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Novel technologies in fruit and vegetable processing

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ABSTRACT

Fruits and vegetables are valuable source of nutritionally important compounds. The aim of novel technologies is to preserve the bioactive compounds with minimal impact on sensory quality and to improve quality control and safety along the food chain. Besides that, the production of shelf-stable semi-fresh products, the reduction of food losses through increased shelf life, the reduction of energy and water use, the generation of food ingredients from by-products are also very important objectives. To achieve the above mentioned goals new technologies, like sensor technology, sustainable packaging, non-thermal pasteurisation and sterilisation, nano and micro technology, the utilisation of rest and by-products, the application of low energy and low water technologies as well as better knowledge transfer should be applied. Recent sensor technologies that include uni-molecular sensors, bio arrays, solid state sensors, optical and spectrographic sensors, radio frequencies and sensor networks are widely tested with encouraging outcomes. In this way the quality and safety can be controlled more precisely during the storage of particular product. Combining sensor technologies and produce physiology (so called dynamic control system) offers more accurate storage conditions requirement (content of O_2 and CO_2) to better preserve quality, the content of bioactive compounds and thus inhibit some physiological disorders without usage of phytopharmaceuticals. Non thermal technologies (pulsed electric field, cold plasma, high hydrostatic pressure) all enable inactivation of microorganisms and enzymes with minimal impact on sensory properties.

Introduction

Therm novel technologies include non-thermal preservation technologies, advanced storage technologies for fresh produce, information technology, wireless data communication, man-machine communication, on-demand printing, biotechnologies and advanced robotics and intelligent packaging. The main philosophy behind all such technologies is: efficient energy use, the reduction of production costs, more environmentally friendly approach and better sensory properties of food. The most important benefit of all non-thermal technologies is better freshness of food products due to much lower heat load. Intelligent packaging systems include several scavengers or absorbers and emitters that are able to control atmosphere within package unit.

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High hydrostatic pressure

High hydrostatic pressure (HHP) is a non-thermal process known for more than hundred years (Park et al., 2017). It is considered an energy-efficient and rapid process. It effectively destroys and inactivates spoilage and pathogenic microorganisms and preserve the quality of food. As reported by Park et al. (2017), it also effectively inactivated murine norovirus-1 (MNV-1) in traditional Korean cabbage Kimchi by employing 500 Mpa pressure. Such hydrostatic pressure did not provoke any significant differences in Kimchi's colour parameters or sensory properties (Park et al., 2017). Beside inactivating spoilage and pathogenic microorganisms, there are scientific reports that HHP might degrade mycotoxins that usually tolerate high temperatures during pasteurisation. In their work, Hao et al. (2016) reported a significant degradation of patulin in model fruit and vegetable juices. They found a 62 ppb decrease of patulin in model juice employing HHP at 600 Mpa for 300 s at 11 °C. Beside pressure and time, the extent of patulin degradation depends also on juice type and composition. *Bacillus subtilis* is often found in food where it is introduced from soil. Dormant *B. subtilis* endospores present in soil are more resistant to high temperatures, low and high pH values, and mechanical stress as compared with vegetative type of microorganism. Thus, more intense treatments are necessary to destroy dormant *B. subtilis*.

Thermoacidophilic and spore-forming bacterium require special treatment to prevent their growth after pasteurization. One such bacterium is *Alicyclobacillus acidoterrestris* that is more resistant to thermal pasteurization. Porębska et al. (2017) employed HHP to pasteurize apple juice inoculated with *Alicyclobacillus acidoterrestris*. Processing conditions at 300 MPa, 50 °C, 15 min inactivated 3.7 log of germinated spores out of 4.4 log. Authors thus proved that HHP treatment combined with moderately elevated temperature can be a useful technique for inactivation of *A. acidoterrestris* spores.

Chen et al. (2015) successfully carried out a five-log reduction of *B. subtilis* spores at following conditions: pressure 464 MPa, temperature 54.61 °C and pressure-holding time 12.8 min. Moussa-Ayoub et al. (2017) compared thermal pasteurization (TP), HHP and pulsed electric field (PEF) on *Opuntia dillenii* cactus juice. All three types of pasteurization reduced microbial population from 103 to less than 10 CFU/mL. TP reduced ascorbic acid by 22% while HHP and PEF preserved ascorbic acid significantly better. Compared to TP, HHP and PEF also better preserved antioxidative potential but no differences were found in flavonol content (Moussa-Ayoub et al., 2017).

HHP is known to have minimal impact on antioxidants in fruit juices. (Błaszczak et al., 2017) used HHP to pasteurize aronia juice. They found ABTS antioxidant values 14% higher as compared to fresh juice. Among polyphenols, cyanidin 3-glucoside was the most stable compound during juice storage. After HHP treatment (400-600 Mpa), microorganisms count was below detection limit (<1 CFU mL−1), aronia juice remained stable during 80 days of storage at 4 °C (Błaszczak et al., 2017).

Pulsed electric field

Pulsed electric field (PEF) is one of the most explored non-thermal technologies applied in food processing. The principle of PEF is based on its ability to electroporate microorganisms cell walls which results in their inactivation. Beside inactivation of microorganisms, PEF is also applied to electroporate fruit tissue in order to increase juice yield or extraction of certain compounds. El Kantar et al. (2017) applied PEF at strength of 3 kV/cm and 10 kV/cm to increase juice yield of orange (25%), pomelo (37%) and lemon (59%) as compared to untreated control. More phenolic compounds were also found in juice produced by means of PEF. Bioavailability of bioactive compounds relates to their bioaccessibility that is the fraction released from food matrix and later available for intestinal absorption. Although PEF disintegrates cell walls, Bot et al. (2018) found no improved bioaccessibility for β-carotene and lycopene from tomato. Extractability of intracellular compounds can be enhanced due to PEF-treatment which provokes reversible pore formation. Immediately after the treatment, Sotelo et al. (2018) reported that juice yield increases with the increased strength of electric field between 0.3 and 2.5 kV/cm. They also found an increase of soluble solids and titratable acidity. Among cyanidins an increase of cyanidin glucoside and cyanidin rutinoside increased with increasing PEF strength (Sotelo et al., 2018). When comparing PEF and thermal pasteurization (TP) of orange juice, Agcam et al. (2016) found better quality of PEF processed juice. Among individual parameters, PEF processed orange juice had higher content of ascorbic acid but only when processed at the electric field strength of 17 kV cm^{-1}. PEF processing resulted in no formation of methyl furfural during or after processing. In general, significant differences between PEF and TP processing were found in pH, titratable acidity, total dry matter, and browning index during storage period.

Cold plasma

Plasma is considered the forth state of matter that recently attracted food scientists as tool for decontamination (Misra et al., 2017). Cold plasma proved to be the efficient technique for inactivating microorganisms in juice processing. In their experiment, Rodríguez et al. (2017) were experimenting with N_2 plasma at flow rates of 10, 30 and 50 mL/min and treatment times of 5, 10 and 15 min. Plasma with lower flow N_2 rates and shorter duration promoted a slight increase of ascorbic acid total polyphenol content and the antioxidant activity, while overexposure provoked a decrease of ascorbic acid. Bursać Kovačević et al. (2016) experimented with cold plasma on anthocyanin stability in pomegranate juice. They found the greatest stability when employing moderate operating conditions, i.e. shorter treatment time (3 min), lower N_2 flow (3.5 L/min). Comparing cold plasma pasteurization with TP of

chokeberry juice, Bursać Kovačević et al. (2016) found significantly better stability of hydrocynnamic acids but lower stability of anthocyanins in plasma treatment.
In initial experiments cold plasma was effectively used to inactivate microorganisms on food surfaces. Surowsky et al. (2014) demonstrated that a direct contact between bacterial cells and plasma is not necessary to achieve adequate inactivation. They inactivate *Citrobacter freundii* in apple juice by about 5 log cycles, exposure time was 480 s using argon and 0.1% oxygen. In their study, Smet et al. (2016) showed that osmotic stress (NaCl) and suboptimal pH influence the efficacy on cold plasma to inactivate *Salmonella typhimurium* and *Listeria monocytogenes*. Namely, when *Salmonella typhimurium* and *Listeria monocytogenes* are grown under osmotic stress or suboptimal pH, both microorganisms become more resistant to plasma treatment.

Dynamic atmosphere

To prolong storage life of fruit, storage conditions, that reduce fruit metabolism, should be applied. That includes low temperature (0 °C) and controlled atmosphere (reduced O_2, elevated CO_2). At the beginning controlled atmosphere consisted of around 3% of O_2 and 3% of CO_2 for most of climacteric fruit. With the progress of storage technology, O_2 and CO_2 concentration was lowered to 1% and was named ultra-low oxygen (ULO). Storage technology was developing further with O_2 amounting to 0.5%. That O_2 concentration may bring fruit to anaerobic metabolism, longer exposure of fruit to anaerobic metabolism may be detrimental to fruit quality. To prevent detrimental effects, so called dynamic atmosphere was introduced where O_2 concentration is maintained at around 0.5% till anaerobic metabolism appears. Storing of fruits in dynamic atmosphere generally maintains fruit quality better than ULO. Quality parameters like firmness, titratable acidity and ground colour are better preserved under dynamic atmosphere. One important advantage is that dynamic atmosphere controls some physiological disorders like superficial scald (Mditshwa et al., 2017). The mechanism to monitor the possible appearance of anaerobic metabolism includes the method based on chlorophyll fluorescence (Prange et al., 2002). On the other hand, Bessemans et al. (2016) developed dynamic controlled atmosphere storage based on the respiratory quotient (RQ-DCA). The RQ-DC manages to control O_2 and CO_2 partial pressures in storage cell in an autonomous way.

Nanotechnology

Nanotechnology is finding applications in food sector as nanosensors, new packaging materials and encapsulated food components (Pathakoti et al., 2017). This technology enables better solubility, improves bioavailability, controlled release and prevents bioactive compounds against deterioration. From microbiological point of view, nanomaterials possess antimicrobial activity against bacteria.
Nanosensors applied with polymers used to monitor pathogens and chemicals are of special interest. Sensors are able to detect toxins, microbiologically derived degradation products (H_2S) and thus track the product's history and expiration date (Li et al., 2014).

Sustainable packaging

Packaging of fruit and vegetables is one of the important technological solutions for maintaining the quality, the content of biologically active substances and the safety along the food chain. Very important concept is so called ”sustainable packaging“ (Langelaan et al., 2013), which anticipates the use of packaging to reduce food loss and maintain quality, the minimum packaging costs for optimum effects, and an increasingly important reduction of negative environmental effects and accumulation of waste materials.
The use of a modified atmosphere, which in fruit and vegetables has a very important effect on respiration intensity, maturation process and other physiological and microbiological activities (Caleb et al., 2012; Belaya et al., 2016), in combination with cooling has been for some time the most established technique to extend shelf-life. In the storage of large quantities of plant raw materials, various applications of the modified atmosphere and control methods are in use, as already mentioned in the text. Similar physiological effects can be achieved using modified atmosphere packaging (MAP) for fresh-cut fruits and vegetables (Caleb et al., 2012; Belaya et al., 2016). A suitable application of a modified atmosphere for various plant material types should take into account the ratio between the intensity of produce respiration and the permeability properties of the packaging films (Caleb et al., 2012; Zhang et al., 2015). Inappropriate permeability causes oxygen consumption and CO_2 accumulation leads to anaerobic conditions. Due to the damaged tissue in fresh-cut products, the intensity of respiration can be significantly increased. The formation of metabolites such as acetaldehyde and ethanol causes tissue decay and various off-flours (Zhang et al., 2015).

Upgrade of MAP represents active and intelligent packaging systems that assist in managing the changes in the packaging unit. In active packaging, different agents are used to modify the conditions during the packaged product storage, which affects the quality and shelf-life of the product. The type of »active« agent which is used for the packaging of food products depends on the type of foods. There are several types of "scavengers" or absorbers and "emitters" or releasing agents in use, which are intended to regulate concentrations of various gases and volatile substances in the packaging unit: oxygen, ethylene, carbon dioxide, water vapour. In addition, antimicrobial agents, antioxidant supplements and others may also be used. Most commonly, the active agents in the packaging unit are added in the form of small bags of porous material, but they can also be incorporated into the packaging material or immobilized on the surface of the packaging material. It is also possible to use various "active" labels inside the packaging unit (Caleb et al., 2012).

In addition to the physiological activity of fresh-cut fruits and vegetables, the control of the microbiological population is also an important issue. For food safety reasons and extension of shelf-life, the growth and activity of microorganisms, which depends on various intrinsic factors, should be minimized. The combinations of modified atmosphere and active antimicrobial agents such as polyphenols, essential oils and other substances can be very effective in this regard (Oliveira et al., 2015; Van Long et al., 2016). The use of active packaging with similar active substances in combination with MAP is also very successful in preservation of nutritional compounds such as antioxidants content in fruits and vegetables. Active substances can be applied to the food as an additive to the gas phase of the packaging unit, as an active agent added into the packaging material or as an immobilized agent on the material surface (Villa-Rodriguez et al., 2015).

Special forms of active packaging that enable control of gas exchange, moisture loss, the reduction of microbiological growth, the application of various substances such as antioxidants, flavours, colour agents and many others are edible coatings. The basic matrix consists of various biopolymers (proteins, lipids, carbohydrates) that form the wrap around the food and represent a carrier for various additives. Edible films can also protect food products against chemical, physical, biological and mechanical damages and represent a barrier for gases, vapours and liquids. Various methods of film applications and numerous combinations of biopolymers and active substances can provide suitable applications of edible coating for a wide variety of foods (Valdés et al., 2017).

Intelligent packaging is a packaging system that monitors the quality and safety of packaged products along the food chain while providing a useful information about the product condition. Intelligent packaging uses indicators of various types which can be external (installed on the outside of the packaging unit) or internal (inside the packaging unit). Indicator groups already in use are temperature indicators (TTIs), indicators of the oxygen or CO_2 presence, freshness indicators, indicators of microbiological growth or microbiological activity (including pathogenic microorganisms). In addition, radio frequency indicators (RFIDs), which allow the control of the place and time of distribution are already used, the indicators of authenticity of the product, and others (Caleb et al., 2012; Zhang et al., 2015).

The use of nanotechnology in the food packaging enables a number of possibilities for applications such as improvement of the barrier and mechanical properties of packaging materials that influence the reduction of the thickness and mass of packaging materials. Various forms of active packaging that positively influence the quality and shelf-life of foodstuffs are also available. The development of various sensors and biosensors in the context of intelligent packaging is the subject of intensive research (Trepti et al., 2017).

The basic principle of improving the barrier properties of packaging materials is based on the incorporation of the nano particles into the matrix of packaging materials. With nano inclusions, the tortuous pathway increases the gas diffusion length and the time of gases and water vapour passage through the packaging material is significantly prolonged. (Duncan, 2011). Even smaller additions of different types of nanoparticles can significantly improve light barrier properties and thermal stability of materials. Nanocomposites can also have the function of active packaging primarily as antimicrobial applications. Several applications of nanosensors have been developed to detect the presence of various pathogenic microorganisms in the packaging unit (Trepti et al., 2017).

Conclusion

The application of novel technologies aims to better preservation of the bioactive compounds as well as sensory characteristics. Contemporary trends in food science also encompass the production of shelf-stable semi-fresh products, the reduction of food losses, the reduction of energy and water use and the generation of food ingredients from by-products. In order to detect food deterioration sensor technologies like uni-molecular sensors, bio arrays, solid state sensors, optical and spectrographic sensors, radio frequencies and sensor networks are widely tested. The knowledge of produce physiology that allows for more accurate storage conditions requirement (content of O_2 and CO_2) to better preserve quality and prevent the appearance of physiological diseases is of great importance.

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