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Authors: M Morales-de la Peña, J Welti-Chanes, O
Martín-Belloso

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NOVEL TECHNOLOGIES TO IMPROVE FOOD SAFETY AND QUALITY

M. Morales-de la Peña [1]; J. Welti-Chanes [1], O. Martín-Belloso [1,2*]

[1] *Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, Centro de Biotecnología FEMSA, Av. Eugenio Garza Sada 2501 Sur, Col. Tecnológico, 64849 Monterrey, México*

[2] *University of Lleida, Department of Food Technology - Agrotecnio Center, Rovira Roure 191, 25198 Lleida, Spain*

[*]Author to whom correspondence should be addressed.

mail: omartin@tecal.udl.cat

HIGHLIGHTS

- Nonthermal technologies produce safe and high-quality foods
- Nonthermal technologies are more energy-efficient than conventional treatments
- Nonthermal technologies are a potential replacement of thermal treatments

ABSTRACT

The demand for fresh, healthy, convenient and safe foods has prompted the development of nonthermal technologies in the food area. Numerous investigations in high-hydrostatic pressures, pulsed electric fields, ultrasound, ultraviolet light, pulsed light and cold plasma have demonstrated their effectiveness to obtain safe products with high-quality standards compared to conventional processes. The understanding of their mechanisms of action has driven to the definition of critical parameters to achieve successful results, satisfying current consumers demands. This review aims to summarize the newest information about emerging technologies used to obtain safe and high-quality products.

Keywords: Nonthermal technologies, preservation treatments, food safety, microbial inactivation.

Introduction

The food preservation concept has gradually changed throughout years. Initially, its purpose was to obtain innocuous products with a long shelf-life. Today, fresh-like characteristics with high content of nutrients and antioxidants are some of the most requested attributes by consumers, without leaving aside food safety. Thermal sterilization/pasteurization treatments guarantee efficient reduction of microorganisms, but provoke significant loss of thermolabile compounds and negatively affect food sensory, physicochemical and nutritional properties [1*]. Hence, the investigation of nonthermal treatments (NTT) such as high hydrostatic pressure (HHP), pulsed electric fields (PEF), ultrasound (US), pulsed light (PL), ultraviolet light (UV), and cold plasma (CP) has increased during the last decades [2,3*].

NTT have demonstrated not only the capacity to assure food safety but also better quality attributes (Table 1), being more energy-efficient processes [4]. Consequently, they have gained industrial interest and are emerging as a potential replacement of thermal processes [5]. This review aims to summarize current information of the key aspects of NTT to obtain safe and high-quality foods.

Basic principles and recent applications

Even though the industrial application of NTT is quite recent, they have been investigated since the early 1900s. Each technology, HHP, PEF, US, PL, UV, or CP, has specific microbial inactivation mechanisms (Fig. 1) and its efficiency is related with processing parameters, type and microbial load, and food properties [6-17]. Complete information about the main parameters of NTT, their technological hurdles, modelling and processing optimization could be found in Barba et al. [2]

a. High-hydrostatic pressure (HHP)

HHP, the most well-developed NTT, is based on the application of high pressures (100-800MPa) to solid or liquid foods. The pressure is transmitted uniformly and quasi-instantaneously within the product through a liquid medium, usually water (Isostatic Principle) [2]. During the pressure build up, adiabatic heating occurs and water temperature increases around 3 °C every 100 MPa [18]. Therefore, HHP should be applied in high-moisture foods; while porous and dry foods are not suitable for this process [3]. According to Barba et al. [3], pressure, temperature, and treatment time are the most important parameters to be considered for processing optimization. Nonetheless, product intrinsic parameters and composition also have a significant influence on processing effectiveness [19].

Along the years, successful results on microorganism inactivation by HHP in plant-based products, egg-products, dairy-products, seafood, meat-products, and beverages have been reported [20-22]. Microbial inactivation by HHP is mainly due to the structural changes caused in the cell membranes [4,23]. Also, some chemical reactions induced by HHP produce microorganism breakdown [1,24,25]. Fungi are the most sensitive microorganisms to HHP, while some spores are highly resistant [26].

Despite the great advances achieved during the last decades, HHP keeps being evaluated to assure safety in novel foods such as hazelnut milk [27], chokeberry juice [28], cucumber juice, mango nectar [29] and prickly pear juice [30]. Overall, HHP has the same efficacy as conventional pasteurization without modifying nutritional and sensory properties of the product. Today HHP is applied at industrial level and numerous HHP-treated products are available in the market [31]. Furthermore, important challenges in the development of basic research and in the equipment design of high temperature and high pressure (HTHP) processing, are being faced in order to achieve food sterilization levels.

b. Pulsed electric fields (PEF)

PEF process involves the application of high-voltage pulses (15-80 kV/cm) during short time (µs-ms) to pumpable-foods passing between two electrodes [4]. For pasteurization purposes, only homogeneous liquids can be treated by PEF. Unlike other NTT, PEF has several critical parameters to be considered for processing optimization including electric field strength (*E*), treatment time, pulse-shape, pulse-width, pulse-frequency, pulse-polarity, and temperature. Among them, *E* is considered the most influencing factor on producing cell damages and thus microbial death [3]. By increasing *E* and treatment time, higher microbial inactivation is expected [32*]. Likewise, PEF effectiveness is highly impacted by the type of microorganism and medium characteristics [33**].

High safety level has been proved in PEF-treated foods by the inactivation of *E. coli*, *L. innocua*, *S. aureus*, *Enterobacteriaceae*, and *P. fluorenscens* [23,33,34*]. The main microorganism inactivation mechanism is the electroporation, which is the formation of pores on the cellular membrane [6]. Nonetheless, Cebrián et al. [35] and McAuley et al [36] recently concluded that structural arrangement of microbial enzymes, electromechanical compression, and osmotic imbalance could also explain microbial death.

Sterilization levels could not be achieved by PEF since the treatment cannot destroy spores on its own. Pillet et al. [37] reported that the cell envelope of *B. subtilis* spores is arranged in successive multilayers, which confers high resistance to PEF. Hence, its combination with thermal processing or other techniques has been proposed to achieve spore inhibition [1]. Cregenzán-Alberti et al. [38] showed that *B. subtilis* spores were decreased by 4.5-log after PEF-treatment of 10 µs, 38 kV/cm, 466 Hz at123 °C in skim milk. Even PEF is not suitable for food sterilization, it can be a potential option for acid products pasteurization, like fruit juices, with an excellent quality compared to heated foods [32].

c. Ultrasound (US)

US technology for food preservation purpose refers to pressure waves with a frequency of 20-100 kHz [39]. It is considered a simple, cheap and energy saving treatment [40]. US utilizes acoustic waves to increase productivity, yield, selectivity, and quality, while being environmentally sustainable [41]. According to Barba et al. [3] its effectiveness is determined by the frequency, power intensity, and treatment time.

US has the potential for ensuring food safety by the inactivation of pathogens/spoilage microorganisms in model systems and real foods such as milk, dairy products [1,32] and fruit juices: blueberry [42], orange [43], strawberry [44], apple [45], carrot [46] and pear [47]. Cavitation is the basic mechanism of action that causes microorganisms destruction [48,49]. However, when US is applied alone, it does not achieve 5-log reductions of microorganisms neither spores [50]. Thus, its effectiveness is enhanced when combined with temperature (thermosonication), pressure (manosonication) or both (manothermosonication) [48].

Guerrouj et al. [43] and Khandpur and Goate [51,52] corroborated that the synergistic effect of mild temperature and sonication improved microbial inactivation and physicochemical quality-attributes of treated products. Likewise, Evelyn and Silva [53] reported that US treatment (24k Hz/0.33 W/mL/1.5 min) at 70 °C enhanced the inactivation of *B. cereus* spores in rice porridge, beef slurry and cheese slurry. On the other hand, a US-processing followed by thermal treatment in beef slurry reduced the $D_{95°C}$-value of *C. perfringens* spores from 21.2 min to 9.8 min [54].

d. Light treatments: Ultraviolet light (UV) and pulsed light (PL)

PL involves the application of intense and short pulses (100-400 μs) of “white-light” (200-1110 nm) [55]. Among the PL spectrum, UV light is the most efficient to kill microorganisms, specially UV-C at 254 nm, being considered as a relatively inexpensive process [33,56]. The main parameters involved in processing efficacy are the medium transparency, energy dose, pulses number, and the depth of the samples for PL [57]and the power, wavelength and treatment time for UV [3].

During several years the main applications of UV-C and PL were surfaces and water decontamination [58]. Nonetheless, the use of PL and UV-C for food safety has been recently reported for fruit and vegetable surfaces, liquid-products and chicken-meat decontamination [50, 59]. Syamaladevi et al. [60] stated that UV efficacy for surface decontamination on apples, cherries, strawberries and raspberries depends on the fruit surface morphology. Else, high inactivation levels of TPC (>5-log) and total mesophilic count (>4-log) in tomato juice were achieved after UV at 254 nm [61]. Recently, McLeod et al. [59] observed that, by applying PL at different fluencies (1.25–18 J/cm^2), several pathogens of fresh chicken-meat were inactivated: 0.9–2.4-log (*Salmonella enteritidis*), 1.1–2.0-log (*Listeria monocytogenes*), 1.3–3.0-log (*Staphylococcus aureus*), 1.1–2.9-log (*Escherichia coli*), 1.7–3.0-log (*Pseudomonas*), 1.3–3.0-log (*Brochothrix thermospacta*), and 1.5–1.8-log reductions (*Carnobacterium divergens*). Essentially, the microbial inactivation mechanism by UV-C relies on disrupting nucleic acids, damages in the cytoplasmic membrane integrity and cellular enzyme activity [62]. Regarding PL, the inactivation mechanism is similar to that in UV, but PL also causes protein denaturation, and other photothermal and photophysical effects [63].

Although UV-C has poor penetration ability in dense and opaque liquids; manipulation of the flow rate enhances its effectiveness on microbial inactivation and turbulent flow lead to lower microbial load [63]. Regarding spore inactivation, UV has little effects; nonetheless, its application sensitizes them and improve the lethal effect of a subsequent thermal treatment [64]). On the contrary, PL is capable of inactivating spores [3]. Artiguez and de Maranon [65] reported 8-log reduction of *B. subtilis* and *G. stearothermophilus* spores using PL treatment of 1.7 J/cm^2 and 4.5 J/cm^2, respectively.

e. Cold plasma (CP)

CP is one of the newest NTT for food preservation, which has shown great potential as sterilization treatment [2]. Compared to thermal processes, CP uses less water and inferior temperatures, with lower operation costs [66,67]. Technically, plasma is produced by applying electromagnetic fields to gas (usually O_2 or N_2), generating a mixture of electrons, ions, atomic species, UV photons, and charged particles that react with the food substrate, releasing the stored energy into target microorganisms [68]. Main processing parameters are electric field, gas fed (pressure, type, flow, frequency), exposure time, and surrounding media [69].

CP has shown high efficiency to inactivate pathogenic/spoilage bacteria, spores, and viruses in vegetable products [68]. Ziuzina et al. [67] reported 7-log reductions of *Salmonella Typhimurium, L. monocytogenes* and *E. coli* in lettuce after a high voltage-CP treatment. Interestingly, Lacombe et al. [70] observed that CP inactivated microorganisms in blueberries. Generally, microbial inactivation occurs by different chemical reactions leading to the degradation of proteins, lipids, and cellular DNA [71]. Also, the accumulation of intracellular charged particles may induce apoptosis, electrostatic disruption [72] and electroporation [73]. Although a significant number of studies have indicated food safety through CP, further research should be conducted to completely understand its mechanism of action.

Conclusions

NTT produce safe products with high-quality standards that could meet consumer expectations. These emerging processes could be effectively applied for pasteurization purposes minimizing quality losses induced by heat. Furthermore, their combination with temperature showed great potential as thermal sterilization alternative. Nonetheless, there is a big challenge to fill the gaps in optimum process designing to maximize their effects in microbial inactivation and to apply them at commercial levels.

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Fruit and vegetable juices are some of the most important products most consumed worldwide. They are rich sources of bioactive and antioxidant compounds that could satisfy current consumers demand. However, their intrinsic characteristics make them a good medium for microbial growth and undergo rapid deterioration. Nonthermal technologies are suitable alternatives to heat pasteurization for achieving efficient microbial inactivation without the adverse effects caused by heat on this kind of products. This paper provides information of the application of NTT in fruit juices to obtain safe and high-quality fruit and vegetable juices.

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Currently, a lot of research has been conducted to find alternative processes for conventional preservation treatments. Despite the progress made so far, there are still technological limitations that prevent the use of novel technologies at industrial levels. This chapter describes the areas of opportunity, research needs and current challenges of different emerging technologies for food processing and preservation to successfully scale up at industrial levels.

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This review collects interesting information about the combination of mild thermal treatments and one non-thermal processing technology such as HHP, UV, PEF, US, PL, or CP in order to achieve sterilization levels in foods to assure safety and better quality attributes.

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This chapter focuses on the modelling and optimization aspects of emerging technologies such as PEF, HHP, and US to obtain safe liquid foods. Authors explain the multiphysics variables such as pressure, electrical field intensity and acoustic intensity, involved in these nonthermal treatments applied to kill pathogenic and deteriorative microorganisms present in foods.

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The inactivation of pathogen microorganisms in foods is fundamental in order to avoid foodborne diseases. Currently, different nonthermal technologies are being successfully applied to destroy these microorganisms, avoiding the negative effects caused by heat. This review gathers important information about the main mechanisms of action for *Salmonella, L. monocytogenes, E. coli* and *Campylobacter* inactivation by mild technologies applied in food products.

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Cold plasma has been applied to decontaminate food surfaces with successful results. Nonetheless, in this article, authors aimed to evaluate the effects of high voltage cold plasma to inactivate *Salmonella enterica* in orange juice. Obtained results corroborated the efficacy of CP on microorganism inactivation for more than 5 log reductions in this kind of product. In addition, no significant changes on physicochemical parameters such as pH or °Bx were observed after CP treatment.

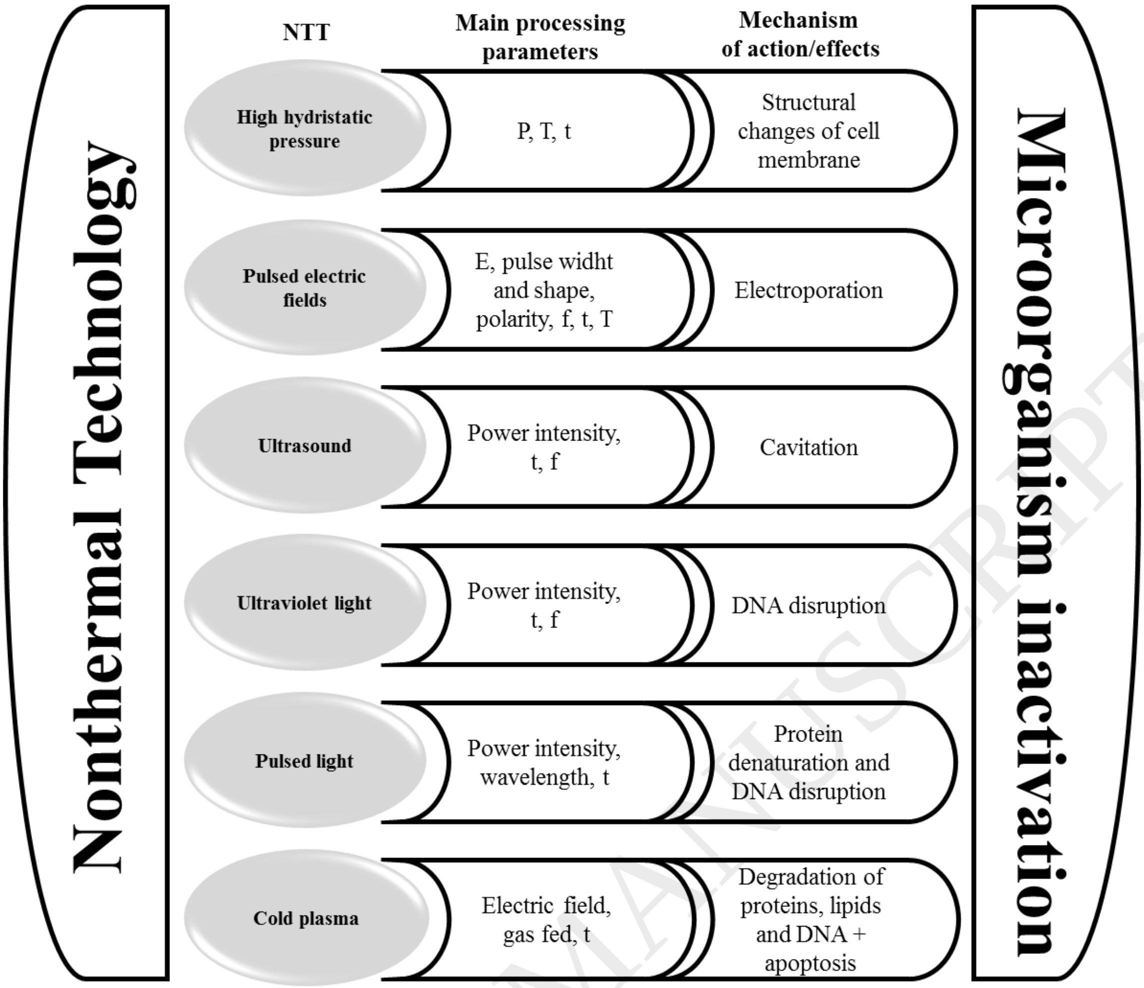

Figure 1. Main processing parameters and mechanism of action or effects in microbial inactivation of nonthermal technologies (NTT).
P: pressure, T: temperature, t: treatment time, f: frequency, E: electric field strength.

Table 1. Recent researches on the effects of nonthermal technologies (NTT) in food safety and quality.

NTT	**Treatment conditions**	**Matrix**	**Target microorganism**	**Microbial reduction**	**Quality effects**	**Reference**
HHP	500 Mpa, 10 min	Mulberry juice	*Total viable count, molds and yeasts*	4.38 log	Higher TPC, TF, resveratrol, and antioxidant capacity than thermal treated juices	74
PEF	35 kV/cm, 1800ms, 4µs-pulse width, 200Hz, bipolar pulses	Mango juice	*L. innocua*	5 log	Sensory properties and color were similar to fresh juice	75
US	24kHz,120 µm, 400W, 50 - 58°C, 0-10min	Carrot juice	*E. coli*	3.5 - 5 log	No significant differences in pH, °Bx, TA, TCC, TPC, ascorbic acid and color between fresh and sonicated juices	76
PL	60 - 240 flashes, 4.8 - 19.2J/cm^2	Tender coconut water	*E. coli*	5.2 log	pH, °Bx, and color showed no significant differences with fresh water	77
UV	18.4 mJ/cm^2	Orange-carrot juice blend	*E. coli, L. innocu, S. Typhimorium*	5 log	No significant changes in protein, vitamin C and antioxidant content.	78
CP	90 kV, air and MA65 gas, 30-120s	Orange juice	*S. enterica*	5 log	Minimal quality degradation	79*

TA: titratable acidity, TCC: total carotenoid content, TPC: total phenolic compounds, TF: total flavonoids