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Introduction

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Introduction

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In the past, consumer demand focused on microbiologically safe, stable food products. Today, consumers are looking for higher quality products with enhanced attributes, such as foods with fresh-like characteristics, fewer additives, improved sensorial and nutritional quality, as well as foods that are affordable at a reasonable cost.

In response to consumer demand, food technologists in academia, the food industry, and government have been combining their efforts in the research of so-called emerging technologies. The main goal of using these technologies is to reduce thermal damage in foods, which is generated by high temperatures and, in some cases, long processing times. Pasteurization and sterilization are the traditional preservation methods used in the food industry today for thousand of products; however, the effects of excessive heat used during preservation to obtain a microbiologically safe product are negatively reflected in the quality of products, such as undesirable changes in flavor, color, texture, and decreased nutrient content.

Two broad fields of research can be seen in emerging technologies, the first of which includes thermal technology. Use of thermal technology means that despite the use of heat to process and preserve foods, processing times can be considerably reduced and the damage to foods minimized when heat is generated by alternative energy methods. Examples of this technology include the use of microwave technology, radio frequency, and ohmic heating (Table 1). The second group of emerging technologies is referred to as nonthermal technology. In this case, heat is not the main preservation factor, but the technology carries the same advantages as heat, such as inactivation of microorganisms or enzymes and retention of fresh-like characteristics in foods. Examples of such preservation factors are pressure, sound, light, and electricity. Some nonthermal technologies under study today include high hydrostatic pressure, pulsed electric fields, ultrasound, ultraviolet, irradiation, and the use of chemicals such as ozone or CO_2 (Table 1).

This chapter is a brief introduction to some of the current emerging technologies. This chapter does not pretend to cover every aspect of each technology; it will provide the reader with a summary of some of these technologies, and more specific information about each one will be provided in subsequent chapters. This chapter also includes a list of some of the research groups currently working on one or more of these technologies in an attempt to unify efforts to develop further research and to respond to some of the current challenges in each field.

Novel Thermal Technologies

Although the use of heat can generate undesirable changes in food during processing by some novel processing technologies that use heat, the application and generation of heat into the food is different from conventional thermal processing. Some emerging thermal technologies that are now under research with encouraging results are microwaves, ohmic heating, radio frequency, and moderate electric fields (MEF). In fact, use of microwave technology is currently undergoing an evaluation process by the USDA to authorize and standardize this process as an official food process for sterilization of foods in the near future.

Microwaves

Microwave technology uses frequencies in the range of 300 MHz to 300 GHz; however, for industrial use only 915 and 2450 MHz are allowed to be used to avoid

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Table 1. Examples of some emerging technologies around the world.

Novel thermal technologies	Novel nonthermal technologies
Microwaves	High pressure
Radiofrequency	Pulsed electric fields
Ohmic heating	Ultrasound
Induction heating	Ultraviolet
	Light pulses
	Ozone
	Cold plasma
	Irradiation
	Dense phase carbon dioxide

interference with telecommunications systems. The advantage of using this technology for processing products is the way in which the heat is generated inside the food. Water molecules and other polar molecules align to the microwave electric fields that are rotating very quickly inside the product. Because of this rotation and friction between particles, heat is generated and this process is called volumetric heating. Some researchers have been exploring the use of microwave technology to pasteurize and sterilize food products, and positive results have been obtained in sterilization trials (2450 MHz), showing high quality of food products processed in pouches and trays (Guan et al., 2003).

Other applications of microwave technology include thawing–tempering processes, vacuum drying, freeze drying, drying, cooking, blanching, baking, and roasting. The number of food items processed under these modalities of microwave technology are meat, fish, butter, seeds, grains, vegetables, fruits, pasta, rice, snacks, bread, cocoa, coffee, dairy products, and other prepared foods (Fito et al., 2005).

Ohmic Heating

This technology is not new; the first data using this process date from 1840. However, the lack of inert materials to manufacture electrodes is one of the main reasons in the delay of the research and use of ohmic heating to process food. Pasteurization in milk was done by passing the milk between two plates with an electrical potential difference. From the 1980s until today, Ohmic heating technology has been researched and improved with new elements in design, new variables, and new materials (Morrissey and Almonacid, 2005). Ohmic heating can be considered to be similar to a high temperature short time HTST process, and the potential for using Ohmic heating in the food industry is very high. Ohmic heating can be used in blanching, evaporation, dehydration, fermentation, and pasteurization (Castro et al., 2004), and it has also been used to pasteurize liquid eggs and to process fruit products (Sastry et al., 2002).

Radio Frequency

Radio frequency is a dielectric heating with energy from the electromagnetic spectrum in the 10–300 MHz range; some of the important characteristics in food to be processed with radio frequency are the called dielectric properties, such as the permittivity, relative dielectric constant, and relative loss factor, each of which is different according to the food product. The basic equipment for radio frequency consists of the generator and the applicator; the first one is the source that generates the radio frequency power, and the second one is the material in which the food will be placed and heated. In food processing, the main applications of radio frequency are for drying and heating; the largest use of radio frequency is in the post bake-drying of some baked goods such as cookies, biscuits, and crackers (Tang et al., 2005). One of the main challenges in radio frequency technology right now is the use of this technology to pasteurize and sterilize food; however, some limiting factors are nonuniform heating and design of the equipment.

Novel Nonthermal Technologies

Some nonthermal technologies that are under research include, but are not limited to, high pressure sterilization, pulsed electric fields, ultrasound, ultraviolet, irradiation, cold plasma, dense phase carbon dioxide, ozone, and some chemicals. Some of these technologies, such as high pressure, are a reality for specific processes in the food industry. For example, irradiation is used worldwide but there are still issues under research. Other technologies, such as ultrasound or cold plasma, are establishing the basis of future promising food processing and preservation technologies.

High Hydrostatic Pressure

Research that has been described in hundreds of articles in the last 10 years and which are related to high pressure (400–600 MPa), are the basis of a newer and current technology to process food. Commercially, several high pressurized food products are available, from juices to oysters, sauces and meat products, fruit jams, and avocado sauce. This technology is based on the important increase of pressure as measured in seconds, and holding times of only a few minutes of processing at room temperature, which is now a reality for pasteurizing and processing some foods with specific characteristics. The mechanisms of cell inactivation are related to the change of volume and ultra-structure of cells, important changes in biochemical activities, gene and protein expressions and important damage in the target organelles, such as ribosome. Although nucleic acids have shown resistance to pressure and heat, some effects of very high pressure can alter the constituents of nucleic acids (Smelt et al., 2001). Nevertheless, there are new challenges to be addressed in using this technology, such as the sterilization of food with consequent bacterial spore inactivation. The use of higher pressures (in the order of 1 GPa) in combination with moderate temperatures is now under research to produce shelf-stable low acid food. Pressure assisted thermal processing (PATP) is the name that now is being mentioned in thousand of research centers as the main objective. The list of items that could be processed using PATP has no end. Examples include some breakfast items (e.g., egg products), pot roasts and stews, RTD teas and coffees, dairy desserts, low acid pasta sauces, liquid flavors, and herbs (Barbosa-Cánovas and Juliano, 2008); all of these products will keep their original and fresh-like characteristics while also ensuring microbiological quality.

Pulsed Electric Fields

The use of electricity to process food is not new; some reports date from the beginning of last century, describing how some researchers have passed electric discharges through milk to 'pasteurize' the product. However, at the end of the same century, a new technology using electricity was being explored as a potential food preservation method, specifically for liquid foods, which is now called pulsed electric fields. This technology is based on the application of short pulses of electric field intensities from 10 to 80 kV/cm with duration from micro to milliseconds, with minimum thermal effects into the product. Treated products include some dairy foods such as raw milk, flavored milk, yogurt and SMUF (simulated milk ultra filtrate), fruit juices, some soups, liquid eggs, and other beverages. Pathogenic bacteria inactivation has been possible, as well as the reduction of some enzymes related with food quality. Spores have been treated with Pulsed electric fields (PEF), showing their resistance to this treatment by itself, but also with viable inactivation patterns using other preservation factors in combination with PEF. The main mechanism of bacteria inactivation is the well-known process of electroporation, which in most inactivation cases is irreversible. When an electric field is induced around the cell, there is a transmembrane potential across the membrane; when the potential exceeds the natural potential of the cell (1V) there is expansion of the current pores and the formation of new cells, changing the permeability of the cell (Pagán and Mañas, 2006).

Currently, no commercial PEF-treated products are available; only a few years ago, the first PEF-treated fruit was introduced to U.S. consumers. However, despite its many advantages, processing of this juice was discontinued because of administrative problems. Nevertheless, the manufacturing of other PEF products will soon be available in markets because of the advantages that this technology offers to the consumer.

Ultrasound

High-frequency ultrasound has been widely used in the food industry as a non-destructive technique to evaluate certain quality control issues during recent years. On the other hand, some researchers have started to explore low-frequency ultrasound to inactivate bacteria and reduce enzyme activity because of the potential of low-frequency ultrasound to destroy cell membranes, promote chemical reactions, and other outcomes. The main mechanism of action of ultrasound is called cavitation, which is defined as the generation of thousands of bubbles inside a liquid medium. When sound waves pass through a liquid medium, a series of compression and expansion cycles is produced inside the medium, with the consequent generation of bubbles. These bubbles produce implosion and explosion phenomena, with violent collapses between them (McClements, 1995). Because of these collapses, there is an important increase in temperature and pressure in transient points of the medium, which will lead to microbial and enzymatic inactivation. Inactivation of bacteria has been possible in milk, juice, and other model systems with minor changes in food quality; at the same time, reduction of enzyme activity is another possibility with power ultrasound. Other uses of ultrasound at low frequency are cleaning, crystallization, and degasification processes.

Currently, ultrasound is used in the food industry only at high-frequency levels, a process that is more concerned about quality assurance issues and the determination of physical properties of food. When ultrasound is used at high frequency, the passage of sound waves through food does not generate any physical or chemical change; the change in the distribution and attenuation of the sound wave will provide information about the food.

Ultraviolet

High intensity light is a disinfection method that involves the use of intense white light. The wavelengths of the electromagnetic spectrum used for this purpose are from the ultraviolet to the near-infrared region. Pulses of light have been used in the food industry as flashes applied in seconds in order to inactivate microorganisms (Butz and Tauscher, 2002). Nevertheless, the most common application of this high intensity energy is as ultraviolet light, which is applied without pulses and with a minimum of visible light (Ohlsson, 2002). Ultraviolet light can be applied to inactivate harmful microorganisms at low temperature. The ultraviolet range is from 100 to 400 nm and each range has different applications. According to the UV range, UV light application can be divided as follows: UV-A is known as long wavelength, with a range from 320 to 400 nm; this is the wavelength responsible for tanning in human skin. UV-B or medium wavelength, ranges from 280 to 320 nm, and it burns the skin; and UV-C (short wavelength) from 200 to 280 nm has a germicidal effect. Finally, UV-V represents the range from 100 to 200 nm, and it corresponds to the vacuum UV range. Doses of energy used are at least 400 J/m^2 and some critical factors are the transmissivity of the product, the geometry, the power and the product flow profile, among others (Butz and Tauscher, 2002). Reducing microbial load in surfaces by means of ultraviolet light has great potential; this process is used in other industries to disinfect the surface of products and utensils. Currently, UV is used for pasteurization of some fruit juices and drinkable water.

Irradiation

This technology has been in use for several years; however, in the beginning of its application a great deal of controversy was observed because of the relationship that some countries found between irradiation and nuclear energy. In some parts of the world 'irradiation' is associated with mutagenic substances and cancer because of the derivation of the word in other languages. In some countries the process of irradiation is known as ionization or electronic pasteurization; this process is now used in more than 40 countries. Irradiation is a kind of energy that causes ionization and produces free radicals. Irradiation can be produced by three sources: Gamma rays, X-rays, or electron beams.

According to the intensity of the dose, irradiation can be classified in three ranges of application: radicidation, which is equivalent to pasteurization; radurization, which is used to improve the quality of foods; and radappertization, which is equivalent to sterilization (Barbosa-Cánovas et al., 1998). Examples of irradiated food include meat, fish, chicken, nuts, grain, vegetables, spices, poultry, and seafood. Some of the current research challenges in this area are focused on the determination of adequate doses of irradiation to each food product.

Dense Phase Carbon Dioxide

Another technology that is currently under research is the use of dense phase carbon dioxide. Dense phase carbon dioxide is suitable for liquid foods; when carbon dioxide is applied at room temperature and pressure between 7 and 34 MPa, pasteurization standards and enzymatic inactivation can be successfully achieved. Fruit juices and milk have shown positive inactivation of yeast and bacteria; however, some undesirable effects are still under research, such as the change of some organoleptic characteristics. The main mechanisms of cell inactivation are related to the decrease of pH in cytoplasm, the rupture of cells and membranes, inactivation of some important enzymes for cell metabolism and changes in intracellular components (Gunes et al., 2006).

Chemicals

Today, consumers are looking for minimal use of chemicals in food. In the past, the use of substances such as benzoate or propionate to preserve foods was very common, but these substances are now being rejected by many consumers because of allergic problems or other concerns. Today the use of 'new chemicals' is being tested and used in food to determine acceptance by consumers. Most of these chemicals are natural antimicrobials, which are substances that are naturally present in foods. However, when they are used in higher concentrations in specific foods, they can show an antimicrobial effect. Today, there are several natural antimicrobials used in foods, such as nisin or some organic acids; other substances such as essential oils and spices are under research with positive antimicrobial effects.

The use of ozone has been explored in aqueous solution and in gaseous phase for microbial inactivation in food, and ozone has been useful for decontamination of food-contact surfaces, sanitizing of equipment, recycling of wastewater and the decrease of pesticide levels on fresh produce. In general terms, ozone can extend the shelf-life of a product and improve the microbiological quality of a food.

Cold Plasma

To define plasma, the best approximation is to say that plasma is a state of matter similar to a chemically and electrically reactive gas. Several authors mention plasma as a fourth state of the matter composed of atoms and molecules, charged gases, radicals, and free electrons (Selcuk et al., 2008). Cold plasma has been effective to sterilize some foods such as seeds because of the instant gaseous discharges that generate free radicals and other chemical entities with antimicrobial activity. This is the newest emerging technology that is currently being tested in a few labs around the world, so most of the information regarding the mechanism of cell inactivation, inactivation of pathogens and other related effects in food products are still under research.

Research Groups Around the World

Currently, there are several research groups working around the world with some of these novel technologies. Listed in Table 2 are just few of the universities, research centers, and industries that are conducting research in some areas of interest. Most of them are working in collaboration with others doing research at the pilot plant scale in universities, and transferring the technology to real-case-scenario in industry. In other cases, in some universities there are groups focused on nonthermal technologies and other groups focused

Table 2. Some research groups working on thermal and nonthermal technologies.

Institution	Country	Available technologies[1]
University of Buenos Aires	Argentina	PEF, US
Food Science Australia	Australia	HP, PEF, US
Catholic University of Leuven	Belgium	HP, PEF
EMBRAPA	Brazil	HP
University of Guelph	Canada	PEF
McGill University	Canada	HP; MW
University of La Serena	Chile	HP
China Agricultural University	China	DPCD
Food Research Institute-Prague	Czech Republic	HP
University of Bordeaux	France	HP, PEF
University of Montpellier	France	HP
German Institute of Food Technology	Germany	HP, PEF, US
Technical University of Berlin	Germany	HP, US, PEF
University of Münich	Germany	HP
KEKI	Hungary	PEF
ICE Tec	Iceland	HP. PEF
University of Parma	Italy	HP
University of Salerno	Italy	PEF
National Food Research Institute	Japan	HP
Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM)	Mexico	HP
University of the Americas	Mexico	HP, US, UV
The University of Auckland	New Zealand	HP, PEF, UV
TNO	The Netherlands	HP, PEF
Unilever Research Vlaardingen	The Netherlands	HP, PEF, MW
University of Aberdeen	Scotland	HP
Agro-chemistry and Food Technology Institute (IATA)	Spain	HP, PEF, MW
Autonomous University of Barcelona	Spain	HP
Instituto del Frío	Spain	HP
Parc Científic i Tecnològic & Universitat de Girona	Spain	HP, PEF, MW, IR
University of Lleida	Spain	PEF
University of Zaragoza	Spain	US, PEF
SIK Goteburg	Sweden	HP, PEF
University of Lund	Sweden	HP, PEF
Nestlé	Switzerland	HP, PEF
Suleyman Demirel University	Turkey	CP
Campden and Chorleywood Food Research Association (CCFRA)	United Kingdom	HP, PEF, US, IR
University of Iowa	United States of America	IR
Cornell University	United States of America	DPCD
Natick Laboratories	United States of America	HP, IR
National Center for Food Safety and Technology	United States of America	HP, PEF, US, UV
Ohio State University	United States of America	HP, PEF, MW, RF, OH, O
Oregon State University	United States of America	HP
Rutgers University	United States of America	HP, PEF
Texas A&M	United States of America	IR
United States Department of Agriculture (USDA)	United States of America	HP, PEF, IR, CP, RF
University of Illinois	United States of America	US
University of Florida	United States of America	HP, DPCD
University of Georgia	United States of America	HP
University of Wyoming	United States of America	HP
Washington State University	United States of America	HP, PEF, US, UV, MW, RF, CP

[1]HP: High Pressure; PEF: Pulsed Electric Fields; US: Ultrasound; UV: Ultraviolet; DPCD: Dense Phase Carbon Dioxide; IR: Irradiation; MW: Microwave; RF: Radio Frequency; OH: Ohmic Heating; CP: Cold Plasma; DPCD: Dense Phase Carbon Dioxide; O: Ozone.

on thermal, which will lead students to obtain a broader knowledge about emerging technologies and the possibility of choosing one of this technologies to conduct research for an advance degree.

Emerging technologies are not limited to a few countries. As it can be observed in Table 2, countries from America, Europe, Asia, and Oceania are participating actively in different projects and research activities, an example of that is the amount of publications, poster presentation, and conference sessions in international meetings that show the cooperative effort to develop both emerging technologies.

FINAL REMARKS

Each novel technology must be explored scientifically to evaluate its potential as a food processing preservation technique, in conjunction with the food industry and associated regulatory approvals, but always with the main goal of achieving acceptance by the consumer. Some of these technologies have been shown to not only preserve food, but also that they could feasibly generate new and better ingredients.

Several workshops in Emerging Food Processing Technologies have been conducted in the past few years; most of them have focused on evaluating and establishing these state-of-the-art novel technologies, from the scientific, industrial, and regulatory points of view, in order to identify the scope of research needed for each one. Important material was generated at these workshops during the breakout sessions among speakers from academia, industry, and government.

Here, the focus is on putting together a document containing all of this valuable information. High hydrostatic pressure, ohmic heating, microwave, radio frequency, pulsed electric fields, ultrasound, ultraviolet light, and several chemical processes were some of the topics discussed, which will be addressed in this special issue of Food Science and Technology International.

This document is an update of the thermal and nonthermal emerging technologies, and is focused on the research needs, priorities, and further recommendations made for each technology, the purpose being to overcome the barriers to commercialization of related products. Ten chapters are therefore presented as an extensive summary of the enormous amount of work conducted in emerging technologies for processing foods.

FINAL RECOMMENDATIONS

a) Creation of a Center of Excellence for Innovative Food Processing Technologies, supported by Government, Food Industry, and Academia.
b) Further research on spore and virus inactivation with high hydrostatic pressure, including development of mathematical models to validate and optimize processes.
c) Studies for localization of cold spots during ohmic heating process, in addition to finding new and better materials for electrode design.
d) More modeling and microbiological studies on microwave to validate and approve technology, with considerable research on radio frequency, from basic aspects such as dielectric properties to microbial, packaging, and system design considerations.
e) Studies on the effect of pulsed electric fields in food systems containing solids, and more extensive studies in microbial and enzymatic inactivation. Control process aspects also need to be addressed.
f) More research performed with ultrasound to establish the foundations of this technology as a viable option for pasteurization of food.
g) Studies on the mechanisms of microbial inactivation due to chemical agents, including final quality of foods processed under these agents.
h) Research emphasis on optimization of ultraviolet light systems and analysis, including classification of available data to establish priorities for future research.
i) Strengthen collaboration between industry, academia, and government in researching new technologies, to satisfy consumer demand for safe, high-quality food products.

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