Emerging Technologies Towards Food Preservation

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Modern food technology deals with further developing of traditional methods e.g. high-temperature short time heating or vacuum cooking and also with procedures, that are taken over from different industry-branches and are adapted to food processing, e.g. extrusion, microwave-technology or high pressure-treatment. Newly developed food-technologies usually focus on a sparing preservation being careful with 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. The newer physical methods for food preservation that have been developed in the last years and decades 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.

Ohmic heating

Ohmic heating (also: Joule heating, electroconductive heating, direct electrical resistance 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, it 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 equipped with several electrodes. The advantage of ohmic heating is its ability to heat materials rapidly and uniformly, including products containing particulates[1]. The principal mechanisms of microbial inactivation in ohmic heating are thermal, while some evidence exists for non-thermal effects of ohmic heating[2]. A large number of potential future applications exist for ohmic heating, including its use in blanching, evaporation, dehydration, fermentation and extraction. The applicability is limited on foods with sufficient conductivity. Ohmic heating is employed to pasteurising and sterilising liquids 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.

Processing with ultrasonic waves

Ultrasonic wave technology employs energy generated by sound waves of 20,000 or more vibrations per second. Ultrasound generates gas bubbles in liquid media, that produce a high temperature and pressure increase when they immediately burst[3]. 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[4]. Because of the complexity and sometimes protective nature of the food the singular use of ultrasound as a preservation method is impracticable. There are not many data on inactivation of food micro-organisms by ultrasound. It seems that 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. Combinations of ultrasound with other

preservation processes (e.g. heat and mild pressure) appear to have the greatest potential are the main subject of research activities.

Treatment with high intensity pulsed electric fields

High intensity pulsed electric field (PEF, also HELP) processing involves the application of pulses of high voltage (typically 20-80 kV/cm) to foods placed between 2 electrodes. First attempts to treat foods (milk) with electro-impulses were reported at the end the twenties in the USA[5]. Further experiments followed in the sixties of the last century rather being molecular-biological research for incorporation of foreign gene material into micro-organisms. During the last years, research in the food-area was reinforced again.

PEF 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[6, 7]. Microbial inactivation by PEF has been explained by several theories, the most studied are electrical breakdown and electroporation[8]. Electric high-voltage-impulses generate a trans-membrane potential across the cell membrane of e.g. 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 1V, polarisation and, in the end, breakdown of the membrane is induced. At sufficient high field-strength (above 10 kV/cm) and duration of the impulses (usually between nano- and microseconds) vegetative micro-organisms in liquid media are inactivated due to irreversible membrane destruction. Bacterial spores are not inactivated. Factors that affect the microbial inactivation with PEF 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 of foods with 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 PEF treatment of foods. Two industrial-scale PEF systems are available, including treatment chambers and power supply equipment. PEF has been applied mainly to improve the quality of foods. Application of PEF is restricted to food products that can withstand high electric fields, 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. PEF has potential as technology for food preservation but existing PEF systems and experimental conditions are diverse. More data and conclusions about the effects of critical process factors on pathogens and inactivation kinetics are needed. Conclusive data on the absence of potential health risks or on the impact of the process on food components are also hardly available. Based on practical experience from pilot plants employment of PEF will mainly be in the sparing pasteurisation of liquid foods e.g. juices, milk or liquid whole egg.

Strong magnetic fields

Strong oscillating (OMF) or static (SMF) magnetic fields (5-50 Tesla) have the potential to inactivate vegetative micro-organisms. The impulse duration is between ten μs and several ms. 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 to100 pulses in an OMF at temperature of 0 to 50°C for a total exposure time ranging from 25 to 100 ms[9]. The effects of magnetic fields on microbial populations have produced controversial results[10]. Consistent results concerning the efficacy of OMF are needed before considering this technology for food preservation purposes.

Application of high intensity light pulses

This method of food preservation 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[11]. 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, also wrapped items can be treated. The inactivation kinetics under a full spectrum of

representative variables of food systems and surfaces should be the subject of further independent research.

High pressure processing (HPP)

High hydrostatic pressure processing, also referred to as ultra high pressure processing (UHP), has been known for more than a century to be a potential preservation technique; microbial spoilage of milk e.g. could be delayed by high pressure[12]. Technical-scientific progress has led to a renaissance of food pasteurisation by hydrostatic high pressure recently[13, 14, 15, 23]. A range of pressure-treated products has already been introduced into the markets of Japan, France, Spain and USA. High pressure processing 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 seconds to over 20 min. Food treated in this way is said to keep its original freshness, colour, flavour and taste. UHP 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 wich saves energy as compared to heat treatment. Water activity and pH are critical process factors in the inactivation of microbes by UHP. 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 UHP treatment. Temperatures in the range of 45 to 50 °C appear to increase the rate of inactivation of food pathogens and spoilage microbes. Temperatures ranging from 90-110 °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[16] 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[17]. Generally any process and any reaction in food are of interest to which the principle of Le Chatelier applies, according to which, 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. The mechanism of protein gelation and of the sol/gel behaviour of polysaccharides e.g. are not well understood. Little is known so far about chemical reactions of low-molecular weight compounds in the matrix ‚food' under pressure, i.e. usually in aqueous media. High pressure, on the other hand, has for long been a means of manipulating organic-chemical reactions[18]. 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. As an example for potential chemical changes, the stability of the artificial sweetener aspartame in milk, TRIS-buffers and water during different pressure-treatments (600 MPa, 60 °C, 3 - 30 min) was investigated[19]. After a holding-time of not more than 3 minutes, only about 50 % of the original content of active aspartame was detectable in the milk (pH 6,8). The non-sweetening components aspartylphenylalanine and a diketopiperazine had been formed. These components originate also during storage of not treated products, but very much slower. The observed decay within a few minutes is comparable with storage-damages of e.g. diet-coke after a storage-time of more than 200 days at 20 °C. In acid media, like fruit preparations or juices or carbonated drinks, aspartame is insensitive to pressure. Also on the level of single amino acids, chemical alterations caused by pressure are possible: Whereas the ability of glutamine to undergo cyclization to pyroglutamic acid upon heating has for long been known, the possible pressure-mediated condensation reaction has not been investigated so far. In a recent study[22], we reported the first results focusing on the formation of pyroglutamic acid from glutamine in Tris/HCl buffer under a pressure of 600MPa at 50 °C which is accelerated by pressure. Another example for pressure induced chemical changes are certain carotenoids. Carotenoids are widespread pigments in nature. The most prominent role of carotenoid pigments in the diet of humans and other animals is their ability to serve as a precursor of vitamin A. Beta carotene posesses the greatest provitamin A activity. Edible plant tissues contain a wide variety of carotenoids. For example, spinach and kale are rich in carotenoids. Many factors influence the carotenoid content of plants. Carotenoids are easily oxidised because of the large number of conjugated

double bonds. Such reactions cause colour loss of carotenoids in foods and are major degradation mechanisms of concern. The stability of a particular pigment to oxidation is highly dependent on its environment. Within tissues, the pigments are often compartmentalised and protected from oxidation or thermal degradation. The products of their degradation are very complex. Besides oxidation, thermal extrusion processing for example decomposes ß-carotene into cis-isomers or into fragmentation products under higher temperatures. Cis/trans isomerization affects the provitamin A activity of carotenoids significantly having important nutritional effects. The stability of ß-carotene in model solutions and in carrots under pressure and different temperatures has been investigated. Carotene in ethanolic model solutions after 20 minutes at 75°C was reduced by more than 50%[20]. Preventing the sample from oxygen did not reduce the loss of ß-carotene under pressure/temperature. The main degradation products were in all cases 9-cis- and 13-cis ß-carotene. In carrot puree, the carotenoids are well protected against pressure/temperature attack since they are buried in lipophilic environments. Even after 40 minutes at 600MPa and 75°C, the initial amount of ß-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-carrot-lemon juice mixture (40 parts of orange juice, 5 parts of lemon juice 20 parts of carrot juice and 35 parts of water containing 8.5 % sucrose; OLC) was studied[21] 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 decreased significantly. In the high pressure treated juices, changes in odour, flavour and overall quality were scarcely noticeable after this storage time. Thus, the potential of high pressure treatment to substantially prolong shelflife of fresh products was successfully demonstrated.

REFERENCES

1. Parrott, D. L. 'Use of Ohmic heating for aseptic processing of food particulates'. *Food Technology* **1992**, *12*, 68-72.
2. Cho, H.-Y., Sastry, S. K. & Yousef, A. E. 'Growth kinetics of Lactobacillus acidophilus under ohmic heating'. *Biotechnol Bioeng.* **1996**, *49*, 334-340.
3. Vollmer, A. C., Everbach, E. C., Halpern, M. & Kwakye, S. 'Bacterial stress responses to 1-megahertz pulsed ultrasound in the presence of microbubbles'. *Appl Environl Microbiol.* **1998**, *64*, 3927-3931.
4. Raso, J., Pagan, R., Condon, S. & Sala, F. J. 'Influence of temperature and pressure on the lethality of ultrasound'. *Appl Environ Microbiol.* **1998**, *64*, 465-471.
5. Fetteman, J. C. 'The electrical conductivity method of processing milk'. *Agric Eng.* **1928**, *9*, 107-108.
6. Jeyamkondan, S., Jayas, D. S. & Holley, R. A. 'Pulsed electric field processing of foods: a review'. *J Food Protect.* **1999**, *62*, 1088-1096.
7. Barbosa-Canovas, G. V., Gongora-Nieto, M. M., Pothakamury, U. R. & Swanson, B. G., eds *Preservation of foods with pulsed electric fields.* Academic Press Ltd. London, 1999. 1-9, 76-107, 108-155.
8. Grahl, T. & Maerkl, H. 'Killing of microorganisms by pulsed electric fields'. *Applied MicrobiolBiotechnol* **1996**, *45*, 148-157.
9. Pothakamury, U.R., Barbosa-Cánovas, G.V., & Swanson, B.G. 'Magnetic-field inactivation of microorganisms and generation of biological changes'. *Food Technol.* **1993**, *47*, 85-93.
10. Tsuchiya, K., Nakamura, K., Okuno, K., Ano, T. & Shoda, M. 'Effect of homogeneous and inhomogeneous high magnetic fields on the growth of Escherichia coli'. *J Ferment Bioeng* **1996**, *81*, 343-346.
11. Barbosa-Canovas, G. V., Palou, E., Pothakamury, U. R. & Swanson, B. G., eds. 'Application of light pulses in the sterilization of foods and packaging materials'. *Nonthermal Preservation of Foods.* Marcel Dekker. New York, 1997. Chapter 6, 139-161.
12. Hite, B. H. 'The effects of pressure in the preservation of milk'. *Bull WV Univ Agric Exp Sta Morgantown* **1899**, *58*, 15-35.
13. Hayashi, R. 'Utilization of pressure in addition to temperature in food science and technology'. In: *'High Pressure and Biotechnology'*, eds. C. Balny, R. Hayashi, K. Heremans & P. Masson, Colloque Inserm/John Libbey Eurotext Ltd. 1992, 195-209.
14. Cheftel, J.-C. 'Effects of high hydrostatic pressure on food constituents: an overview'. In: *'High Pressure and Biotechnology'*, eds. C. Balny, R. Hayashi, K. Heremans & P. Masson, Colloque Inserm/John Libbey Eurotext Ltd. 1992, 195-209.
15. Tauscher, B. 'Pasteurization of food by hydrostatic high pressure: chemical aspects'. *Z. Lebensmittel- Untersuchung und -Forschung* **1995**, *200*, 3-13.
16. Smelt, J. P. P. 'Recent advances in the microbiology of high pressure processing'. *Trends Food Sci Technol* **1998**, *9*, 152-158.
17. Heremans, K. 'High pressure effects on biomolecules'. In: *'High Pressure Processing of Foods'*, eds D. A. Ledward, D. E. Johnston, R. G. Earnshaw & A. P. M. Hasting , Leicestershire, UK. Nottingham University Press, 1995.

18. Le Noble WJ ed, '*Organic high pressure chemistry*'. Elsevier, Amsterdam Oxford New York Tokyo, 1988.
19. Butz P, Fernandez A, Fister H & Tauscher B 'Influence of high hydrostatic pressure on aspartame: instability at neutral pH'. *J Agric Food Chem* **1997**, *45*, 302-303.
20. Tauscher, B 'Effect of high pressure treatment to nutritive substances and natural pigments'. In: *'Fresh Novel Foods by High Pressure'*, ed. Karin Autio, VTT Technical Research Centre of Finland, Espoo, 1998, 83-95.
21. Bognar, A., Butz, P., Fernández García, A., Tauscher, B. 'Influence of high pressure treatment and storage on the quality of orange juice and of orange-lemon-carrot mixed (OLC) juice'. *Proceedings of the Ninth Congress, International Society of Citriculture*, Orlando, Florida, Dec. 3-7, 2000, 1206-1209.
22. Schneider, T., Butz, P., Ludwig, H., and Tauscher, B., Pressure-induced formation of pyroglutamic acid from glutamine in neutral and alkaline solution. *Lebensm.-Wiss. u.-Technol.* **2003**, *36*, 365-367
23. Butz, P., Fernandez Garcia, A., Lindauer, R., Dieterich,S., Bognar, A., Tauscher, B. Influence of ultra high pressure processing on fruit and vegetable products. *Journal of Food Engineering* **2003**, *56*, 233-236