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Review

Mild processing applied to the inactivation of the main foodborne bacterial pathogens: A review

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A B S T R A C T

Background: Salmonella, Listeria monocytogenes, Escherichia coli O157:H7 and *Campylobacter* are the major bacterial pathogens associated with foodborne diseases and their inactivation is fundamental to ensure microbiologically safe products. Although efficient in generating safe foods with proper shelf-lives, pasteurization and commercial sterilization may result in numerous nutritional and sensory changes in foods. To address these disadvantages, mild processing methods (i.e., processing technologies for food preservation that apply mild temperature; <40 °C) aiming to destroy microbial food contaminants have been developed.

Scope and approach: This review emphasizes the main applications of mild technologies aiming to the inactivation of the four main pathogenic bacteria of relevance for food safety as well as their mechanisms of action.

Key findings and conclusions: Mild processing technologies such as high pressure processing, ultrasounds, pulsed electric fields, UV-light, and atmospheric cold plasma may serve, in some conditions, as useful alternatives to commercial sterilization and pasteurization aiming to destroy foodborne pathogens. Each of these mild technologies has a specific mode of microbial inactivation and their knowledge is of foremost importance in the design and practical application aiming to produce high quality and safe foods. This is necessary to ensure that mild technologies are highly advantageous in comparison to conventional technologies not only for preservation of nutritional and sensorial aspects of foods but also to ensure their safety throughout shelf-life.

1. Introduction

Food preservation has greatly relied on the application of effective processes able to inactivate foodborne microorganisms. These processes are of paramount importance and formed the solid basis for the industrialization and commercialization of foods in large scale. Pathogenic microorganisms are normally the major targets of several industrial food processes because of the burden posed by foodborne diseases. Moreover, these microorganisms may be able to adapt and withstand stressful conditions faced during food production and storage.

The main traditional methods applied by industries for food preservation include the application of heat (pasteurization and sterilization), decrease of temperature (freezing and chilling), reduction of water activity (addition of salt and sugar, or drying) and addition of preservatives, among others. These methods may be very effective, if correctly designed and applied, in inactivating or ensuring pathogenic microorganisms will not grow and reach levels that will impair food safety. Nonetheless, these methods usually result in changes in nutritional, chemical/biochemical and sensorial properties of foods that reduce their acceptance by consumers. In addition, environmental and wellness concerns served

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as basis for the development of novel food preservation methods (mild technologies) such as high pressure-based processes, pulsed light, among others, have been introduced into food industries (Georget et al., 2015; Jermann, Koutchma, Margas, Leadley, & Ros-Polski, 2015; Koutchma, 2009; Saldaña, Álvarez, Condón, & Raso, 2014; Serment-Moreno, Barbosa-Cánovas, Torres, & Welti-Chanes, 2014; Serment-Moreno, Fuentes, Barbosa-Cánovas, Torres, & Welti-Chanes, 2015). Despite this, it is the ability of a technology to efficiently destroy a microbial target that will determine its potential practical applications. Given this, the understanding of mechanisms and factors impacting on microbial inactivation by mild technologies, specially speaking about the main foodborne bacterial pathogens, is of foremost relevance for ensuring food safety. Therefore, in this paper a comprehensive review of literature on the key aspects of the application of mild technologies aiming to ensure the production of safe foods is presented.

2. Key microorganisms impacting on food safety

Foodborne illnesses can be defined as any disease originated from consumption of foodstuffs contaminated with microorganisms or chemicals (Tauxe, Doyle, Kuchenmüller, Schlundt, & Stein, 2010). Foodborne diseases cause the illness of several millions of people around the world. For instance, in the United States, an estimated 76 million illnesses occur annually, with more than 5.2 million of the infections that are attributed to foodborne pathogens (Mead et al., 1999). These infections result in 128,000 hospitalizations and around 3000 deaths annually in the United States (CDC, 2010). Due to their high morbidity and mortality rates, foodborne illnesses have taken great attention worldwide (Tauxe et al., 2010).

Salmonella spp., *Listeria monocytogenes, Campylobacter* spp., and *Escherichia coli* O157:H7 comprise the most important bacterial foodborne pathogens associated with foodborne diseases (Alocilja & Radke, 2003; Chemburu, Wilkins, & Abdel-Hamid, 2005).

The *Campylobacter* species such as *C. jejuni* and *C. coli* have long been recognized as the most important pathogens in veterinary field. Moreover, *Campylobacter* spp. have received special attention due to their repetitive occurrence in some foods for human consumption. *C. jejuni* is nowadays considered as the first causative agent of human foodborne infection in developed countries (Rantsiou & Cocolin, 2016). For instance, it was reported that both *C. coli* and *C. jejuni* species cause the infection of approximately 2.4 million persons annually in the United States (CDC, 2011). Also, *C. jejuni* is the most commonly isolated species from fecal specimens, with almost 90% of the reported cases (Fitzgerald, 2015).

Salmonella is the second most common bacterial pathogen involved in foodborne diseases after *Campylobacter.* After consuming contaminated foods, the symptoms (diarrhea, abdominal cramps, nausea, vomiting, fever, headache, and blood in the feces (Poppe, 2011) may appear usually after 12–72 h and last for 4–7 days. In most cases, *Salmonella* infections do not require hospitalization, but high risk groups (children, elderly and those who have weak immune system) are more prone to become ill and the illness might be more severe (Grant, Hashem, & Parveen, 2016). *Salmonella* infection cases are reported to be approximately 1.4 million in the United States of America annually, which result in approximately 16,000 hospitalizations and about 600 deaths (Cummings et al., 2010; Turner, 2010). In poultry industry, *Salmonella* and *Campylobacter* are considered as the major concerns compromising the safety of poultry products. It is widely recognized that chicken represents the major vehicle for these pathogens (Domingues, Pires, Halasa, & Hald, 2012; Greig & Ravel, 2009; Guo et al., 2011; Hermans et al., 2012; Newell et al., 2011). However, many other sources (raw or unpasteurized milk, eggs, meat, etc) have also been associated to salmonellosis (Gurtler et al., 2015; Poppe, 2011; Wingstrand & Aabo, 2014).

L. monocytogenes constitutes another major foodborne pathogen because of its psychrotrophic behavior (ability to grow below 7 °C) (Junttila, Niemelä, & Hirn, 1988; Walker, Archer, & Banks, 1990), under aerobic and anaerobic conditions (Välimaa, Tilsala-Timisjärvi, & Virtanen, 2015) and in a modified atmosphere packaging (Swaminathan & Gerner-Smidt, 2007). In addition, this bacterium is able to grow in a broad pH range (4.0–9.6) (Farber & Peterkin, 1991), and at low water activity levels such as 0.9 (Nolan, Chamblin, & Troller, 1992; de Daza, Villegas, & Martinez, 1991). These features make *L. monocytogenes* a great concern in food industry that requires very effective control measures to be implemented along the food chain (Lambertz, Ivarsson, Lopez-Valladares, Sidstedt, & Lindqvist, 2013). The disease caused by *L. monocytogenes*, i.e., listeriosis, is a severe foodborne disease that is associated with the consumption of fish, meat, dairy products, as well as fresh products. In fact, part of these food products have usually a long shelf-life, and their storage at low temperatures and in vacuum or modified atmosphere packages does not prevent the growth of *L. monocytogenes* (Välimaa et al., 2015). Despite this, it should be highlighted that *L. monocytogenes* has also been associated to foodborne disease outbreaks linked to the consumption of wholesome foods that are not necessarialy commercialized at low temperature conditions, such as fruits. *L. monocytogenes* can be isolated not only from raw and processed foods but also from environmental sources. It is a ubiquitous bacterium of special concern for specific population groups (e.g. pregnant women, babies, the elderly and people with reduced immunity), for which the illness can be more severe and even evolute to death.

The fourth main bacterial pathogen associated with foodborne diseases is *E. coli* O157:H7, which is mainly transmitted to food products, directly or indirectly, by the feces of cattle. Once contamination takes place during processing, foods reach humans and *E. coli* O157:H7 may cause the disease (Bari & Inatsu, 2014). This microorganism produces verocytotoxin or shiga-toxin (verocytotoxin-producing *E. coli*, or VTEC; Shiga-toxin producing *E. coli*, or STEC), which symptoms may include bloody diarrhea, hemolytic anemia, low platelet count and thrombocytopenia (Karmali, Gannon, & Sargeant, 2010). This type of pathogenic *E. coli* was identified for the first time in the late 1970s (Konowalchuk, Speirs, & Stavric, 1977) and their toxin structure (described as “Shiga-like” toxin) was recognized in 1983 to have similar structure and antigenicity as Shiga toxin produced by *Shigella dysenteriae* type 1 (O'Brien & LaVeck, 1983). VTEC strains involved in human diseases are especially found in cattle and foods of bovine origin (i.e. undercooked ground beef patties and unpasteurized milk) (Griffin & Tauxe, 1991; Rangel, Sparling, Crowe, Griffin, & Swerdlow, 2005). Other important foodstuff involved in VTEC outbreaks were well reviewed by Rangel et al. (2005) and include fresh products such as apple cider, spinach, lettuce, radish sprouts, alfalfa sprouts.

The burden caused by these and other foodborne pathogens have motivated the food industry to apply strict and robust hygienic protocols to avoid food contamination, as well as to develop inactivation methods to destroy microorganisms likely present. A recent and important trend due to consumer's demands is that inactivation methods must also preserve the sensory and nutritional aspects of foods, while ensuring a proper shelf-life.

3. Key aspects in the design of processes to ensure microbiologically safe foods during shelf-life

A food preservation method is considered as “ideal” when it allows improving the shelf-life (inactivation of pathogens and spoilage microorganisms), preserves the nutritional and