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Emerging technologies: chemical aspects

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Abstract

Consumer demands for high-quality foods with "fresh-like" characteristics that require only a minimum amount of effort and time for preparation has led to the introduction of convenience foods preserved by mild treatments. Non-thermal methods allow the processing of foods below temperatures used during thermal pasteurisation, so flavours, essential nutrients, and vitamins undergo minimal or no changes. Foods can be non-thermally processed by irradiation, high hydrostatic pressure, antimicrobials, ultrasound, filtration, and electrical methods such as pulsed electric fields, light pulses, and oscillating magnetic fields. Due to technological developments, high pressure processing and high electric field pulse processing have received increased attention during the last decade. This paper focuses on high pressure treatment of foods, a process which is also used to create food and food ingredients with new sensory and functional properties including also physiological functionality. Effects of high pressure on chemical and sensory changes in foods are discussed.

Keywords: Non-thermal; Food processing; High hydrostatic pressure; High electric field pulses

1. Introduction

Food processing procedures like cooking, blanching or freezing are familiar to the consumers, because they apply them in their own households. In the food industry these and other operations are carried out by the aid of modern process-technology plants utilising technical possibilities, that are normally not available for the consumer. Modern food technology on the one hand deals with further development of traditional methods, e.g. high-temperature short time heating or vacuum cooking, and on the other hand with procedures, that have been taken over from different industry-branches and adapted to food processing, e.g. extrusion, microwave-technology or high pressure-treatment. Newly developed food technologies usually focus on preservation while keeping food quality attributes. Therefore the frequently used concept of "minimal processing" is not absolutely apt, since actually the principle "as little as possible, but as much as necessary" is meant.

Table 1 lists newer physical food preservation methods, that have been developed in the last few years and decades. They can be divided into thermal and non-thermal procedures. Special attention of research and development is on the non-thermal "cold" procedures. The expectation is, that undesirable micro-organisms and enzymes are inactivated without damage to nutritional and sensory properties resulting normally from thermal treatment. In the following the principles and possible applications of a selection of newer physical procedures are described. Some are already used industrially while others are still in development or testing.

2. Ohmic heating

Ohmic heating is a thermal method that minimises energy input and thus reduces thermal damage to food. If an electric current is passing through a conductive medium, in this case the food, the medium warms up as a result of the movement of ions. The conductive electric resistance heating—ohmic heating—utilises the effect of the electrical resistance within a conductive liquid or solid material. In this manner a direct conversion of electric energy into heat takes place. In production plants the product is continuously pumped through a column

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Table 1
New non-thermal food processing methods

Process	Description	Critical factors	Mechanism of inactivation	Status
UV-light/pulsed light	UV radiant exposure, at least 400 J/m^2	Transmissivity of the product, the geometry, the power, wavelength and arrangement of light source(s), the product flow profile	DNA mutations induced by DNA absorption of the UV light	Used for disinfection of water supplies and food contact surfaces
	Intense and short-duration pulses of broad spectrum (ultraviolet to the near infrared region)			
Ultrasound	Energy generated by sound waves of 20,000 Hz or more	The heterogeneous and protective nature of food (e.g. inclusion of particulates) severely curtails the singular use of ultrasound for preservation	Intracellular cavitation (micro-mechanical shocks that disrupt cellular structural and functional components up cell lysis)	Combination with e.g. heat, pressure has certain potential
Oscillating magnetic field (OMF)	Subjecting food sealed in plastic bags to 1–100 OMF pulses (5–500 kHz, 0–50 °C, 25–100 ms)	Consistent results concerning the efficacy of this method are needed	Controversial results on effects of magnetic fields on microbial populations	Application at the moment not considered
Pulsed electric field (PEF)	High voltage pulses to foods between two electrodes (<1 s; 20–80 kV/cm; exponentially decaying, square wave, bipolar, or oscillatory pulses at ambient, sub-ambient, or above ambient temperature)	Electric field intensity, pulse width, treatment time, temperature, pulse wave shapes, type, concentration and growth stage of microorganism, pH, antimicrobials, conductivity and medium ionic strength	Most theories studied are electrical breakdownand electroporation	Different laboratory- and pilot-scale treatment chambers designed and used for foods, only two industrial-scale PEF systems available
High pressure processing (HPP)	Liquid/solid foods, with/without packaging (100–800 MPa, below 0 °C to >100 °C, from a few seconds to over 20 min Instantaneously and uniformly throughout a mass of food independent of size, shape and food composition	Pressure, time at pressure, temperature (including adiabatic heating), pH, composition	Denaturation of enzymes, proteins; breakdown of biological membranes; cellular mass transfer affected	In use since 1990 (Japan, USA, France, Spain) Current pressure processes include batch and semi-continuoussystems

equipped with several electrodes. The advantage of ohmic heating is its ability to heat materials rapidly and uniformly, including products containing particulates (Parrott, 1992). The principal mechanisms of microbial inactivation in ohmic heating are thermal while some evidence exists for non-thermal effects of ohmic heating as well (Cho, Sastry, & Yousef, 1996). A large number of potential future applications exist for ohmic heating, including its use in blanching, evaporation, dehydration, fermentation and extraction. Ohmic heating is employed in pasteurising and sterilising of liquid and particulate foods, especially of ready-to-serve meals, fruits, vegetables, meat, poultry or fish, and is an alternative to sterilisation of foods by means of conventional heat exchangers or autoclaves. The applicability is limited to foods with sufficient conductivity.

3. High electric field pulses

The first attempts to treat foods (milk) with electro-impulses were reported at the end of the 1920s in the USA (Fetteman, 1928). Further experiments followed in the 1960s primarily within molecular-biological research for incorporation of foreign gene material into micro-organisms. During the last few years research in the food-area has been reinforced again.

High intensity pulsed electric field (PEF or HELP) processing involves the application of pulses of high voltage (typically 20–80 kV/cm) to foods placed between two electrodes. HELP may be applied in the form of exponentially decaying, square wave, bipolar, or oscillatory pulses and at ambient, sub-ambient, or slightly above-ambient temperature for less than 1 s. Energy loss due to heating of foods is minimised, reducing the detrimental changes of the sensory and physical properties of foods (Barbosa-Canovas, Gongora-Nieto, Pothakamury, & Swanson, 1999; Jeyamkondan, Jayas, & Holley, 1999). Microbial inactivation by HELP has been explained by several theories. The most studied possibilities are electrical breakdown and electroporation (Grahl & Maerkl, 1996). Electric high-voltage-impulses generate a trans-membrane potential across the cell membrane of, for example, a bacterial cell which overlays the natural membrane potential. If the difference between outer and inner membrane potential rises above a critical value of about 1 V, polarisation and in the end breakdown of the membrane is induced. At sufficient high field-strength (above 10 kV/cm) and duration of the pulses (usually between nano- and microseconds) vegetative micro-organisms in liquid media are inactivated due to irreversible membrane destruction. Bacterial spores, however, are not inactivated. Factors that affect the microbial inactivation with HELP are process factors (electric field intensity, pulse width, treatment time and temperature and pulse wave shapes), microbial entity factors (type, concentration and growth stage of micro-organism) and media factors (pH, antimicrobials and ionic compounds, conductivity and medium ionic strength). Important aspects in pulsed electric field technology are the generation of high electric field intensities, the design of chambers that impart uniform treatment to foods with a minimum increase in temperature and the design of electrodes that minimise the effect of electrolysis. Different laboratory- and pilot-scale treatment chambers have been designed and used for HELP treatment of foods. Two industrial-scale HELP systems are available including treatment chambers and power supply equipment. HELP has been applied mainly to improve the quality of foods. Application of HELP is restricted to food products that can withstand high electric fields, i.e. have low electrical conductivity, and do not contain or form bubbles. The particle size of the liquid food in both static and flow treatment modes is also a limitation. Although HELP has potential as a technology for food preservation, existing HELP systems and experimental conditions are diverse, and conclusions about the effects of critical process factors on pathogens of concern and kinetics of inactivation need to be further studied.

Based on practical experience from pilot plants employment of HELP will mainly be in the sparing pasteurisation of liquid foods e.g. juices, milk or liquid whole egg. Conclusive data on the absence of potential health risks or on the impact of the process on food components are hardly available yet.

4. Light pulses

Pulsed light is a method of food preservation that involves the use of intense and short-duration pulses of broad spectrum "white light" (ultraviolet to the near infrared region). For most applications, a few flashes applied in a fraction of a second provide a high level of microbial inactivation (Barbosa-Canovas, Palou, Pothakamury, & Swanson, 1997). This technology is applicable mainly in sterilising or reducing the microbial population on packaging or food surfaces. It could be shown that light-impulses are able to extend the durability of bread, cakes and pastries, sea food or meat. As light pulses penetrate certain packaging materials, wrapped items also can be treated. Still there is a need of independent research on the inactivation kinetics under a full spectrum of representative variables of food systems and surfaces.

5. Oscillating magnetic fields

Experiments have shown, that strong static (SMF) or oscillating (OMF) magnetic fields (5–50 Tesla) have the potential to inactivate vegetative micro-organisms. The impulse duration is between 10 μs and several miiliseconds. The frequencies are maximally 500 MHz, because above that value the items begin to warm up noticeably. Preservation of foods with OMF involves sealing food in a plastic bag and subjecting it to 1–100 pulses in an OMF at temperature of 0 to 50 °C for a total exposure time ranging from 25 to 100 ms (Pothakamury, Barbosa-Cánovas, & Swanson, 1993). The effects of magnetic fields on microbial populations have produced controversial results (e.g. Tsuchiya, Nakamura, Okuno, Ano, & Shoda, 1996). Before considering this technology for food preservation purposes consistent results concerning the efficacy of the method are needed.

6. Ultrasound

Ultrasonic waves (energy generated by sound waves of 20,000 Hz or more) generate gas bubbles in liquid media, that produce a high temperature- and pressure increase when they immediately burst (Vollmer, Everbach, Halpern, & Kwakye, 1998). The bactericidal effect of ultrasound is attributed to intracellular cavitation, that is, micro-mechanical shocks that disrupt cellular structural and functional components up to the point of cell lysis. Critical processing factors are the nature of the ultrasonic waves, the exposure time with the micro-organisms, the type of micro-organism, the volume of food to be processed, the composition of the food, and the temperature.

The effects, however, are not severe enough for a sufficient reduction of micro-organisms so most applications use combinations with other preservation methods (Raso, Pagan, Condon, & Sala, 1998). Because of the complexity and sometimes protective nature of the food the singular use of ultrasound as a preservation method is impracticable. Although ultrasound technology has a wide range of current and future applications in the food industry, including inactivation of micro-organisms and enzymes, presently, most developments for food applications are non-microbial. There are not many data on inactivation of food micro-organisms by ultrasound. Research activities centred on the combination of ultrasound with other preservation processes (e.g. heat and mild pressure) which appears to have the greatest potential for industrial applications.

7. High pressure processing

The technology of high pressure processing (HPP), also referred to as ultra high pressure UHP) or high hydrostatic pressure (HHP) has been known to be a potential preservation technique for more than a century (e.g. Hite, 1899); for instance, microbial spoilage of milk could be delayed by high pressure. Technical-scientific progress has led to a renaissance of food pasteurisation by hydrostatic high pressure recently (Cheftel, 1992; Hayashi, 1992; Tauscher, 1995). A range of pressure-treated products has already been introduced into the markets of Japan, France, Spain and USA. HPP subjects liquid and solid foods, with or without packaging, to pressures between 100 and 800 MPa. Process temperature during pressure treatment can be from below 0 °C to above 100 °C. Exposure times can range from a few seconds to over 20 min.

Food treated in this way has been shown to keep its original freshness, colour, flavour and taste. HPP acts instantaneously and uniformly throughout a mass of food independent of size, shape and food composition. Compression will increase the temperature of foods approximately 3 °C per 100 MPa and may also shift the pH of the food as a function of imposed pressure. Pressure pasteurisation is feasible also at room temperature and energy saving as compared to heat treatment. Water activity and pH are critical process factors in the inactivation of microbes by HPP. An increase in food temperature above room temperature and to a lesser extent a decrease below room temperature in some cases increases the inactivation rate of micro-organisms during HPP treatment. Temperatures in the range of 45–50 °C appear to increase the rate of inactivation of food pathogens and spoilage microbes. Temperatures ranging from 90 to 110 °C in conjunction with pressures of 500–700 MPa have been used to inactivate spore-forming bacteria such as *Clostridium botulinum*. Current pressure processes include batch and semi-continuous systems.

Besides destruction of micro-organisms (e.g. Smelt, 1998) there are further influences of pressure on food materials to be expected: protein denaturation or modification, enzyme activation or inactivation, changes in enzyme–substrate interactions, changes in the properties of polymer carbohydrates and fats (e.g. Heremans, 1995). Generally any process and any reaction in food to which the principle of Le Chatelier applies are of interest. According to this principle, under equilibrium conditions, a process associated with a decrease in volume is favoured by pressure, and vice versa. An increase of pressure has been found to change the reaction rate of chemical reactions in solution. But this effect is small as compared to the influence of temperature. The renewed interest in high-pressure pasteurisation of food has raised questions e.g. on the pressure–temperature behaviour of macromolecular food components such as proteins, lipids and polysaccharides. For example, the mechanism of protein gelation and of the sol/gel behaviour of polysaccharides are not well understood. Little is known so far about chemical reactions of low-molecular weight compounds in the food

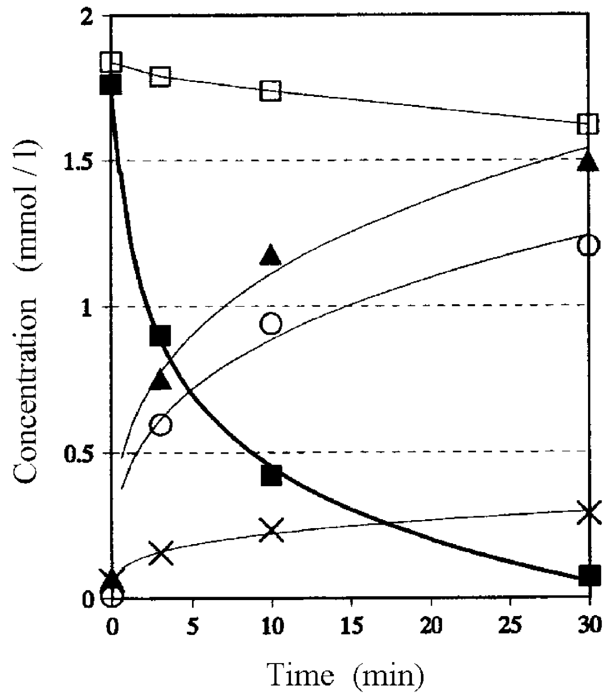

Fig. 1. High pressure treatment of aspartame (1.7 mmol/l) in full cream milk; ■ aspartame; □ aspartame control at 60 °C; ▲, molar sum of aspartylphenylalanine and diketopiperazine; O, diketopiperazine; ×, aspartylphenylalanine.

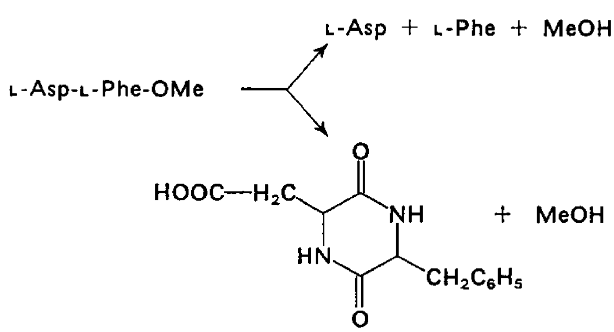

Fig. 2. Intramolecular condensation of aspartame yielding a diketopiperazine degradation product and aspartylphenylalanine.

matrix under pressure, usually in aqueous media. High pressure, on the other hand, has for long been a means of manipulating organic-chemical reactions (e.g. Le Noble, 1988). High pressure influences organic reactions in general. So at pressures >500 MPa which are employed for food sterilisation chemical reactions in the food are to be expected which may be of desirable character or not.

Examples for potential chemical changes are given in the following: Butz, Fernandez, Fister, and Tauscher (1997) investigated the stability of the artificial sweetener aspartame in milk, TRIS-buffers and water during different pressure-treatments (600 MPa, 60 °C, 3–30 min). As shown in Fig. 1 after a holding-time of not more than 3 min only about 50% of the original content of active aspartame was detectable in the milk (pH 6.8).

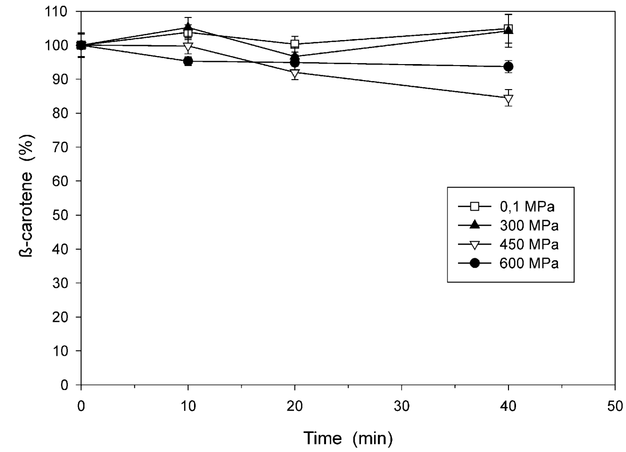

Fig. 3. Effect of different pressure treatments at 75 °C on β-carotene content in carrot puree.

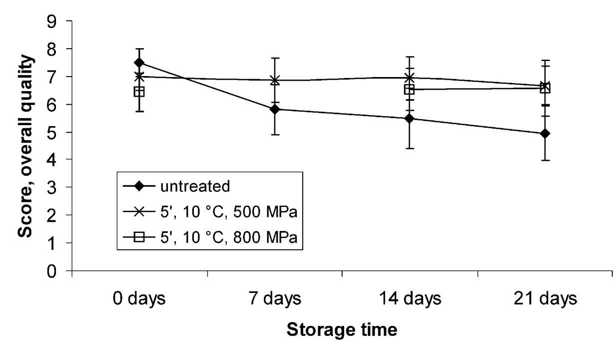

Fig. 4. Overall sensory quality of orange/lemon/carrot mixed juice (OLC) as a function of high pressure treatment and storage time at 4 °C. The scores correspond to the following general descriptions: 9.0–7.0, perfect, optimal to typical with slight deviations; 6.9–5.5, noticeable deviations to noticeable detractions and slight defects; 5.4 to 3.0, distinct to strong defects.

The non-sweetening components aspartylphenylalanine and a diketopiperazine had been formed (Fig. 2). These components are also formed during normal storage, but very much slower. The observed decay within a few minutes of HPP is comparable with storage of, for example, Diet Coke for more than 200 days at 20 °C. From Fig. 1 it is obvious, that the molar sum of these two components correspond to the decay of aspartame. In acid media like fruit preparations or juices or carbonated drinks like Diet Coke aspartame is insensitive to pressure.

Another example of pressure-induced chemical changes concern certain carotenoids. We investigated in the stability of β-carotene in model solutions and in carrots under pressure and different temperatures. It has been shown that carotene in ethanolic model solutions after 20 min at 75 °C is reduced by more than 50% (Tauscher, 1998). Protecting the sample from oxygen does not reduce the loss of β-carotene under pressure/temperature. The main degradation products are in all cases 9-*cis*- and 13-*cis* β-carotene. In carrot puree, the carotenoids are well protected against pressure/temperature attack since they are buried in lipophilic environments. Fig. 3 shows that even after 40 min at 600 MPa and 75 °C, the initial amount of β-carotene has not been reduced significantly. This demonstrates the importance of the food matrix and its beneficial protective action.

Thermally pasteurised fruit juices are often characterised by a loss of desirable fresh flavour characteristics. This flavour difference makes the freshly squeezed, unpasteurised juice a unique product that is perceived by customers to be of superior quality, but it's shelf-life is very limited as is the safety status. The non-thermal pasteurisation using high pressure is said to extend shelf-life, guarantee safety and maintain fresh quality. The effect of different high pressure treatments on odour and aroma of an orange–lemon–carrot (OLC) juice mixture (40 parts of orange juice, five parts of lemon juice, 20 parts of carrot juice and 35 parts of water containing 8.5% sucrose) was studied using the triangular "Forced Choice" technique. The juice mixture, furthermore, was analysed as a function of high pressure treatment and storage time (up to 21 days at 4 °C). In OLC mixed juice treated at 500 MPa (5 min), the changes in odour and flavour were only small and not significant in the sensory triangle test. After storage for 21 days at 4 °C, odour and flavour quality and the originally harmonious impression of the non-treated OLC juice—determined by a trained panel using a 9-score rating scale—decreased significantly (Fig. 4). In the high pressure treated juices, changes in odour, flavour and overall quality were scarcely noticeable after this storage time. Thus, in this case high pressure treatment really met the expectations.

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