Scientific Bulletin. Series F. Biotechnologies, Vol. XIX, 2015
ISSN 2285-1364, CD-ROM ISSN 2285-5521, ISSN Online 2285-1372, ISSN-L 2285-1364

UNCONVENTIONAL ANTIMICROBIAL TREATMENTS FOR FOOD SAFETY AND PRESERVATION

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Abstract

Despite intensified prevention efforts, foodborne illness remains a serious health problem worldwide. Food spoilage is caused by both biologically and chemically agents. The growth of microorganisms is the major route for food spoilage, leading to low quality, shortened shelf-life, and changes in natural micro-flora that could induce pathogenic problems. Microbial spoilage of food products is caused by many bacteria, yeast, and moulds. For the food industries, the prevention of food spoilage is a very important issue in determining profit. Furthermore, reducing food spoilage can prolong the shelf-life of food products and accordingly extend market boundary, resulting in increased profit.
The objective of this work is to make a short review in respect to unconventional antimicrobial treatments of food, which are used nowadays in industry or are in the research and development phase. The paper presents an inventory of novel techniques such as: ohmic treatment, PEF, microwave treatment, IR, UV, UHP, ozone treatment, light pulses treatment, plasma treatment, active packaging, encapsulation of antimicrobial compounds, edible films, radio frequency treatment.

Key words: *food spoilage, antimicrobials, food safety and preservation.*

INTRODUCTION

In recent years, there has been a significant increase in consumer interest in the quality and safety of food products (Marszałek et al., 2015). Food safety and food quality are the major concerns for food producers, food industries, governments, and consumers. Spoilage of food products is caused by physical, chemical, and biological factors in the detriment of the organoleptic characteristics and consumer safety. Microbial growth damages the overall quality and safety of a product. As a result of microbial growth, off-odours and changes in the aroma, colour, and texture can be accelerated. Additionally, some microorganisms and their toxins may cause food recalls and serious foodborne outbreaks. Effective preventive measures and intelligent preservation methods have been put into place to reduce food spoilage and to prolong food shelf life (Corrales et al., 2014). The food industry is interested in developing alternative process technologies to accomplish a microbiological reduction in various foods without compromising fresh-like product characteristics (Gupta and Balasubramaniam, 2012).

Innovative nonthermal processes for food preservation have attracted the attention of many food manufacturers (Tao et al. 2014). For example, the conventional method of heat sterilization often leads to overcooking the food material causing unwanted loss of nutrients and organoleptic changes but the electric heating methods offer novel possibilities for sterilization providing better retention of quality attributes (Deak, 2014). Two types of electrical heating methods are known and have been practically explored: direct and indirect. In the case of the direct method electrical current is passed directly into the food (called ohmic heating, OH, or electrical resistance heating). With indirect electroheating the electric energy is first converted to electromagnetic radiation which subsequently generates heat within a product (microwave (MW) and radiofrequency (RF) heating) (Deak, 2014). This study presents some unconventional antimicrobial treatments of food which are used nowadays in industry or are in the research and development phase.

OHMIC TREATMENT (OH)

Ohmic heating is a thermal processing method in which an alternating electrical current is passed through food products to generate heat internally (Darvishi et al., 2012). This treatment appears as a solution to reduce thermal damage because it heats materials in a rapid and homogeneous manner and may allow improved retention of vitamins, pigments and nutrients, resulting in less thermal damage to labile substances (Sarkis et al., 2012). The obvious advantage of ohmic treatments over conventional methods is the lack of high wall temperatures and limiting heat transfer coefficients requirements (Icier, 2012). To our knowledge, this is the only electric resistance heating technology exhibiting a wall temperature that can be cooler than the heated medium, a fouling that can be kept to a minimum, and high energy efficiency (Goullieux and Pain, 2014).

Ohmic treatment is used in a wide range of applications such as preheating, cooking, blanching, pasteurization, sterilization and extraction of food products (Yildiz-Turp et al., 2013). Other examples for applications are the following: it's potential to increase dye diffusion in beet, its capability to extract sucrose from sugar beet, and its possibility to enhance the diffusion of soy milk from soybeans. Several past studies have shown an additional effect of electricity during the ohmic heating of plant tissues, vegetative microorganisms and bacterial spores (Somavat et al., 2013). Park reviewed the effective mechanisms of electrical current on microorganisms and he observed that the mechanism may include disruption of bacterial membrane integrity or electrolysis of molecules on the cell surface. When a voltage is applied, it increases the energy of the membrane such that an increase in membrane pore size takes place up to a transition to hydrophilic pores, where free diffusion may occur (Icier, 2012). That explains how many microorganisms such as *Escherichia coli, Bacillus subtilis, Bacillus licheniformis, Streptococcus thermophilus Geobacillus stearothermophilus, V. parahaemolyticus* are destroyed.

Ohmic heating is not only a useful thermal process in food stabilization, but also a pretreatment to prepare vegetal tissues before a mass transfer operation (e.g., diffusion, extraction, or dehydration).

PULSED ELECTRIC FIELD (PEF)

Pulsed electric field (PEF) processing is a non-thermal food-processing technology, which uses short bursts of electricity, providing fresh-like, safe foods and reduces loss of quality (Wang et al., 2014).

In general, PEF treatment systems are composed of PEF treatment chambers, a pulse generator, a fluid-handling system, and monitoring systems. The treatment chamber is used to house electrodes and deliver a high voltage to the food material. It is generally composed of two electrodes held in position by insulating material, thus forming an enclosure containing the food material. Therefore, the proper design of the treatment chamber is an essential component for the efficiency of the PEF technology (Elez- Martinez et al., 2012). Regarding microorganisms a uniform distribution of electric field strength in the PEF treatment chamber is necessary to ensure that each microbial cell within a population receives the same PEF treatment and, thus, to develop mathematical kinetic models for the prediction of microbial inactivation and quality control (Min et al., 2014). Compared to traditional thermal pasteurization, PEF technology is a non-thermal food preservation method, which kills most pathogenic or spoilage microorganisms and inactivates enzymes, and minimizes the loss of taste, colour, texture, nutrients, and heat labile functional components of foods (Han et al., 2009). Most of the studies in PEF have concentrated on aspects of food science (Wang et al., 2014) such as: extracting bioactive compounds from raw material (Zhao et al., 2011); extension of food storage shelf life by food sterilization and enzyme inactivation (Salvia-Trujillo et al., 2011); maintaining physical–chemical property and nutritional values of foods (Zhao et al., 2008); and degrading the behaviour of two pesticides, methamidophos and chlorpyrifos in apple juice (Chen et al., 2009).

The effects of PEF on the microorganisms in foods have mainly been studied in juices and milk, although there have been attempts to use PEF technology to process other products (Martin- Belloso et al, 2014). Antimicrobial effect of PEF is depending on the electric field strength, number of pulses applied, temperature and added antimicrobials (Nguyen and Mittal, 2006). The use of this technology in combination with other nonthermal technologies or mild heating would increase the microbial destruction (Martin-Belloso et al., 2014; Pool et al., 2001).

In the last years, there has been considerable interest in the adoption of PEF processing, and research into process scale-up. In other applications than foods, PEF processing can also improve the performance of industrial processes such as the removal of water from sludge, or the extraction of sugars and starches from plants, because the ruptured cells release their intracellular liquids more easily into their surroundings. (Kempkes, 2010).

MICROWAVE TREATMENT (MW)

Microwaves are electromagnetic radiation with wavelengths from 1 mm to 1 m in length and with frequencies from about 300 MHz to 300 GHz (Scaman et al., 2014). Since its first application for cooking, microwaves have been used for many purposes, including chemical synthesis of organic and inorganic substances, industrial processes, biosciences, food industry, and environmental treatments, among others. Dielectric heating, which uses electromagnetic radiations such as microwave (MW) is gaining popularity in food processing (Hebbar and Rastogi, 2012) and it provides volumetric heating, which means that heat is generated inside the material via absorption of electromagnetic energy from the applied field. Microwaves from household ovens and many industrial applications are produced efficiently by continuous wave magnetrons. A magnetron is a vacuum diode in which the cathode is surrounded by a coaxial anode (Scaman et al., 2014). The anode has an even number of vanes that extend toward the cathode. The open areas between each of the vanes are resonant cavities that determine the output frequency of the magnetron. The intensity and frequency of the field as well as dielectric properties of the material determine the degree of volumetric power absorption and the rate of heat generation (Ozkoc, 2014). Microwave heating is most efficient on liquid water, but much less efficient on fats and sugars (which have less molecular dipole movement), and frozen water (where the molecules are not free to rotate). MW heating sometimes occurs due to rotational resonance of water molecules, which happens only at much higher frequencies, in the tens of Gigahertz (Dev et al., 2012).

The mechanism of inactivation of microorganisms in volumetric heating processes is mainly due to thermal effects. Electromagnetic energy in MW inactivates microbes via conventional thermal mechanisms, including thermal irreversible denaturation of enzymes, proteins, and nucleic acids (Dev et al., 2012). The future of MW heating in food processing applications is promising, but successful exploration of MW heating applications relies on a thorough understanding of the interaction between MW and foods, and on the ability to predict and provide a desired heating pattern in foods for specific applications. These facts together with the possibility of offering continuous systems are seen as advantages in the food processing industry, although the issue of non-uniformity remains unresolved (Dev et al., 2012).

INFRARED TREATMENT (IR)

IR radiation is part of the electromagnetic spectrum in the wavelength range between 0.5 and 1000 mm, which is mainly utilized for food processing because of the several advantages such as higher heat-transfer capacity, instant heating because of direct heat penetration, high energy efficiency, faster heat treatment, fast regulation response, better process control, no heating of surrounding air, equipment compactness, uniform heating, preservation of vitamins, and less chance of flavor losses from burning of food products (Rastogi, 2012). All matter above the temperature of absolute zero possesses electromagnetic energy and emits radiation, in a wide range of electromagnetic spectral frequencies (Susek, 2010). These frequencies are produced by the oscillation of individual atoms or molecules with electric charges. The temperature of the emitting surface has a direct impact on these frequencies and the total amount of energy radiated. Since the maximum radiated power at room temperature occurs in the IR region (0.78–1000 mm) of the electromagnetic spectrum, using this frequency of radiation holds special significance, especially in food applications (Ramaswamy et al., 2012).

IR technology is generally applied to: the dehydration of vegetables, fish, pasta and rice; heating flour; frying meat; roasting cereals; roasting coffee and cocoa; and baking biscuits and bread. The technique has also been used for thawing, surface pasteurization of bread and packaging materials (Rastogi, 2015). However, the use of IR irradiation for food decontamination applications has not been widely researched and reported; the literature available is limited to a very few microorganisms and some raw foods. It is clear that the equipment (lamp, waveguide, power, etc.) and process parameters (time, power of exposure, distance of application, etc.) need to be optimized for specific applications (Ramaswamy, et al., 2012).

ULTRAVIOLET TREATMENT (UV)

Ultraviolet (UV) light is the part of the electromagnetic spectrum with wavelengths between 100 and 400 nm (Gomez- Lopez et al., 2012). Ultraviolet (UV) light is an economical intervention toward improved hygiene control measures in the food industry. Sanitation, decontamination, disinfection, and oxidation with UV light is a versatile, environmental-friendly technology, which can be used in the food production and storage facilities to reduce microbial contamination and consequently to improve safety of finished products (Koutchma, 2014). UV light is emitted by the source that consists of an inert-gas flash lamp that converts high-power electricity to high-power radiation. UV is categorized in long-wave (UV-A; 315-400 nm), medium-wave (UV-B; 280-315 nm), and short-wave (UV-C; 200-280 nm) diapasons. A few types of continuous light UV sources are commercially available that include LPM and MPM lamps, low-pressure amalgam (LPA), and ELs. LPM and MPM lamps are the dominant sources for UV light treatment of fluid foods, drinks and beverages including water processing. However, only LPM lamps that emit UV light at 253.7 nm are currently approved by the US FDA for food applications (Keklik et al., 2012; Koutchma, 2014). The use of UV has been proposed for the pasteurization and sterilization of food and contact surfaces (Fredericks et al., 2011; Molina et al., 2014) being the potential of the UV light on the destruction of bacteria, viruses and parasites widely documented (Mukhopadhyay and Ramaswamy, 2012). The inactivation mechanism of UV is the formation of photoproducts in the DNA. UV light inactivates microorganisms by disrupting their nucleic acid (DNA) through the formation of pyrimidine dimers between adjacent pyrimidine molecules on the same strand of DNA. (Franz et al., 2009; Lacroix, 2014). Microorganisms can find protective sites in some product surfaces (e.g. lettuce, carrots) and can migrate to these sites when UV radiation is applied. The DNA damage inflicted by UV-C radiation leads to lethality by directly altering microbial DNA through dimer formation between neighbouring pyrimidine nucleoside bases in the same DNA strand (Birmpa et al., 2013). UV systems demonstrated capability to deliver the performance that is equivalent to existing industrial practices using thermal processing and achieves required food safety objective. The examples of existing and potential applications of UV light include juice products, raw milk, cheese milk, sugar syrups, liquid eggs and egg components, and wine and whey protein ingredients. Additionally, the unique advantages of UV processing and added value products have been produced in commercial scale (Koutchma, 2014).

ULTRA HIGH PRESSURE (UHP)

High-pressure processing (HPP) is a method of food processing where food is subjected to elevated pressures (up to 87,000 pounds per square inch or approximately 600 MPa), with or without the addition of heat, to achieve microbial inactivation or to alter the food attributes in order to achieve consumer-desired qualities. The technology is also referred as

High Hydrostatic Pressure Processing (HHP) and Ultra High Pressure Processing (UHP) in the literature. HPP retains food quality, maintains natural freshness, and extends the microbiological shelf-life of the food (Gupta and Balasubramaniam, 2012; Ramaswamy et al., 2013). The history of the use of high pressure to inactivate microorganisms in food dates back to 1899, when Hite demonstrated the application of high pressure in preserving milk and later to preserve fruits and vegetables (Gupta and Balasubramaniam, 2012). Earlier studies have shown that by subjecting foods to high pressures in the range of 300–400 MPa, vegetative cells of microorganisms and certain enzymes can be inactivated at ambient temperature without degradation of flavour and nutrients. However, bacterial spores can only be killed by high pressures (600–700 MPa) in combination with heat (>70°C) (Daryaei and Balasubramaniam, 2012).

Today, a wide range of value-added pressure-treated foods such as fruit smoothies, guacamole, ready meals with meat and vegetables, oysters, ham, chicken strips, fruit juices, and salsa (Ramaswamy et al., 2013) are available to consumers. To carry out HP processing cyclically on a production line, it is necessary to design HP equipment with sufficient capacity and durability. Well-designed HP equipment should be composed of a pressure chamber, closures to seal the chamber, a device to hold the closures during processing, HP intensifier pumps, systems to monitor and control the pressure and temperature, a temperature control device, and a product-handling system to transfer product to and from the pressure chamber (Tao et al., 2014). After treatment, the pumpable product (e.g. juices) can be pumped to an aseptic filling line, similar to that used for ultra-high-temperature (UHT) processed liquids to be packaged in glass bottles or gable cartons. The realization of HPP sterilization concepts for low-acid foods could represent a breakthrough in ambient distribution as it will result in higher nutritional and sensory standards of preserved food (Daryaei and Balasubramaniam, 2012).

OZONE TREATMENT

Ozone is a triatomic form of oxygen and is characterized by a high oxidation potential that conveys bactericidal and virucidal properties. It is a powerful broad-spectrum antimicrobial agent active against bacteria, fungi, viruses, protozoa, and also against bacterial and fungal spores. Ozone inactivates microorganisms through oxidization, and residual ozone spontaneously decomposes to non-toxic products (oxygen), making it an environmentally friendly antimicrobial agent for use in the food industry (Patil and Bourke, 2012). The rising interest in novel food processing and preservation systems is driven by a number of factors including consumer preference for minimally processed food free of chemical preservatives; recent highly-publicized outbreaks of foodborne diseases caused by pathogens such as *Salmonella*, *Escherichia coli*, and *Listeria monocytogenes*; and the passage of new food safety legislations in the US and other countries (e.g., FDA, 2011) (Chawla et al., 2012). One of the most important factors in the efficacy of the ozone application is the treatment temperature since it affects the solubility, stability and reactivity of gas. As the temperature increases, reaction rate also increases but ozone becomes less soluble and less stable. Therefore as the treatment temperature increases, the increase in ozone reactivity is negated by the decrease in its stability, without causing significant changes in the efficacy of ozone (Cárdenas et al., 2011). Ozone is now an accepted commercial technology in many aspects of the agri- foods industry, ranging from irrigation and soil treatment, to spraying crops, odour control in animal housing and for uses in food processing plants (water and air treatment, food processing, packaging and storage) (Rice, 2010). Meanwhile, relevant literature has indicated ozone treatment to be a good candidate for the seafood industry (Okpala, 2014). In recent years it has been recognized that the combination of ozone with other acceptable food processing technologies (electrolyzed water, ultrasound, modified air packaging, ultraviolet radiation) can overcome the deficiencies of employing ozone by itself to solve a particular food disinfection problem

(Rice, 2010). Bermúdez-Aguirre and Barbosa-Cánovas (2012) demonstrated that the effectiveness of the ozone disinfection treatment is influenced by the dose of the agent, the exposure time and the surface of the food product. Smooth surface of vegetables such as tomatoes represents an easy product to allow direct contact of the sanitizer with the bacteria. When the surface becomes more complex in terms of porosity and roughness, the inactivation seems to be more complicated and reduced. Some changes in the color of produce can be controlled if the exposure time and/or concentration of the disinfection agent are kept as low as possible to inactivate the microorganism but still preserving the quality of the product.

PULSED LIGHT TREATMENT (PLT)

Pulsed light technology (PLT) involves the use of inert-gas flash lamps that convert short-duration and high-power electric pulses. Electromagnetic radiation is emitted and propagated by means of waves that differ in wavelength, frequency, and energy. The term "light" is generally used to mean radiation in which ranges from about 100 to 1100 nm, which includes ultraviolet rays (UV, λ=100-400 nm, roughly subdivided into UV-A, λ= 315-400 nm, UV-B, λ= 280-315 nm, UV-C, λ= 200-280 nm, and vacuum UV, λ=100-200 nm), visible light (VL, λ= 400-700 nm), and IR rays (IR, λ= 700- 1100 nm) (Cacace and Palmieri, 2014). Pulsed light results in very few residual compounds and does not involve the use of chemicals that cause environmental pollution or harm humans. Moreover, since a xenon lamp does not contain mercury, it is also more eco-friendly than a UV lamp. Each flash has an intensity almost 20,000x that of sunlight at sea level, and contains UV wavelengths that do not reach the earth's surface since they are filtered by the atmosphere (Choi et al., 2009). Microbial inactivation is mainly attributed to photochemical damage caused by the UV-C component, although photothermal damage has also been proposed (Hierro et al., 2012). Various studies have demonstrated the positive effect of pulsed light on inactivation of microbial populations on food surfaces. Reductions in counts of *Escherichia coli* O157:H7 on alfalfa seeds, *Aspergillus niger* spores on corn meal, *Listeria monocytogenes* and *E. coli* O157:H7 on raw salmon fillets, *Salmonella enterica* and *E. coli* O157:H7 on raspberries and strawberries and *L. monocytogenes* on infant foods have been reported, indicating this technology could be a powerful nonchemical (residue-free) option for decontaminating foods (Gómez et al., 2012).

PLASMA TREATMENT

Cold plasma is promising as a nonthermal food processing technology. Plasma plumes have been used to treat glass, electronics, textiles, paper, and other products. More recently it became a subject of research as an intervention to improve the safety of foods. However, the technical aspects of cold plasma are as yet largely unfamiliar to food producers, processors, and researchers (Niemira, 2014).
Cold plasma technology is offering many potential applications for food packaging. While it was originally developed to increase the surface energy of polymers, enhancing adhesion and printability, it has recently emerged as a powerful tool for surface decontamination of both foodstuffs and food packaging materials (Pankaj et al., 2014). Plasma source may offer significantly different modes of application. A plasma-jet for instance, can be applied to a sample directly, if the treatment distance is held short enough that the plasma filaments are touching the sample surface. This mode allows for interactions of the complete composition of plasma species with the sample surface (Baier et al., 2014). There are three primary mechanisms by which cold plasma inactivates microbes: (1) direct chemical interaction of cells with reactive species and charged particles; (2) UV damage of cellular components and membranes; (3) UV-mediated DNA strand breakage. While one mode of action may be more predominant than another in any given cold plasma system, the greatest sanitizing efficacy will result from multiple antimicrobial mechanisms (Niemira, 2014). Special attention needs to be given to food products, which do not undergo further heat treatment (pasteurization and sterilization processes), like ready-to-eat dishes. For example, the decontamination of dried

products, like herbs and spices is difficult, because the resistance of microorganisms, especially sporulated ones, in a medium with a low a_w is higher when compared to the resistance of the same microorganisms in a water rich medium. Thus, the remote plasma system was able to inactivate bacterial spores, vegetative bacteria, molds and yeast under ambient conditions on different types of herbs and spices with various surface- to-volume ratios (Hertwig et al., 2014).

ACTIVE PACKAGING

Developments in food packaging have evolved in response to the need for protection of the food product from both external and internal environments and in response to consumer expectations for convenience and product safety (Singh and Heldman, 2014).

Active packaging can be looked at from different perspectives. For example, a food technologist will be interested in studying the effects of active packaging solutions on food quality; a polymer engineer will focus his attention on the modification of traditional polymers to modulate the absorption or release of active substances; a chemical scientist will focus his research on the interactions between active substances and foods, and so on (Limbo and Khaneghah, 2015).

Active packaging is an innovative approach to enhance the shelf life of food stuffs while improving their quality, safety and integrity. Active packaging can be defined as a packaging system that interacts with the package components and the food to extend the shelf life or to improve the safety or sensory properties of the food, while maintaining the quality of the packaged product. Active packaging systems can be classified into active-releasing systems (emitters) which add compounds to the packaged food or into the headspace, or active scavenging systems (absorbers), which remove undesired compounds from the food or its environment (Yildirim, 2011).

One of the earliest active packaging systems was Modified Atmosphere Packaging (MAP) (Singh and Heldman, 2014). Modified atmosphere packaging (MAP) is a packaging system that involves changing the gaseous atmosphere surrounding a food product inside a pack, and employing packaging materials and formats with an appropriate level of gas barrier to maintain the changed atmosphere at an acceptable level for preservation of the food. Changing the gaseous atmosphere may mean removing air completely, that is by vacuum packaging, or replacing air with other gases (Emblem, 2013). Its use has been extended to fish, fresh produce, pasta, pizza, other baked goods, and dry products such as nuts and snacks, and it is believed that MAP is the fastest growing method of food preservation at the expense of more traditional methods such as retorting and freezing (Emblem, 2013). Another interesting development is incurporation of antimicrobial agents directly into packaging, which allows the industry to combine the preservative function of antimicrobials with the protective function of packaging (Yildirim, 2011).

Antimicrobial food packaging materials extend the lag phase and reduce the growth phase of microorganisms in order to extend shelf life and to maintain food quality and safety. (Realini and Marcos, 2014). It has been considered as a complementary method to the existing preservation methods to control undesirable microorganisms on foods by means of the incorporation of antimicrobial substances in the packaging films or application as a coating onto the packaging materials (Yildirim, 2011).

ENCAPSULATION OF ANTIMICROBIAL COMPOUNDS

In the last years, natural antimicrobials have attracted considerable attention due to the increased consumer awareness on the aspects of food quality and safety (Donsi et al., 2011).

Nanoencapsulation of bioactive compounds represents a viable and efficient approach to increase the physical stability of the active substances, protect them from the interactions with the food ingredients and, because of the subcellular size, increasing their bioactivity. In the case of antimicrobials, encapsulation can increase the concentration of the bioactive compounds in food areas where microorganisms are preferably located, for example water-rich phases or liquid-solid interfaces (Donsi et al., 2011).

Encapsulation technologies that effectively reduce antimicrobial interaction with food components or protect antimicrobial compounds from food processing measures have the potential to improve the microbiological safety of ready-to-eat foods (Taylor et al., 2008). Many compounds have been encapsulated; some of them are antioxidants, flavours, and antimicrobial compounds. Each of the different encapsulation systems has advantages and disadvantages. In general, the nanoencapsulation systems have excellent sustained-release properties, subcellular size, and biocompatibility with tissue and cells, allow alterations in the bioavailability of drugs, and improve the pharmacokinetic profile of numerous actives. Additionally, the encapsulation of antimicrobial compounds reduced their toxicity, the resistance is overcome, and the cost of using them is decreased because a less amount of the active is required. Limitations of all nanoencapsulation systems for their use in food industry are related to their high production costs and lack of allowed materials (Blanco-Padilla et al., 2014).

EDIBLE FILMS

An edible film is defined as a thin layer, which can be consumed, coated on a food or placed as barrier between the food and the surrounding environment (Skurtys et al., 2010). The use of edible films in food protection and preservation has recently increased since they offer several advantages over synthetic materials, such as being biodegradable and environmentally friendly. When those films take contact with food, moisture from food induce liposome membrane to slowly release antimicrobial extracts which will be trapped between food surface and liposome membrane. This fact is more efficient for inhibition food spoilage and food pathogen microorganisms because it maintain a high concentration. Moreover, edible film has abilities to retard moisture, oxygen, aromas and solute transportation (Mekkerdchoo et al., 2010).

The development of new natural edible films with the addition of antimicrobial compounds to preserve fresh and minimally processed fruits and vegetables is a technological challenge for the industry and a very active research field worldwide. Antimicrobial agents have been successfully added to edible composite films based on polysaccharides or proteins such as starch, cellulose derivatives, chitosan, alginate, and fruit puree, isolated whey protein, soy protein, egg albumen, wheat gluten, or sodium caseinate (Chamorro et al., 2011).

The main disadvantage of these techniques is the loss of quality of the edible coatings and films since there is no control over the shape, size and size distribution of the dispersed elements (e.g. additives, ingredients, etc.) and the support structure matrix is poor. Another disadvantage of these techniques is that the thickness of the films is generally not constant or controlled (Skurtys et al., 2010).

RADIOFREQUENCY TREATMENT

Radio frequency (RF) heating forms part of a group of innovative techniques based on electromagnetic heating (example: infrared, and microwave), and, non-thermal methods (such as high pressure, pulsed electric and ultrasonic waves) that have been touted to have the potential of providing high quality foods from an economically point of view (Awuah et al., 2005). The use of radio frequency electric fields (RFEF) as a pasteurization method has been studied for more than 60 years. There has been a long debate for over 50 years over whether there are nonthermal effects associated with electromagnetic fields (Trujillo and Geveke, 2014). In a RF heating system, the RF generator creates an alternating electric field between two electrodes. The material to be heated is placed between the electrodes, where the alternating energy causes polarization, in which the molecules in the material continuously reorient themselves to face opposite poles. At radio frequencies (e.g. 27.12 MHz), the electric field alternates 27,120,000 times per second. The friction resulting from the rotational movement of the molecules and from the space charge displacement causes the material to rapidly dissipate energy as heat throughout its mass (Orsat and Raghavan, 2014). Although identical to the microwave in terms of its heating characteristics, radio frequency has the additional advantage of uniform heating in homogeneous foods, and most important of all, high penetration depth that could be used to pasteurize or sterilize liquid products. For RF heating, penetration depth is generally greater than 1 m, and can be determined from a relationship that embodies the dielectric constant, the loss factor, the speed of wave propagation in vacuum and, operating frequency. Depending on concentration and temperature, the penetration depth of starch solutions ranged from 0.2 to 2.1 m in the radio frequency range, while salt enriched starch solutions had comparatively low penetration depths (Awuah et al., 2005).

Cathcart and Park first studied the use of RF heating to thaw frozen eggs, fruits, vegetables, and fish. Radio frequency dielectric heating is now widely used in industrial applications such as drying textile products (spools, rovings, skeins), final drying of paper, final dehydration of biscuits at outlets of baking ovens, and melting honey (Wang et al., 2003). As a rapid heating method, RF heating offers a considerable speed advantage over conventional heating methods, particularly in solid foods in which heat transfer is predominantly governed by heat conduction. However, even with this major advantage and the fact that this technology has been available for many years, its uptake by industry have been relatively slow (Marra et al., 2008).

In Table 1 is presented an overview of the present work, where for each analyzed new technology there are described the parameters that were used by researchers in the treatment of food products. These parameters were presented as effective for food decontamination and shelf life prolongation.

Table 1. Parameters used by researchers in the treatment of food products

Unconventional treatment	Product	Parameters	Author, year
Ohmic treatment	Pomegranate juice	Voltage gradient=30- 35 V/cm	Darvishi et al., 2012
	Blueberry pulp	Voltage=160V, 200 V and 240 V	Sarkis et al., 2012
	Tomato juice	Frequency=10 and 60kHz	Somavat et al., 2013
PEF	Green tea beverage	Electric field strength= 18.1 kV/cm; 27.4 kV/cm and 38.4kV/cm	Zhao et al., 2008
	Corn- starch	Electric field strength=30 kV/cm, 40 kV/cm and 50 kV/cm Temperature= 50°C	Han et al., 2009
	Glutathione from different products	Electric field intensity= 9.74 kV/cm Frequency=2549.08Hz	Wang et al., 2014
MW	Apple cylinders	Temperature=40°C Incident microwave power=3 and 10 W/g Air velocity=1m/s	Bilbao- Sainz et al., 2006
	Strawberry halves	Temperature= 40°C Incident microwave power=0.2 W/g Air velocity=2.6m/s	Contreras et al., 2008
	Potato omelet	P= 300W, 450W, 600W and 800W τ= 30s and 40s	Valero et al., 2014
	Hazelnut	Temperature=100-160°C Activation energy= 1891.6kJ/kg	Ozdemir and Devres, 2000

IR	Banana slices	Intensity= 3000 W/m^2, 4000 W/m^2 and 5000W/m^2,	Zhongli et al., 2008
UV	Porcine and fish gelatine	Radiation absorbed dose=2-10 kGy	Sung and Chen, 2013
	Sea bass fillets	λ= 250mm	Molina et al., 2014
UHP	Lychee (*Litchi chimensis* Sonn.	Pressure= 200- 600 MPa Temperature= 20-60°C τ= 10min and 20min	Phunchaisri and Apichartsrangkoon, 2005
	Corn starch	Pressure= 0.1-400 MPa	Choi et al., 2009
Ozone treatment	Dried oregano	Ozone concentration= 2.8 mg/L and 5.3 mg/L τ=120min	Torlak et al., 2013
	Wheat grains	40 and 60 µmol/mol τ=30min, 60min, 120min and 180 min	Savi et al., 2014
PLT	Beef and tuna slices	Fluences dose= 0.7J/cm^2, 2.1J/cm^2, 4.2 J/cm^2, 8.4 J/cm^2 and 11.9 J/cm^2	Hierro et al., 2012
	Fresh cut apples	Fluences dose= 71.6J/cm^2	Gomez et al., 2012
Plasma treatment	Sour cherry Marasca juice	Volume of juice= 3ml τ=3min	Garofulic et al., 2014
Atmospheric cold plasma	Strawberry	DBD= 60kV Frequency= 50Hz	Misra et al., 2014
Active packaging	Meat	60-70%CO_2 and 30-40%N_2	Cooksey, 2014
	Fatty fish	40%CO_2 and 60%N_2	Cooksey, 2014
	Non- fatty fish	30%O_2, 40%CO_2 and 30%N_2	Cooksey, 2014
RF	Milk	Frequency=27.12MHz	Awuah at al., 2005
	Soybean milk	Frequency=28MHz	Uemura et al., 2010
	Black and red pepper spice	Frequency=27.12MHz	Kim et al., 2011

CONCLUSIONS

Research in novel heating of foods, for applications such as cooking, pasteurisation/sterilisation, defrosting, thawing and drying, often focuses on areas such as the assessment of processing time, the evaluation of heating uniformity, the appraisal of the impact on quality attributes of the final product as well as the prediction of the energy efficiency of these heating processes (Marra et al., 2008).

The aim of the current review is to establish the unconventional antimicrobial treatments for foods, as evidenced by the refereed publications which have appeared in this area in the last years. In addition future trends for research in this field were also discussed. To ensure a comprehensive overview is provided, this paper included a description of the mechanism of unconventional treatments; an overview of typical equipment used for non- thermal treatments; examples of the wide range of this methods applications in food processing which have been proposed in the scientific literature in recent years, with related description of the effects of unconventional treatments on quality attributes of products.

ACKNOWLEDGEMENTS

This paper was published under the frame of Partnerships in priority areas Programme, PCCA Contract no. 164 / 2014, RAFSIG.

REFERENCES

Awuah G.B., Ramaswamy H.S., Economides A., Mallikarjunan K., 2005. Inactivation of Escherichia coli K-12 and Listeria innocua in milk using radio frequency (RF) heating. Innovative Food Science and Emerging Technologies, 6, 396 – 402.

Baier M., Görgena M., Ehlbeck J., Knorr D., Herppicha W. B., Schlüter O., 2014. Non thermal atmospheric pressure plasma: Screening for gentle process conditions and antibacterial efficiency on perishable fresh produce. Innovative Food Science and Emerging Technologies, 22, 147–157.

Bermúdez-Aguirre D., Barbosa-Cánovas G. V., 2012. Disinfection of selected vegetables under nonthermal treatments: Chlorine, acid citric, ultraviolet light and ozone. Food Control, 29, 1, 82–90.

Bilbao-Sainz C., Andres A., Chiralt A., Fito P., 2006. Microwaves phenomena during drying of apple cylinders. Journal of Food Engineering, 74, 160- 167.

Birmpa A., Sfika V., Vantarakis A., 2013. Ultraviolet light and Ultrasound as non-thermal treatments for the inactivation of microorganisms in fresh ready-to-eat foods. International Journal of Food Microbiology, 167, 96–102.

Blanco-Padilla A., Soto K.M., Iturriaga M. H., Mendoza S., 2014. Food Antimicrobials Nanocarriers. The Scientific World Journal, 2014, Article ID 837215, 11 pages.

Cacace D., Palmieri L., 2014. High-intensity Pulsed Light Technology. Emerging Technologies for Food Processing (Second Edition), 239–258.

Cárdenas F.C., Andrés S., Giannuzzi L., Zaritzky N. Antimicrobial action and effects on beef quality attributes of a gaseous ozone treatment at refrigeration temperatures. Food Control, 22, 8, 1442–1447.

Chamorro S. A. V., Paloua L., Ríoa M. A. Pérez-Gagoa M. B., 2011. Antimicrobial Edible Films and Coatings for Fresh and Minimally Processed Fruits and Vegetables: A Review. Critical Reviews in Food Science and Nutrition, 51, 9, 872-900.

Chawla A. S., Kasler D. R., Sastry S. K., Yousef A. E., 2012. Microbial decontamination of food using ozone. Woodhead Publishing Limited, 495- 532.

Chen F., Zeng L. Q., Zhang Y. Y., Liao X. J., Ge Y. Q., Hu X. S., Jiang L., 2009. Degradation behaviour of methamidophos and chlorpyrifos in apple juice treated with pulsed electric fields. Food Chemistry, 112, 956–961.

Choi M.S., Cheigh C.I., Jeong E.A., Shin J.K., Chung M.S., 2009. Nonthermal sterilization of Listeria monocytogenes in infant foods by intense pulsed-light treatment. Journal of Food Engineering, 97, 504–509.

Contreras C., Martin-Esparza M.E., Chiralt A., Martinez-Navarrete N., 2008. Influence of microwave application on convective drying: effects on drying kinetics, and optical and mechanical properties of apple and strawberry. Journal of Food Engineering, 88, 55-64.

Cooksey K., 2014. Modified Atmosphere Packaging of Meat, Poultry and Fish. Innovations in Food Packaging, 475- 493.

Corrales M., Fernandez A., Han J.H., 2014. Antimicrobial Packaging Systems. Innovations in Food Packaging (Second Edition), 133-170.

Darvishi H., Khostaghaza M. H., Najafi G., 2012. Ohmic heating of pomegranate juice: Electrical conductivity and pH change. Journal of the Saudi Society of Agricultural Sciences 12, 101–108.

Daryaei H., Balasubramaniam V. M., 2012. Microbial decontamination of food by high pressure processing. Woodhead Publishing Limited, 370- 406.

Deak T., 2014. Chapter 17 – Thermal Treatment. Food Safety Management A Practical Guide for the Food Industry, 423–442.

Dev S. R. S., Birla S. L., Raghavan G. S. V., Subbiah J., 2012. Microbial decontamination of food by microwave (MW) and radio frequency (RF). Woodhead Publishing Limited, 274- 299.

Donsi F., Annunziata M., Sessa M., Ferrari G., 2011. Nanoencapsulation of essential oils to enhance their antimicrobial activity in foods. LWT - Food Science and Technology, 44, 1908-1914.

Elez-Martinez P., Sobrino-Lopez A., Soliva-Fortuny R., Martin-Belloso O., 2012. Pulsed Electric Field. Processing of Fluid Foods. Novel Thermal and Non-Thermal Technologies for Fluid Foods 63–108.

Emblem A., 2013. Modifi ed atmosphere packaging and other active packaging systems for food, beverages and other fast- moving consumer goods. Woodhead Publishing Limited, 22- 34.

Franz C.M.A.P., Specht I., CHO G.S., Graef V., Stahl M.R., 2009. UV-C inactivation of microorganisms in naturally cloudy apple juice using novel inactivation equipment based on Dean vortex technology. Food Control 20, 1103-1107.

Fredericks I. N., du Toit M., Krügel M., 2011. Efficacy of ultraviolet radiation as an alternative technology to inactivate microorganisms in grape juices and wines. Food Microbiology, 28, 510–517.

Garofulić I. E., Jambrak A. R., Milošević S., Dragović-Uzelac V., Zorić Z., Herceg Z., 2014. The effect of gas phase plasma treatment on the anthocyanin and phenolic acid content of sour cherry Marasca (Prunus cerasus var. Marasca) juice. LWT - Food Science and Technology, 1-7.

Gómez P.L, García-Loredo A., Nieto A., Salvatori D.M., Guerrero S., Alzamora S.M., 2012. Effect of pulsed light combined with an antibrowning pretreatment on quality of fresh cut apple. Innovative Food Science and Emerging Technologies, 16, 102–112.

Gomez-Lopez V.M., Koutchma T., Linden K., 2012. Ultraviolet and Pulsed Light Processing of Fluid Foods. Novel Thermal and Non-Thermal Technologies for Fluid Foods, 185–223.

Goullieux A., Pain J.P., 2014. Ohmic Heating. Emerging Technologies for Food Processing (Second Edition) 399–426.

Gupta R., Balasubramaniam V.M., 2012. High-Pressure Processing of Fluid Foods. Novel Thermal and Non-Thermal Technologies for Fluid Foods, 109-133.

Gupta R., Balasubramaniam V.M., 2012. High-Pressure Processing of Fluid Foods. Novel Thermal and Non-Thermal Technologies for Fluid Foods, 109–133.

Han Z., Zeng X., Zhang B., Yu S., 2009. Effects of pulsed electric fields (PEF) treatment on the properties of corn starch. Journal of Food Engineering, 93, 318–323.

Hebbar H. U., Rastogi N. K., 2012. Microwave Heating of Fluid Foods. Novel Thermal and Non-Thermal Technologies for Fluid Foods, 369–409.

Hertwig C., Reineke K., Ehlbeck J., Erdogdu B., Rauh C., Schlüter O., 2014. Impact of remote plasma treatment on natural microbial load and quality parameters of selected herbs and spices. Journal of Food Engineering.

Hierro E., Ganan M., Barroso E., Fernández M., 2012. Pulsed light treatment for the inactivation of selected pathogens and the shelf-life extension of beef and tuna carpaccio. International Journal of Food Microbiology 158, 42–48.

Icier F., 2012. Ohmic Heating of Fluid Foods. Novel Thermal and Non-Thermal Technologies for Fluid Foods, 305–367.

Keklik N. M., Krishnamurthy K., Demirci A., 2012. Microbial decontamination of food by ultraviolet (UV) and pulsed UV light. Woodhead Publishing Limited, 344- 369.

Kempkes M. A., 2010. Pulsed electric field (PEF) systems for commercial food and juice processing. Woodhead Publishing Limited, 73-102.

Kim S.Y., Sagong H.G., Choi S. H., Ryu S., Kang D.H., 2012. Radio-frequency heating to inactivate Salmonella typhimurium and Escherichia coli O157:H7 on black and red pepper spice. International Journal of Food Microbiology, 153, 171–175.

Koutchma T., 2014. Chapter 1 – Introduction, Food Plant Safety. UV Applications for Food and Non-Food Surfaces, 1.

Koutchma T., 2014. Chapter 3 – UV Light Sources, Preservation and Shelf Life Extension. UV Applications for Food, 13–15.

Lacroix M., 2014. Irradiation. Emerging Technologies for Food Processing (Second Edition), 293–312.

Limbo S., Khaneghah A.M., 2015. Active packaging of foods and its combination with electron beam processing. Electron Beam Pasteurization and Complementary Food Processing Technologies, Woodhead Publishing Series in Food Science, Technology and Nutrition, 195–217.

Marra F., Zhang L., Lyng J.G., 2008. Radio frequency treatment of foods: Review of recent advances. Journal of Food Engineering 91, 497–508.

Marszałek K., Mitek M., Skąpska S.,2015. The effect of thermal pasteurization and high pressure processing at cold and mild temperatures on the chemical composition, microbial and enzyme activity in strawberry purée. Innovative Food Science and Emerging Technologies, 27, 48-56.

Martin-Belloso O., Marsellés-Fontanet R., Elez-Martinez P., 2014. Food Safety Aspects of Pulsed Electric Fields Emerging Technologies for Food Processing (Second Edition), 155–168

Mekkerdchoo O., Patipasena P., Borompichaichartkul C., 2010. Liposome encapsulation of antimicrobial extracts in pectin film for inhibition of food spoilage microorganisms. Asian Journal of Food and Agro-Industry, 2(04), 817-838.

Min S. C., Zhang H. Q., Han J. H., 2014. Packaging for Nonthermal Food Processing. Innovations in Food Packaging (Second Edition) 515–535.

Misra N.N., Patil S., Moiseev T., Bourke P., Mosnier J.P., Keener K.M., Cullen P.J., 2014. In-package atmospheric pressure cold plasma treatment of strawberries Journal of Food Engineering, 125, 131–138.

Molina B., Sáez M.I., Martínez T.F., Guil-Guerrero J.L., Suárez M.D., 2014. Effect of ultraviolet light treatment on microbial contamination, some textural and organoleptic parameters of cultured sea bass fillets (Dicentrarchus labrax). Innovative Food Science and Emerging Technologies, 26, 205–213.

Mukhopadhyay S., Ramaswamy R., 2012). Application of emerging technologies to control Salmonella in foods: A review. Food Research International, 45, 666–677.

Nguyen P., Mittal G.S., 2006. Inactivation of naturally occurring microorganisms in tomato juice using pulsed electric field (PEF) with and without antimicrobials. Chemical Engineering and Processing, 46, 360–365.

Niemira B. A., 2014. Decontamination of Foods by Cold Plasma. Emerging Technologies for Food Processing (Second Edition), 327–333.

Okpala C.O. R., Investigation of quality attributes of ice-stored Pacific white shrimp (Litopenaeus vannamei) as affected by sequential minimal ozone treatment. LWT - Food Science and Technology, 57, Issue 2, 538–547.

Orsat V., Raghavan G.S.V., 2014. Radio-Frequency Processing. Emerging Technologies for Food Processing (Second Edition), 385–398.

Ozdemir, M., Devres, O., 2000. Analysis of color development during roasting of hazelnuts using response surface methodology. Journal of Food Engineering, 45, 17-24.

Ozkoc S. O., Sumnu G., Sahin S., 2014. Recent Developments in Microwave Heating. Emerging Technologies for Food Processing (Second Edition), 361–383.

Pankaj S.K., Bueno-Ferrera C., Misraa N.N., Milosavljevi V., O'Donnell C.P., Bourkea P., Keenera K.M., Cullen P.J., 2014. Trends in Food. Science & Technology, 35, 5-17.

Patil S., Bourke P., 2012. Ozone Processing of Fluid Foods. Novel Thermal and Non-Thermal Technologies for Fluid Foods, 225–261.

Phunchaisri C., Apichartsrangkoon A., 2005. Effects of ultra-high pressure on biochemical and physical modification of lychee (Litchi chinensis Sonn.). Food Chemistry, 93, 57–64.

Pool, I.,E., Hennie, C.,M., Slump, R.,A., Popa, M.E., Smid, E.,J., 2001.Influence of food matrix on inactivation of Bacillus cereus by combinations of nisin, pulsed electric field treatment and carvacrol, in Journal of Food Protection, 64, 7, 1012-1018.

Ramaswamy R., Ahn J., Balasubramaniam V.M., L.R. Saona, Yousef A. E., 2013. Food Safety Engineering. Handbook of Farm, Dairy and Food Machinery Engineering, 43–66.
Ramaswamy R., Krishnamurthy K., Jun S., 2012. Microbial decontamination of food by infrared (IR) heating. Woodhead Publishing Limited, 450- 471.
Rastogi N. K., 2012. Infrared Heating of Fluid Foods. Novel Thermal and Non-Thermal Technologies for Fluid Foods, 411–432.
Rastogi N.K., 2015. Infrared heating of foods and its combination with electron beam processing. Electron Beam Pasteurization and Complementary Food Processing Technologies, Woodhead Publishing Series in Food Science, Technology and Nutrition, 61–82.
Realini C.E., Marcos B., 2014. Active and intelligent packaging systems for a modern society. Meat Science, 98, 404–419.
Rice R. G., 2010. Commercial applications of ozone in food processing. Woodhead Publishing Limited, 258-282.
Salvia-Trujillo L., Morales P. M., Rojas-Graü M. A., Martín-Belloso O., 2011. Changes on phenolic and carotenoid composition of high intensity pulsed electric field and thermally treated fruit juice–soymilk beverages during refrigerated storage. Food Chemistry, 129, 982–990.
Sarkis J. R., Jaeschke D.P., Tessaro I.C., Marczak L.D.F., 2012. Effects of ohmic and conventional heating on anthocyanin degradation during the processing of blueberry pulp. Food Science and Technology 51, 79-85.
Savi G. D., Piacentini K. C., Bittencourt K. O., Scussel V. M., 2014. Ozone treatment efficiency on Fusarium graminearum and deoxynivalenol degradation and its effects on whole wheat grains (Triticum aestivum L.) quality and germination. Journal of Stored Products Research, 59, 245-253.
Scaman C.H., Durance T. D., Drummond L., Sun D.W., 2014. Combined Microwave Vacuum Drying. Emerging Technologies for Food Processing (Second Edition), 427–445.
Singh R. P., Heldman D. R., 2014. Packaging Concepts. Introduction to Food Engineering (Fifth Edition), Food Science and Technology, 767–791.
Skurtys O., Acevedo C., Pedreschi F., Enrione J., Osorio F., Aguilera J. M., 2010. Food Hydrocolloid Edible Films and Coatings
Somavat R., Mohamed H.M.H., Sastry S.K., 2013. Inactivation kinetics of Bacillus coagulans spores under ohmic and conventional heating. LWT - Food Science and Technology 54 (2013) 194-198.
Sung W.C., Chen Z.Y., 2014. UV treatmentand γ irradiation processing on improving porcine and fish gelatin and qualities of their premix mousse. Radiation Physics and Chemistry, 97, 208–211.
Susek W., 2010. Thermal microwave radiation for subsurface absolute temperature measurement. Acta Physica Polonica A, 118, 1246–1249.
Tao Y., Sun D.W., Hogan E, Kelly A. L., 2014. High-Pressure Processing of Foods: An Overview. Emerging Technologies for Food Processing (Second Edition), 3-24.
Taylor T. M., Bruce B. D., Weiss J., Davidson M., 2008. Listeria monocytogenes and Escherichia coli O157:H7 inhibition in vitro by liposome encapsulated nisin and ethylene diaminetetraacetic acid. Journal of Food Safety 28, 2, 183–197.
Torlak E., Sert D., Ulca P., 2013. Efficacy of gaseous ozone against Salmonella and microbial population on dried oregano. International Journal of Food Microbiology, 165, 276–280.
Trujillo F. J., Geveke D. J., 2014. Nonthermal Processing By Radio Frequency Electric Fields. Emerging Technologies for Food Processing (Second Edition), 259–269.
Uemura K., Takahashi C., Kobayashi I., 2010. Inactivation of Bacillus subtilis spores in soybean milk by radio-frequency flash heating. Journal of Food Engineering, 100, 622–626.
Valero A., Cejudo M., García-Gimeno R.M., 2014. Inactivation kinetics for Salmonella Enteritidis in potato omelet using microwave heating treatments. Food Control, 43, 175- 182.
Wang J., Wang K., Wang Y., Lin S., Zhao P., Jones G., 2014. A novel application of pulsed electric field (PEF) processing for improving glutathione (GSH) antioxidant activity. Food Chemistry, 161, 361–366.
Wang Y., Wig T.D., Tang J., Hallberg L.M., 2003. Sterilization of Foodstuffs Using Radio Frequency Heating. Journal Of Food Science 68, 2, 539- 544.
Yildirim S., 2011. Active packaging for food biopreservation. Woodhead Publishing Limited, 460-489.
Yildiz-Turp G., Sengun I.Y., Kendirci P., Icier F., 2013. Effect of ohmic treatment on quality characteristic of meat: A review. Meat Science 93, 441–448.
Zhao W. Z., Yu Z. P., Liu J. B., Yu Y. D., Yin Y. G., Lin S. Y., et al., 2011. Optimized extraction of polysaccharides from corn silk by pulsed electric field and response surface quadratic design. Journal of the Science of Food and Agriculture, 91, 2201–2209.
Zhao W., Yang R., Lub R., Wang M., Qianb P., Yang W., 2008. Effect of PEF on microbial inactivation and physical–chemical properties of green tea extracts. LWT, 41, 425–431.
Zhongli, P., Shih, C., McHugh, T.H., Hirschberg, E., 2008. Study of banana dehydration using sequential infrared radiation heating and freeze drying. LWT Food Science Technology, 41, 1944-1951.

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