S. Food and Drug Administration consequently approved the use of irradiation to control *T. spiralis* in pork at a minimum absorbed dose of 0.3 kGy, not to exceed 1.0 kGy.²² Similarly, doses of 0.3 to 0.7 kGy are required to kill *Toxoplasma gondii* and render the pork safe for human consumption.²³ Gamma irradiation of *Cysticercus bovi*-infected beef, with a dose of 0.4 kGy, prevents development of this parasite in the human host.²⁴

III. THERMAL INACTIVATION

The use of heat treatment to kill bacteria is the most common food preservation process in use today. Heat treatment designed to achieve a specific lethality for foodborne pathogens in the specific target food is fundamentally important to assure the shelf-life and microbiological safety of such thermally processed foods. The heat resistance of bacteria is described by two parameters, the D and z values. The D value is defined as the heating time required at a specific temperature to destroy 90% of the viable cells or spores of a specific organism. The z value is defined as the change in heating temperature needed to change the D value by 90% (1 log cycle). The z value provides information on the relative resistance of an organism to different destructive temperatures in a given substrate. D and z values are invaluable tools in the design of heat-processing requirements for desirable destruction of microorganisms in specific target food products.

During thermal processing, the rate of destruction of the microbial population was traditionally assumed to follow first-order kinetics; that is, at a given temperature, the reduction in the log number of survivors occurs in a linear manner with time.²⁵ However, the traditional log-linear thermal-death-time model is often a good representation of the actual inactivation data only in situations when inactivation is rapid. Significant deviations from the log-linear declines with time are frequently observed.^{26,25} These deviations include survival curves exhibiting an initial lag period or shoulder before any death occurs — time period when the bacterial population remains at the inoculation level — followed by an exponential decline. In some instances, a tailing of a subpopulation of more resistant bacteria that decline at a slower rate than the majority of the cells is observed (Figure 12.1). Hansen

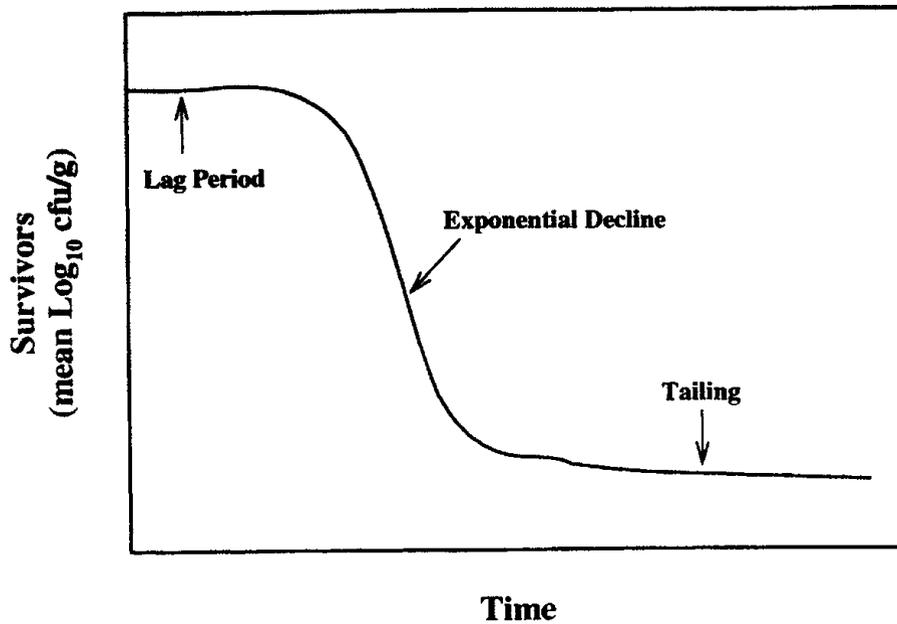


FIGURE 12.1 Heat inactivation of microorganisms showing a lag period, an exponential decline, and a tailing.

and Rieman²⁷ suggested that the deviations in linear survival curves may be due to variability of heat resistance within a population. Also, the “shoulder effect” observed may be attributed to poor heat transfer through the heating menstruum and may be due to an initial requirement for the bacterial cells to sustain sufficient injury before the bacterial destruction exhibits first-order inactivation kinetics. The “tailing effect” may be due to the clumping of a small number of cells in the heating menstruum, resulting in their protection and therefore an apparent increase in thermal resistance.²⁷

A. FACTORS AFFECTING HEAT RESISTANCE

An appropriate heat treatment designed to achieve a specified lethality of microorganisms is influenced by many factors, some of which are due to the inherent resistance of microorganisms, while others are due to environmental influences. Examples of the inherent resistance include differences among species and the different strains of bacteria, as well as the differences between spores and vegetative cells. Environmental factors include those affecting the microorganisms during growth and formation of cells or spores (e.g., stage of growth, growth temperature, growth medium, previous exposure to stress, etc.) and those acting during exposure to heat, such as the composition of the heating menstruum (amount of carbohydrate, proteins, lipids, solutes, etc.), water activity, pH, added preservatives, method of heating, recovery procedures, etc. Similar to ionizing radiation doses required to inactivate a certain number of specific organisms in a specific substrate, thermal processes should be designed for the specific food and not adapted from information derived for other foods.

TABLE 12.4

Relative Heat Resistance of Some Foodborne Pathogens

Organism	Heating Medium	Heating Temperature (°C)	D Value (minutes)	Ref.
<i>L. monocytogenes</i>	Beef	62	2.9–4.2	Gaze et al. ⁴⁹
<i>Y. enterocolitica</i>	Physiological saline	60	0.40–0.51	Sörqvist ⁵⁰
<i>A. hydrophila</i>	Physiological saline	51	8.08	Palumbo ⁵¹
<i>Escherichia coli</i> O157:H7	Beef	62.8	0.93	Juneja et al. ²⁶
<i>Salmonella</i> spp.	Beef	62.8	0.54	Goodfellow and Brown ⁵²
<i>C. perfringens</i> (spores)	Turkey	99	23.2	Juneja and Marmer ⁵³
<i>C. botulinum</i> (non-proteolytic, type B)	Turkey	75	32.5	Juneja et al. ⁵⁴

B. HEAT RESISTANCE OF PATHOGENS

Table 12.4 depicts the heat resistance of some foodborne pathogens. Clearly, the heat resistance varies with the intrinsic properties of the heating medium. Among the non-spore-forming bacteria, *L. monocytogenes* is relatively more heat resistant. Among spores, proteolytic *Clostridium botulinum* type A and B are the most heat resistant. These spores are targeted for destruction to ensure the microbiological safety of low-acid foods. The canning industry adopted a D value at 121°C of 0.2 minutes and a 12-log reduction as the standards for designing a required thermal process for an adequate degree of protection against *C. botulinum*. The non-proteolytic *C. botulinum* strains produce less heat-resistant spores. Thus, it is even practically feasible to inactivate these spores by the type of mild heat treatment given to minimally processed foods, without negatively impacting the product quality.

It is worth mentioning that the heat resistance of pathogens is influenced by heat shock. In a study by Juneja et al.,²⁸ when beef gravy samples inoculated with *E. coli* O157:H7 were subjected to sublethal heating at 46°C for 15 to 30 minutes and then heated/cooked to a final internal temperature of 60°C, the organism survived longer than non-heat-shocked cells; the time to a 4-D (D being the time to inactivate 90% of the population) inactivation value at 60°C increased 1.56-fold. There is concern that a heat-shocking condition may be created in cook-chill processing, potentially facilitating an increase in the heat resistance of pathogens. Manufacturers must be aware of the heat-shock-induced thermotolerance of the pathogens and take into account this factor when designing the heating processes for their products. Likewise, hazard analysis and critical control point (HACCP) plans should include an adequate

heat treatment designed to kill heat-sensitive microorganisms (e.g., spoilage bacteria, infectious pathogens, some spore-formers), cooling at a rapid rate, and subsequent chilled storage to control the growth of spores that have survived the heat treatment.

IV. HIGH-INTENSITY ELECTRIC FIELD PULSES

The lethal effect of a pulsed electric field against microorganisms can potentially be used for cold pasteurization and commercial sterilization of foods. Microbial cells are inactivated when a certain threshold electric field intensity is exceeded. The antimicrobial effect is due to the rupture of the cell membrane. Exposure of the cell to high-voltage electric field pulses can produce a potential difference between the inside and outside of a cell membrane. When the transmembrane potential exceeds the critical value of approximately 1 V, the pore formation becomes irreversible, leading to the destruction of the membrane functions and subsequently the cell death. Pulses ranging for 2 to 20 μsec with an electric field strength of 15 to 25 kV/cm are necessary for the destruction of microorganisms. For bacterial and fungal spores, higher voltage and longer duration pulses are required. Electric field pulses can be combined with temperature and lysozyme for the inactivation of spores.

Factors affecting the extent of microbial inactivation include: (1) temperature, pH, and ionic strength of food; (2) electric field intensity and duration of exposure; and (3) the type of microorganisms and their growth stage.²⁹ Gram-positive bacteria and yeasts are more resistant to pulsed electric fields than Gram-negative bacteria.³⁰ While the inactivation increases with an increase in the electric field intensity, exposure time, and temperature of food, every effort should be made to maintain the temperature below 30 to 40°C.

V. INTENSE LIGHT PULSES

Microorganisms on food and packaging can be reduced by high-intensity, short-duration pulses (1 μsec to 0.1 sec) of white light. The intense light pulses can be generated using gas-filled flash lamps or spark gap discharge apparatus. Both full- and filtered-spectrum light are used.³¹ The filtered spectrum is achieved with glass or liquid filters and is more effective for microbial inactivation than full-spectrum light. The light pulses have a wavelength spectrum between 170 and 2600 nm; thus, both ultraviolet and near infrared wavelengths are used to inactivate microorganisms, including bacterial and fungal spores. The light pulses for a fraction of a second can result in inactivation of a substantially high number of microorganisms. Among the organisms that have been shown to be inactivated by this method are *E. coli*, *Staphylococcus aureus*, *Bacillus subtilis*, and *Saccharomyces cerevisiae*. This method can reduce the need for chemical disinfectants and preservatives, and can clear packaging material of hydrogen peroxide residues that may result from some preservation methods. In addition to its use for the sterilization of packaging material used in aseptic processing, this method can also be used for surface sterilization of animal carcasses, fruits and vegetables, bakery goods, solid dairy products, bulk

sterilization of transparent homogeneous liquids, etc.³² Fruits and vegetables, such as tomatoes, potatoes, bananas, and apples, can have an extended shelf-life through light pulse treatment. Fresh cut potatoes and apples exposed to light pulses do not undergo enzymatic browning for an extended period of time.

VI. OSCILLATING MAGNETIC FIELD PULSES

Inactivation of microorganisms by magnetic fields requires a magnetic field intensity or magnetic flux of 5 to 50 telsa, frequency of 5 to 500 kHz, and an exposure time of from 25 μ sec to a few milliseconds.³³ Some evidence exists to document that such treatments can reduce microbial population densities by 2 logs. In pasteurization processes using oscillating magnetic fields (OMFs), food is sealed in plastic bags and subjected to 1 to 100 pulses in an OMF with a specific frequency and temperature, depending upon the food type and the microbial lethality required. High electrical resistivity (greater than 10 to 25 ohms per cm) is essential for many foods that have electrical resistivity in this range.

The advantages of using OMFs include: (1) avoidance of post-process contamination, as foods are treated inside a flexible film package; (2) minimal thermal denaturation of nutritional and organoleptic attributes of foods; and (3) reduced energy requirements for adequate processing. Only flexible films or paper packaging materials can be used, and reflective metallic packaging materials cannot be used.³³ Foods tested for antimicrobial effectiveness and sensorial acceptability using oscillating magnetic fields include orange juice, milk, and yogurt.

VII. HIGH HYDROSTATIC PRESSURE

This process involves filling a sterilized container with the food product, sealing the container, and placing it in a pressure chamber. Thereafter, the water surrounding the food is compressed by pumping additional liquid into the closed chamber, thereby subjecting the food to very high pressure (4000 to 9000 atm³⁴). Because of the uniform and instantaneous pressure throughout the food, no deformation on the package occurs, and the processing time is not a function of container size. Also, the temperature remains essentially unchanged. Microbial cell death has been attributed primarily to the damage and loss of activity of the cytoplasmic membrane.³⁵ Pressure-induced membrane function impairment causes inhibition of amino acid uptake, probably due to protein denaturation in the membrane.³⁶ Smelt et al.³⁷ reported that bacteria with a relatively high content of diphosphatidylglycerol are more susceptible to inactivation. Some studies have indicated that denaturation of enzymes, such as membrane-bound ATPases, plays an important role in pressure-induced injury and inactivation of microorganisms.^{38,39} For spores, a combination of high pressure and high temperature is necessary for inactivation. Under high pressure, bacterial spores germinate to vegetative cells and are then inactivated due to the effect of temperature.

High pressure weakens or denatures protein molecules in the food components because the hydrophobic and ion-pair bonds are disrupted. Covalent bonds are not

affected. However, changes in the tertiary structure from the breaking and reformation of chemical bonds can alter the coagulation or gelation characteristics of some foods, giving them a unique and novel texture. The flavor or nutrient content of a food is generally not altered. Some of the applications of the high-pressure technology include gelation of surimi; manufacture of food purees, jams, and jellies from strawberries and marmalade from oranges; and a shelf-life extension of juices and milk.

VIII. MICROBIAL CONTROL BY PHYSICAL REMOVAL

A variety of approaches can be used to physically remove microorganisms from solid or liquid foods or reduce population densities, thus increasing the efficiency of subsequent intervention steps. These methods include:

1. *Centrifugation*: This method can be used to remove undesirable particles such as dust, leucocytes, etc. For example, centrifugation can be used to remove thermophilic bacterial spores in milk that are not inactivated by the normal pasteurization time and temperatures.
2. *Filtration*: This method can be used to remove yeasts, molds, and most bacterial cells and spores from liquid foods. Also, filtration of air is performed for spray drying of milk. By using this method, the natural flavor and nutrient content of food are not altered.
3. *Trimming*: This method is used to physically remove the grossly visible damaged and spoiled portions of fruits and vegetables and meat. For example, trimming the outer leaves of cabbage or lettuce; visible mold growth from hard cheeses, fermented sausages, and bread; fecal stain marks and abscesses from animal carcasses, etc.
4. *Washing*: Fruits and vegetables, shell eggs, and animal carcasses including beef, pork, lamb, etc. are commonly washed during processing. Also, chicken and turkey carcasses during processing are exposed to water several times. The effectiveness of hot water, steam, ozonated water, and water containing chlorine, acetic and propionic acids, lactic acid, tripolyphosphates, or bacteriocins of lactic acid bacteria have been assessed in removing the bacterial contamination. While washing alone can reduce the bacterial numbers, the efficacy can be increased by a combination of two or more of the above-named agents.

IX. CLEANING AND SANITATION

Microorganisms can gain access to foods from a variety of sources; therefore, proper cleaning and sanitation of all food production and distribution facilities are important critical control points in the reduction of microbial levels and must be incorporated in HACCP plans. Before surfaces can be sanitized, they must be cleaned (dirt and soil removed). This is critical because bacteria can form biofilms on the surface of stainless steel or other food contact or equipment surfaces, floors, drains, and even

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food surfaces. To remove biofilms, adequate amounts of detergents and hot water must be applied, and mechanical action with a scrub brush or pressure sprayer must be used to loosen the surface biofilms, which can be 25 to 30 microorganisms “deep.” After the cleaned surface is rinsed, a sanitizing agent can be applied. Sanitizing agents will be ineffective if the biofilms are not first removed from surfaces.

A. CLEANING AGENTS (SOAPS AND DETERGENTS)

The minerals, commonly calcium and magnesium, present in hard water replace the sodium in regular soap to form an insoluble curd. As a result, the ability of soap to emulsify grease and free dirt and films from surfaces is diminished. Detergents that are surface-active agents are usually biodegradable alkyl sulfates, ethoxylates, and their sulfates or alkylbenzenesulfonates. The action of detergents lifts and suspends the oily or greasy portion of soil by reducing interfacial and surface tension.

B. SANITIZERS

Sanitizers are chemical compounds used to reduce the bacterial count on or within surfaces to safe levels. Sanitizer activity or effectiveness is affected by exposure time, temperature, concentration, water hardness, and surface cleanliness.⁴⁰ Chemical sanitizers can be classified into two classes: (1) halogens, which include chlorine (as a hypochlorite) and iodine (iodophors) compounds; and (2) surfactants, which include quaternary ammonium compounds (quats) and acid ionic compounds. Chemical sanitizing is done in two ways: either by immersion in an appropriate concentration of sanitizers or by rinsing, swabbing, or spraying with double the immersion concentration (an exception would be that the quat concentration is the same for both methods). Water also acts as a sanitizer when hot (above 76°C) or in the form of steam.

X. CONCLUSIONS AND OUTLOOK TO THE FUTURE

Research continues to demonstrate that food irradiation is a suitable process to control and potentially eliminate foodborne pathogens in a number of raw and cooked foods. In view of the consumers’ demand for high-quality, convenient meals that require minimal preparation time, irradiation as a non-thermal treatment holds promise in combination with other intervention techniques for ensuring the safety of these new generation foods. Heat treatment is the most common and effective method in use today for the inactivation of microorganisms and may be used in combination with irradiation. The non-thermal processes outlined here show promise as alternative methods for enhancing food safety. Both conventional and non-thermal processes can be used in combination and along with other preservative factors to control the pathogens and enhance the safety and shelf-life of foods.

Early findings suggest that non-thermal technologies will induce only minimal quality changes in food; however, the comparative efficacy of these non-thermal physical treatments or processes in inactivating a specific organism, as well as changes in organoleptic attributes and the quality and shelf-life of foods, need to be assessed to determine which method is superior for a specific food. Much research

on these emerging technologies has focused on applications; however, additional mechanistic studies are still needed, as is research regarding the expansion of these technologies to an industrial scale.

NOTE

Mention of brand or firm name does not constitute an endorsement by the U.S. Department of Agriculture over others of a similar nature not mentioned.

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