NON-THERMAL NOVEL FOOD PROCESSING TECHNOLOGIES. AN OVERVIEW

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Abstract

The conventional heat treatment is designed to ensure food safety but it can lead to undesirable changes both in the nutritional and in the sensorial properties of the foods. In order to avoid these unfavourable changes during the heat treatment, in the last decades novel non-thermal food technologies are receiving much attention. High Hydrostatic Pressure (HHP), Pulsed Electric Fields (PEF), High Voltage Arc Discharge (HVAD) and Cold Plasma (CP) are considered to be viable options for extending food shelf-life. This review presents some general aspects about HHP, PEF, HVAD, CP and makes a reflection on their opportunities and drawbacks for the food industry.

Keywords: High Hydrostatic Pressure, Pulsed Electric Fields, High Voltage Arc Discharge, Cold Plasma

1. Introduction

The thermal food processing is a classic technique for ensuring the microbiological safety of foods [1-2]. This technique leads to unwanted changes in the foods' sensory attributes (by overheating) or to low nutritional value of the food products [1-4]. The increased consumers' interest in high quality foods with higher nutritive value and fresh-like sensory attributes led to the development of a number of non-thermal food processing technologies as alterative to conventionally heat treatments [2, 5-6]. Among these novel technologies, High Hydrostatic Pressure (HHP) and Pulsed Electric Fields (PEF) are the most investigated ones [1, 7-9]. HHP is an innovative technology for food preservation that protects the foods' sensory attributes and produces minimal quality loss [2, 10-15]. In addition, HHP has the potential to improve energy efficiency and sustainability of food production [16]. Pulsed Electric Field (PEF) is a non-thermal technology that provides minimally processed, safe, nutritious and like-fresh foods to consumers [9, 17]. PEF has been commercially applied for preservation of liquid foods, as pre-step for solid food processes such as drying and for extraction [18]. These two technologies rely on the lethal effect of high hydrostatic pressures and strong electric fields, respectively and are entrusted to result in better quality retention and longer shelf-life [7, 9]. In the recent years, the High Voltage Arc Discharge (HVAD) and the Cold Plasma (CP) are also proposed as alternative non-thermal processing for foods. HVAD consists in application of electricity to pasteurize fluids by rapidly discharging electricity through an electrode gap, generating intense waves and electrolysis, thereby inactivating the microorganisms [19]. The use of arc discharge for liquid foods is unsuitable largely because electrolysis and the formation of highly reactive chemicals occur during the discharge. CP is a relatively unexplored decontamination technology which does not require extreme process conditions compared to HVAD treatment, [20]. Although several researches have demonstrated the effectiveness of plasmas for killing microorganisms, further studies into the nutritional and chemical changes in plasma treated food are required to accurately assess the effect of plasma treatment on product quality and shelf-life and to confirm that no harmful by-products are generated [21]. Although HHP, PEF, HVAD and CP offer great opportunities for food preservation, they are often technically difficult to apply into production practice, expensive and require specialized equipment and trained personnel [1].

Moreover, consumer acceptance and safety issues should be considered. The majority of European food producers are small companies with few resources and limited expertise to develop and implement novel emerging technologies. The aim of this review is to present some general aspects about HHP, PEF, HVAD, CP and make a reflection on the opportunities and drawbacks for the food industry.

2. High Hydrostatic Pressure

High hydrostatic pressure offers to food industry an innovative, emerging technology for food preservation which minimizes loss of physicochemical and nutritional quality matching consumer demands for like-fresh foods [10, 16]. HHP is used for preservation of a wide range of foods: meat, fish and seafood, dairy and vegetable products, ready-to-eat meals, but also for some fermented products such as beer or wine [10, 13, 15, 22-24]. The pressure acts mostly instantaneously and uniformly in all points of the foods which mean that no matter the food shape or size the effect of pressure in evenly distributed according to Pascal law [5,13]. HPP processing conditions are typically in the range of 300–800 MPa, combined with different time periods, in general minutes that should result in an inactivation of microorganisms [5, 14, 24]. The microorganisms inactivation mechanism with HPP takes place at low energy and does not promote the formation of unwanted chemical compounds, or free radicals that can result when foods are irradiated (for example) [5]. The 600 MPa pressure is considered by many authors as threshold value and also is considered to be economical and microbiologically safe for achieving the pasteurization level f it is combined with temperatures in the range 35-55 ºC [25-27]. The critical factors that may affect the inactivation efficiency of HPP are: pressure's level, time at pressure, time to achieve treatment pressure, adiabatic heating, decompression time, treatment temperature and product's initial temperature, the foods' intrinsic factors: *p*H, composition and a_w (water activity), packaging materials and extrinsic factors prior to processing, during storage and distribution [10, 27-28]. HHP has the potential to produce high-quality foods that display characteristics of fresh products and are microbiologically safe [10, 29]. An important advantage of HPP is that foods can be subjected to high pressure with or without packaging, which in former case eliminates the possibility of post-treatment contamination [10]. However, pressure treatment alone is often not sufficient for substantial reduction of viable spore counts, as spores of some species were found to survive up to 1200 MPa at room temperature [10, 30]. T0 cope with this important drawback of HHP, the combining pressure processing with other hurdles have been suggested: the increase of temperature and pressure, the increase in exposure' time, high pressure in lower *p*H environments, combination with some antimicrobial agents (for example nisin) [10, 30]. On the other hand, simultaneous application of high pressure and high temperature treatments can produce undesirable effects on food packaging films such as: lose the barrier to oxygen, delamination phenomena and unacceptable modifications of the integrity of the packaging structure [14]. In this case, the selection and optimization of packaging structures for HHP processing are of extreme importance to food manufacturers in terms of correct processing, shelf-life enhancement, economy, marketing, logistics, and distribution [14]. An important drawback of the HHP at the present time is the cost of this technogy.

HHP process should not be confused with hydrodynamic pressure process (HDP). Hydrostatic pressure refers to the characteristics of liquids and the pressure in a liquid, or exerted by a liquid on an immersed object. Hydrodynamics refers to the motion of the fluids and the force acting on solid bodies immersed in these fluids. HDP is a novel technology used to extend the shelf-life of meat products, in particular for tenderizing meat using shock waves from underwater detonation of explosive materials [31]. The effects of HDP treatment on further processed meat products are not fully understood and additional studies on processed meat products of various textures are necessary to determine the effect of HDP.

3. Pulsed electric fields

PEF is used in food industry to process and preserve liquid and semi liquid nature foods that do not have air bubbles. It is more efficient than traditional heat treatments of food and consequently it presents several advantages over conventional heat treatments: better retention of flavour, colour and nutritional value, improved protein functionality, increased shelf-life and reduced pathogen levels [2, 32]. PEF involves the discharge of high voltage electric short pulses which causes a transitory or a permanent permeabilization of the cell membranes [2, 33]. Successful application of the PEF treatment depends on biological factors, such as: cells` type, size and shape of the cells, cells' density, arrangement and cells` position; dielectric breakdown and physical and chemical properties of foods are also considered (conductivity, *p*H, and ionic strength) [2]. The use of PEF food processing has numerous advantages, such as: the PEF processing inactivate microorganisms with minimal or no effect on the quality attributes of food; retention of the fresh aroma and flavour of the food; it can also be applied in other industrial food processes such as extraction of sugar from plants; in terms of efficiency the PEF technology is better than the traditional thermal methods that take long periods of time [34].

However, some authors pointed out that the PEF technology has a major drawback. It is the fact that spores of microorganisms are able to survive the PEF food processing [35]. The issue of resistant spores hence makes the choice of thermal food treatment methods preferable than the use of the PEF technology. Spores that persist in the food during the processing in industries would lead to spoilage of food sooner than expected. Other drawbacks are connected with the use of PEF systems that has not been optimized because adequate research has not been done to justify the use of the systems in the food processing industries.

There is limited commercial availability of PEF processing systems because of the high initial costs. The initial investment costs of the PEF technology are higher than the other food processing systems such as refrigeration [36]. The technical and economic limitations of acquisition of the PEF systems have therefore contributed to their reduced application in food processing as compared to the thermal methods. The high cost of the PEF systems has contributed to the resistance of the food processing industry in purchasing these systems. Therefore a major part of the food industry have opted to use conventional food processing methods such as canning and refrigeration as opposed to application of the PEF technology.

The combination of HHP and PEF is one of the most attractive combinations of emerging technologies that was not studied so far, due to the supposed synergistic effect of HPP and PEF on the inactivation of microorganisms.

4. High Voltage Arc Discharge

The arc discharges have been used in many areas such as biochemistry, biology, medicine, microbial inactivation of food and also for bio-compounds extraction from different products [37-40]. One of the most important features of this technology is the generation of strong dynamic shock waves generated by an electrical arc [40]. The arc discharge leads to a multitude of physical and chemical effects. The high pressure shock waves can induce bubbles cavitations which can create strong secondary shocks with very short duration. These shocks can interact with structures of the cells. The phenomena result in mechanically rupture of the cell membranes that accelerate the extraction of intracellular compounds [40-41]. The voltage arc discharge prompts the formation of highly reactive free radicals from chemical species in foods, such as oxygen. The free radicals are toxic compounds that serve to inactivate certain intracellular components required for cellular metabolism. The bacterial inactivation was not due to heating, but mainly to irreversible loss of membrane function as a semipermeable barrier between the bacterial cell and the environment. Moreover the formation of toxic compounds (oxygen radicals and other oxidizing compounds) was noticed.

The major drawbacks of this electrical method are the contamination of the treated foods by chemical products of electrolysis and disintegration of food particles by shock waves. The method based on continuous high voltage arc discharges may be unsuitable for use in the food industry [42].

5. Cold Plasma

Cold plasma is a novel non-thermal food processing technology designed for the inactivation of pathogenic microoganisms and food safety improvement [43]. CP is a ionized gas that comprises a large number of different species such as electrons, positive and negative ions, free radicals, electrons and gas atoms, photons and it is suitable to be used in processes for which high temperature is not recommended [44-45]. CP could be employed in inactivation of the microorganisms on the surface of fresh and processed foods. The accumulation of charged particles can rupture the cell membrane. Oxidation of the lipids, amino acids and nucleic acids with reactive oxygen species and nitrogen species cause changes that lead to microbial death or injury. Contribution of mentioned mechanisms depends on plasma characteristics and on the type of microorganisms [46-48]. CP has been applied in the food industry including for decontamination of raw agricultural products (apple, lettuce, almond, mangoes and melon), egg surface and real food system (cooked meat, cheese) [49]. However, there are few studies on the application of this technology in real food systems and on the effects of cold plasma on nutritional and chemical properties of food are not known well.

Key limitations for cold plasma are the relatively early state of the technology development, the variety and complexity of the necessary equipment, and the largely unexplored impacts of cold plasma treatment on the sensory and nutritional qualities of treated foods. The treatment must be proven not to have negative impact on the organoleptic and nutritional properties of foods. Hence, it is necessary for further studies to specify the extent in which CP affect the chemical and the nutritional properties of foods and its shelf-life [43]. Furthermore, the studies which explore the safety and cost aspects to apply into practice the CP and for scaling up this technology in food industry should be addressed to determine the applicability of this method [50]. Combining the CP treatment with other non-thermal processes could be a possible future breakthrough in this field. In this case, synergistic effects may be more considerable, however scaling up this technology remains for the moment a challenge to be solved.

6. Conclusions

The novel non-thermal emerging technologies for food processing already mentioned (HHP, PEF, HVAD and CP) hold potential for producing safe foods. Both the HHP and the PEF technologies are considered to be very promising alternative to classical processing technologies. A clear advantage of two techniques for certain operating parameters is the inactivation of microorganisms with maintaining of the foods' sensory attributes and minimal quality loss. However, for HVAD and CP emerging technologies, that kind of information is still scarce or nonexistent in the published literature. Because of the limited information about the nutritional and chemical changes in food products treated with CP technology, specially, sensitive food which have high amounts of lipid and vitamins are additional issues that must be considered. Current limitations, related with high investment costs, full control of variables associated with the process operation have been delaying a wider implementation of these technologies at the industrial scale.

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