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An Appraisal of Novel Technologies for Microbial Inactivation in Food

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Abstract: An evolving array of technologies is currently in place to satisfy consumer's demand for fresh, safe and healthy foods that are free from harmful microorganisms and devoid of chemical preservatives. These processes make the food retain its nutritional and organoleptic characteristics while prolonging its shelf life. Health issues have also necessitated consumers concern about the microbial quality of processed foods. Maintaining product quality remains the goal of food manufacturers. Thermal processes such as pasteurization and sterilization exposes food to high temperature, this inactivates microorganisms present and prolong the shelf life of the food but could result in the loss of nutritional, textural and organoleptic characteristics of food. Some of the novel thermal and non-thermal technologies used for microbial inactivation in foods such as radio frequency heating, ohmic heating, microwave heating, infrared heating, high pressure processing, pulsed electric field, pulsed light, ultrasound, ozone, cold plasma, irradiation are discussed. Irrespective of the high capital cost (of some techniques like HPP, PEF), they have been shown to render food free of pathogens and spoilage organisms and improve shelf life and texture of foods. Most of these novel technologies are resistant to spores inactivation; thus finding applications as hurdles when used with conventional preservation methods, especially at ambient or moderately elevated temperatures and short treatment times to increase its effectiveness.

Keywords: Food Safety, Food Quality, Microbial Inactivation, Non-Thermal Technologies, Shelf Life

1. Introduction

Food preservation procedures are targeted towards inactivating or inhibiting the growth of microorganisms as they are the main agents responsible for food spoilage and food poisoning. Maintaining the quality of food is paramount when processing food for preservation. Thermal processes such as pasteurization and sterilization expose food to high temperature, which inactivate microorganisms present and prolong the shelf life of the food but could result in the loss of nutritional, textural and organoleptic characteristics of food. Also, consumers now lean towards having food free from harmful microorganisms and at the same time retaining its high nutritional and organoleptic qualities [29]. Thermal technologies used for preservation have resulted in the formation of chemical toxicants in food that are carcinogenic and thus harm the human body [71, 72]. This has led to extensive research into novel treatments of food. Heating techniques have made significant advances over the years. These technologies include ohmic heating, induction heating, microwave and radiofrequency heating. These methods known as modern thermal techniques, generate heat inside the food, thus, it is very efficient and produces a lot of energy. They have the potential to produce safer, nutrient-rich, organoleptic food that has almost no side effects due to prolonged heating of the product [1]. Since there is no chance for the formation of any undesirable products or by-products in or on the surface of food (as it is not exposed to higher temperature), the preservation effect of non-thermal technologies is more than that of thermal technologies [97].

Novel processes that are able to inactivate microorganisms at ambient or sub-lethal temperature are called non-thermal. Depending on the source of energy transfer, non-thermal technologies have different types of action. They could be used alone or in hurdle concept. Combining non-thermal processes with conventional preservation methods or hurdle technology can lead to effective microbial inactivation and allow the use of lower individual treatment intensities [16]. They are used in inactivation in radical formation (plasma, ultrasound, ozonation, UV light, etc.); mechanical action through hydrodynamic effects, shock waves (ultrasound and plasma), electric and magnetic fields (pulsed electric fields, cold plasma, radiofrequency and oscillating magnetic fields, electrohydrodynamic processing, and electron beam processing); or extremely high pressures that are causing rupturing and bursting of microorganisms [13, 63]. This review discusses some of the novel thermal and non-thermal technologies used for microbial inactivation in foods.

2. Thermal and Non-Thermal Food Processing Techniques

Major non-thermal food preservation techniques include: high pressure processing (HPP), pulsed electric field (PEF), pulsed light, irradiation, ultrasound, oscillating magnetic fields, and cold atmospheric plasma. The technologies can be grouped into two major groups: physical processes (pulsed electric field, high-pressure processing, ultraviolet radiation, pulsed light, ultrasound, and ionizing radiation) and chemical processes (ozone treatment, and cold plasma) [15]. For each non-thermal technology, there are specific applications in terms of the type of food processed, that is, theyare not applicable in processing every variety of food. For instance, pulsed electric fields are more suitable for liquid foods while irradiation is useful for solid foods. High pressure processing, oscillating magnetic fields, antimicrobials, light pulses, and hurdle technology are useful in processing both liquid and solid foods. Techniques like irradiation, light pulses and magnetic fields can be used to process prepackaged foods, reducing the risk of cross- or post-process contamination. In many cases, for non-thermal technology, the use of a combined method or hurdle approach is necessary [8].

Alzamora et al. [5] mentioned some successful synergistic preservation techniques combinations by various researchers such as:

1) High hydrostatic pressure and lowered pH which prevents microbial growth and the germination of spores that can survive HHP treatment at acidic pH.
2) High hydrostatic pressure and antimicrobial agents as sublethal injured cells by HHP become more susceptible to antimicrobials.
3) Pulsed electric fields and heat: high temperatures increase the fluidity and the thickness of membranes, increasing the lethality of PEF treatment.
4) Pulsed electric fields and antimicrobials: antimicrobials which act on the cell membrane may increase the susceptibility of membranes to dielectric breakdown and/or PEF may facilitate the access of antimicrobials that cross the membrane and acts in the cytoplasm.

3. Novel Thermal Technologies

3.1. Radio Frequency (RF) Heating/Dielectric Heating

This is a process of heating a dielectric material to create a high-frequency radiowave using a generator. Heat is quickly generated in the center of the food. It has numerous applications in the food industry which can be applied for continuous and batch heat processes. Compared to conventional thermal processing, RF requires less energy and penetrates deeply, rapidly and uniformly even in large size food particles [103]. Post-baking drying of biscuits, crackers and breakfast cereals, baking of bread, thawing of food products, disinfestation and sanitization of dry food commodities such as grains, seeds, legumes and dry fruits, and sterilization of packaged solid or viscous liquid food products may also be carried out using RF heating [44, 78, 99, 104].

3.2. Microwave Heating

Microwave heating used in both domestic and industrial operations is performed with electromagnetic microwave radiation (1–100 GHz) and heat transfer. It heats a food that is exposed to it due to the electric and magnetic fields that generate heat. Heating with microwave is not uniform and results in nutrient losses due to the high temperature of the heated surface [53]. Microwave intensity weakens as microwaves travel into the food product; the outer food surface absorbs more energy and heats up faster than the inner region. This results in uneven heating in deeper regions along with nutrient loss due to high surface temperature. The food industry has adopted the technique because of its rapid and uniform energy transfer, selective and volumetric heating, easily controllable and clean environment at the point of use [17, 95]. Microwave heating minimizes bacterial growth and also reduces the degradation of desired components in the food and have therefore, been efficiently used for drying of foods, baking of biscuits and breads, precooking and cooking of meals, cereals, meats and meat products, thawing of frozen food products, blanching of vegetables, pasteurization and sterilization of fast food meals and various other food products [56, 60, 64]. During baking applications, it helps to retain the distinctive flavor, color and texture and minimizes the cracking of the baked products [17]. Microwave heating has been successfully combined in batch and continuous forms with RF heating to obtain the benefits of both dielectric and conduction forms of heating [25].

3.3. Ohmic Heating

This is an electro-heating, or electro-conductive heating that has no penetration depth limitation compared to microwave and radio frequency heating. It heats food evenly, without damaging the nutrients in the food [100]. According to Abdilova et al. [1], ohmic heating has the capacity to destroy microorganisms and produce safe products by preserving nutrients and does not harm the quality of the products. Fast and uniform heating of the products can be achieved by this method. This technique has both thermal and non-thermal effects on the products concerned.

3.4. Infrared Heating

This is an indirect mode of heating which uses electromagnetic energy thatpenetrates the food, gets adsorbed on the surface and then converts to heat. Infrared radiation (IR) alters the quality of food by changing the flavor, aroma, and the color of the food surface [53]. It is used in the food industry for roasting, cooking, baking, dehydrating, drying, pasteurizing, peeling, bleaching, and food processing [65, 79]. Based upon its spectral range, IR are normally categorized into near-infrared (700-1400 nm), mid-infrared (1400-3000 nm), and far-infrared (3000-10000 nm) regions [79]. IR rapidly and uniformly heats the product which not only reduces the processing time and energy costs but also prevents the product overheating because of rapid heating rates [78]. It has been successfully employed to inactivate lipooxygenase, lipases, α amylases and other enzymes responsible for the development of off-flavors and deterioration of fruits and vegetables. Additionally, it is effective to inactivate bacteria, spores, yeast, and mold in both liquid and solid foods [10].

4. Non-Thermal Technologies

4.1. High-Pressure Processing (HPP)

HPP is one of the non-thermal technologies that uses high pressure to ensure food safety, extends microbiologically shelf life while importantly retaining food quality and freshness. HPP was first used for the preservation of milk as reported by Hite [41] and extended for processing and preservation of fruits and vegetables [42]. HPP uses pressure of 100-1000MPa for inactivation of microorganisms while higher pressures of >1,200 MPa are required to inactivate bacterial spores [50]. It acts uniformly and instantaneously throughout a mass of food independent of size, shape and food composition [46]. It is highly effective for sterilization when combined with other treatments and has also been studied as a means of reducing mycotoxins in food [6]. For foods to receive HPP treatment, it must be pre-packed in vacuum packs or plastic bottles as it is important that the packaging must be able to withstand the high pressures applied without leaching undesirable chemicals into the product nor losing seal integrity or barrier properties and also have the ability to return to its original shape [30]. HPP can be used for heat sensitive products as they can be conducted at ambient or refrigerated temperature which eliminates thermal effects [83]. Food types with high moisture content like fish and sea food, meat and dairy products, fruit and vegetable, juices, beverages and ready to eat foods are suitable for HPP while those containing air bubbles such as breads and mousses are not as they can be damaged by the high pressures applied [7, 30].

Factors like changes in the cell membranes, cell wall, proteins and enzyme-mediated cellular functions contribute to the inactivation of microorganisms by HPP [88]. The extent of deactivation is dependent on the applied pressure and temperature as well as by the intrinsic properties such as pH, water activity, fat contents, minerals and sugar contents, bacterial growth phase and pressure, temperature and time combinations that are applied [51]. At ambient temperature, vegetative bacteria, yeasts and viruses have been inactivated significantly at pressures higher than 300 MP. In practice, pressures up to 700 MPa and treatment times from a few seconds to several minutes are used to inactivate microbial cells. Generally, bacteria are more resistant to HPP than yeasts and molds; with Gram-positive bacteria being more resistant to pressurization compared to Gram-negative species, as a result of the presence of rigid teichoic acid in its cell wall [86]. Spores of bacteria are extremely resistant to HPP, though inactivation can be achieved by combining HPP with heat treatment as heat generated within the pressure is able to destroy the microbial spores which results in increasing the shelf life of food materials [27, 102]. When non-thermal treatments are applied at temperatures above room temperature, a higher microbial inactivation rate is usually observed. HPP have been used with the addition of essential oils (Eos) (from cinnamon) to effect inactivation of microorganisms as demonstrated by Gayan et al. [36]. It was concluded that food safety was enhanced with *L. monocytogenes* (which is pressure-tolerant) being inactivated in food as EOs act synergistically with HPP, leading to food products with higher sensorial properties and reductions in processing costs. A multi-hurdle strategy of combining HPP with other antimicrobial interventions to increase the lethality of HPP and decrease production costs is relied upon in meat processing [45]. Likewise, HPP can be combined with heat (process known as pressure-assisted thermal processing) to improve inactivation of pathogenic spores in meat products [87, 105].

Table 1. *Microbial inactivation by HPP in different food products.*

S/N	Food Product	Target microorganims	Pressure	Temperature	Holding time	Reduction	Reference
1	Maize	*Fusariumgraminearum*	380 MPa	60°C	30 min	100%	Kalagatur et al. [47]
2	Ground beef (HPP + extracts of *Melissa officinalis*)	Shiga toxin– producing *Escherichia coli*				3 - 6 log10 CFU/g	Chien et al. [18]
3	Dry-cured ham slices (HPP + enterocins)	*L. monocytogenes*	450	4°C and 12°C	10 min		Pérez-Baltar et al. [75]
4	Black olive oils	Total mold	250 MPa 250 MPa	25°C 4°C	5 min 5 min	90% 100%	Tokusoglu et al. [98]

S/N	Food Product	Target microorganims	Pressure	Temperature	Holding time	Reduction	Reference
5	Milk	*Clostridium perfringens*	600 MPa 900 MPa	65°C 100°C	12.5 min 5 min	2.54-log 4-log	Gao et al. [33] Shao et al. [85]
6	Beef broth	*B. stearothermophilus*	600 MPa	105°C	5 min	3-log	Devatkal et al. [21]
7	Cactus juice	Viable microbial cells, Yeast/Molds Acid tolerant microorganism	600 MPa	15°C	10 min	3 log	Moussa-Ayoub et al. [66]
8	Black Tiger Shrimp (*Penaeusmonodon*)	Total Microorganism *Escherichia coli* *Staphylococcus aureus*	100-435 MPa		5 mins	0.1-1.2 log CFU/g 0.4-1.5 log CFU/g 0.3-1.0 log CFU/g	Kaur et al. [48]
9	Oysters	*Vibrio parahaemolyticus*	200–300 MPa		5-10 mins	> 7.4 log CFU/g	Phuvasate and Su [76]
10	Octopus (*Octopus vulgaris*)	Psychrotropic bacteria	150–600 MPa		6 mins	0.1-2.8 log CFU/ml	Hsu et al. [43]

4.2. Pulsed Electric Fields (PEF)

This is an extensively used non-thermal processing treatment in the food sector. It applies short pulses (e.g. 1–50 μs) of very high DC voltages (≤100,000 V) at frequencies up to 1000 Hz to a food. The food is placed between two electrodes and subjected to PEF for a short period of time, often less than one second. It damages the cell wall of microorganisms, leading to the death of microbes and the reduction of the microbial load and has the capacity to inactivate enzymes and microorganisms at temperatures that do not negatively impact on the sensory or nutritional value of foods [30, 101]. The intensity of the electric field, pulse width, treatment time, pulse wave-shape and temperature play important roles in microbial reduction in food exposed to pulse electric field treatment [68]. It is very important that electric field intensity should be evenly distributed in the treatment chamber to achieve an efficient treatment, as PEF inactivation greatly depends upon intrinsic parameters of microorganisms like, shape, size, species, or growth stage [16]. The use of PEF mainly focuses on reducing food borne pathogens and spoilage microorganisms to produce safe foods with high retention of nutrients and extended shelf life. Gram positive vegetative cells are more resistant to PEF, than gram negative while, yeasts show greater sensitivity than bacteria. Bacteria and mold spores are resistant to PEF processing and thus, will not be inactivated. PEF is more suitable for liquid foods however; several solid products have been investigated to be efficiently treated by deploying PEF treatment [94]. Food products like milk, fruit juices, yoghurt drinks, apple sauce and salad dressings, soups, liquid eggs and liquid egg products have been shown to retain fresh like characteristics with increased shelf life [12, 16]. Though, this technology continues to have limited applicability in enhancing the microbiological safety of meat and meat products [90]. The PEF technology is more effective when used with other preservation methods, like high hydrostatic pressure.

4.3. Pulsed Light

Also known as pulse white light, pulsed ultraviolet (UV) light and high intensity broad spectrum pulse light [89]. It uses intense and short-duration pulses of broad spectrum. The wavelength range of pulse light is 200– 1100 nm, which includes ultraviolet (200–400 nm), visible (400–700 nm), and near-infrared region (IR) (700–1100 nm) [23, 73]. This technique uses light energy in concentrated form and exposes the substrate to intense short bursts of light (pulses). Typically for food processing about one to twenty flashes per second are applied. The intensity of light, which lasts for only a second, is 20,000 times brighter than sunlight, but there is no thermal effect, so quality and nutrient content are retained [14]. It is used to ensure microbial decontamination on the surface of food or packaging materials and equipment [2]. Microbial inhibition by PL is due to the broad spectrum UV content and the energy density applied. The use of UV with short pulse and high width instead of traditional UV ensures higher reduction of food pathogens [69]. The lethal effect of pulsed light can be due to photochemical or photothermal mechanism or both may exist simultaneously. The primary target cell of pulsed light in photochemical mechanism is nucleic acid as DNA is the target cell for these ultraviolet wavelengths. PL systems have relatively low operation costs and generate only reduced amounts of solids wastes.

The efficacy of PL as a preservation technology has been extensively reviewed. In a study by Hierro et al. [40], the surface application of PL at 8.4 J/cm^2 resulted in 1.78 and 1.11 $\log_{10}$ CFU/cm^2 reductions of *L. monocytogenes* in vacuum packaged cooked ham and bologna slices, respectively. Similar reductions were achieved for *L. monocytogenes* and *S. typhimurium* on the surface of dry cured meat products when pulsed light was applied at 11.9 J/cm^2 [32]. PL treatment have been used for surface decontamination of eggs contaminated with *Salmonella* cell [39, 54]; decontamination of surface of chicken from *Salmonella typhimurium* and *Listeria monocytogenes* using treatment of 1,000 pulses, duration of 200 seconds and total ultraviolet light dose 5.4 Joule/cm^2 [74]; treatment for freshly cut mushroom by flashing at 4.8, 12 and 28 Joules/cm^2 increased the shelf life by 2-3 days in comparison to untreated samples with 4.8 Joule/cm^2 increasing the shelf-life without affecting the texture and antioxidant properties [70]. *Saccharomyces cerevisiae* have been decontaminated from food powders using 58 Joule/cm^2 of pulsed light leading to a reduction in the microbial load by 7 log [28].

4.4. Ultrasound Processing

Ultrasound is defined as sound waves with frequencies above the threshold for human hearing (>16 kHz). Power ultrasound (16–100 kHz), high frequency ultrasound (100 kHz–1 MHz) and diagnostic ultrasound (1–10 MHz) are the three frequency ranges of ultrasound [92]. Practically, the use of ultrasound for food preservation have been effective in hurdle technology, when used in conjunction with different treatments i.e low temperature (ultrasonication), pressure treatment (manosonication), heat treatment (thermosonication) or both pressure and heat (manothermosonication). Ultrasonication involves generating sound waves in an ultrasonic bath (where the food material or packaged food is kept) that creates ultrasound effect which in turn brings about desired changes in food [59]. It was developed to ensure safety of food products as it ensures provision of high quality, minimal processed healthy products [52, 92]. In combination with heat, ultrasonication can quicken the rate of sterilization of foods, hence decreasing both the span and force of thermal treatment and the resultant harm. There is limitation on the lethal effects of low-power ultrasonic waves on microorganisms in foods, as high ultrasonic power is normally required to achieve a high level of microbial reduction [93]. Cheese, fish, meats, vegetables, bakery and snack foods, candy and confectionery are some food industries using ultrasonic food processing.

Ultrasound is effective against indigenous food spoilage microorganisms and has been applied to many liquid foods for inactivation of microbes [22, 82]. Also, there has been research on the inactivation effects of ultrasound on various human pathogens in foods, such as *Salmonella* species *Listeria monocytogenes*, *Escherichia coli* O157:H7, *Staphylococcus aureus*, and *Cronobactersakazakii* [81, 84]. In a study, ultrasonic was applied to apple cider and milk where the levels of *E. coli* O157:H7 and *Listeria monocytogenes* respectively were reduced by 5 log cfu/ml [34]. The effectiveness of an ultrasound treatment is dependent on the type of bacteria being treated; a variety of microorganisms (especially spores) are relatively resistant to ultrasound, thus extended periods of ultrasonication would be required to render a product safe [4, 77].

4.5. Ozone

Ozone has been applied in food processing successfully, specifically in sanitation by disinfecting food plant equipment and contact surfaces, packaging materials, water, air in storage and refrigeration systems, and for foods such as dried and fresh fruits and vegetables. It acts as a powerful sterilizer against gram-positive and gram-negative bacteria, bacterial spores, fungi, viruses, and protozoa [31, 57]. It affects the unsaturated lipids in the cell membrane causing leakage of cellular components that can lead to cell death. The shelf life and quality of different food products can be maintained using ozone through reduction of spoilage microorganisms [106]. The efficacy of ozone has been demonstrated against Gram positive (*Listeria monocytogenes, Staphylococcus aureus*, *Bacillus cereus*, *Enterococcus*) and Gram-negative (*Pseudomonas aeruginosa*, *Yersinia enterocolitica*, *Escherichia coli*) is one of the most sensitive to ozone damage, while Gram-positive cocci (*Staphylococcus* and *Streptococcus*) and Gram-positive bacilli (*Bacillus*) and mycobacteria are among the most resistant to ozone damage [55].

4.6. Cold Plasma

Plasma is of two types, the high temperature plasma (equilibrium plasma) and low temperature plasma (cold plasma). Low temperature plasma is further of two types, thermal plasma (quasi equilibrium) and non-thermal plasma (non-equilibrium plasma) [16]. Cold plasma works in the temperature range of 25-65°C [67]. This ambient temperature prevents thermal damage to heat-sensitive food material as it is non-dependent on high temperature for microbial inactivation [96]. The composition of plasma consists of combinations of ions such as UV photons, electrons, reactive species, and charged elements. The composition of the plasma reactive species largely depends on the composition of gas which is ionized [3]. The gases commonly used for the generation of plasma include helium, oxygen, nitrogen, and air [49]. The reactive species formed due to oxygen are found to be most effective against microbial cells which may result in the death of the microorganism. Cold plasma sterilization is safe, fast and chemical free method, widely used in the food sector for disinfection of processing equipment and food contact surfaces, extension of shelf life by reduction of microbial load in food and surface of food as well as, treatment of food packaging materials without altering their properties and inactivation of food spoilage enzymes. It has advantages over most other methods of decontamination as it does not require water or chemicals, leaves no chemical residues, and may be applied to thermally sensitive materials.

Applications of cool plasma treatment for food contact surface decontamination like glass, plastics and stainless steel is found to be effective for the inactivation of microorganisms, including bacterial spores. Though, treatment of more complex surfaces like food, is more challenging due to the limited penetrative capacity of plasmas; however, sufficient inactivation of pathogens has been observed on meat and in milk [11, 19, 62]. Time plays an important role in achieving the desired results in cold plasma treatment [20].

4.7. Irradiation

The irradiation of food is a process used to increase the shelf life, and improve the microbial safety of food. It is effective against pathogenic microbes including *E. coli*, *Staphylococcus*, and *Salmonella* [35, 80]. Irradiation process involves the application of electromagnetic waves or electrons to foods. Irradiation sources are either gamma rays from cobalt-60, electron beams or X-rays, and the amount of irradiation absorbed by a food is measured in kGy (1 Gy ¼ 1 J kg1) [61]. It works by passing energy waves through food products to generate reactive ions, free radicals and excited molecules. These in turn chemically attack essential biomolecules including the DNA and RNA, membrane lipids, of pathogens and spoilage microorganisms, causing their death or preventing them from reproducing [16]. Vegetative cells are less resistant to irradiation than spores, whereas moulds have a susceptibility to irradiation similar to that of vegetative cells. However some fungi can be as resistant as bacterial spores [24]. Irradiation of food does not significantly affect composition of food; any chemical changes in food due to irradiation are relatively minor and hence there is little change in the nutritional quality as well as no toxic or radioactive compounds being produced. Fresh fruit and vegetables are irradiated to control ripening, aging and germination.

Changing the intensity of irradiations shows more intense effects on the inactivation of microbes in food. Irradiation can destroy yeasts, molds and viable microorganisms with a dosage of 0.4-10 KGy, a dosage of 0.1-8 KGy is used to destroy non-spore forming food borne pathogens and a dosage of 10-50 KGy is used to sterilize food product by killing both vegetative bacteria and spores. A dose of 1-10 kGy can control food-borne parasites responsible for diseases such as trichinosis, while, a minimum dose of 0.15 kGy can prevent development of insect infestation in dried fish [26, 83]. However, high irradiation doses could lead to undesirable changes in food as seen in meats (where slight change in color and lipids may lead to rejection by consumers) and in cereals and food grains [9, 58]. Irradiation is usually done with a low dose and its effect is combined with other treatment like antimicrobial agents to achieve the desired inactivation in food with no or little change in the food composition [37]. However, the use of this technique in food preservation and processing still faces low consumer acceptance because of the perceived negative toxicity; thus, changing the views of consumers and encouraging them to buy irradiated food will influence the irradiated food market to a large extent.

4.8. Modified Atmosphere

Amending the food atmosphere to increase its shelf life is a modified atmosphere. This means the atmosphere of a package containing food is changed to get rid of microbial spoilage [38]. This process tries to lower the oxygen and increase the carbondioxide contents in the package which lowers the pH and inhibits the growth of microbes.

5. Conclusion

The need for enhancing food safety and quality without compromising the nutritional, functional and sensory characteristics of foods has necessitated interests in novel thermal and non-thermal processes for microbial inactivation and preservation of foods. Irrespective of the high capital cost (of some techniques like HPP, PEF), they have been shown to render food free of pathogens and spoilage organisms and improve shelf life and texture of foods. Most of these novel technologies are resistant to spores inactivation; thus finding applications as hurdles when used with conventional preservation methods, especially at ambient or moderately elevated temperatures and short treatment times to increase its effectiveness.

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