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INNOVATIVE PRESERVATION TECHNOLOGIES FOR A SUSTAINABLE FOOD SYSTEM

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Abstract

Nowadays the producers are looking for innovative solutions able to assure high-quality products but at the same time more healthy and environmentally friendly food products. Food preservation is one of the basic steps in food technology for any type of product. Different classical preservation technologies as drying, sterilization, pasteurization, freezing, chilling, etc. were developed along with food product development in order to preserve food quality and safety. In the last decades novel and innovative preservation technologies were developed being focused not only on the food shelf-life extension but also on the better preservation of nutritional quality of the products and on reducing environmental impact through different mechanisms. Despite the classical methods mainly based on the thermal effect, these new technologies are based on different physical factors using high pressure, electric fields, cold plasma, ultraviolet radiation, or new packaging technologies leading to a more sustainable food system and a better preservation of food nutritional quality. The mechanisms, advantages, and drawbacks of these technologies currently still under investigation for different applications will be outlined in this paper.

***Key words**: innovative preservation technologies, nutritional quality, sustainability.*

INTRODUCTION

In recent years there has been a growing consumer interest in food quality, safety and sustainability. The research community and also the food industry manufactures are aiming at a sustainable food system and supply chain. The food supply chain consists of several steps, from farming, primary processing, distribution and at the end, being sold to the final consumer. A sustainable food system should be able to assure the safety and quality of the food products, improve the nutritional value, minimize the use of additives and the impact over the environment (Lazaridesa, 2011). Thus, a number of innovative processing methods have been developed to meet the requirements of both consumers and producers.

The main objective of food processing is to preserve the overall quality of food for a certain period of time, known as the shelf life. The most common types of food spoilage are microbial, enzymatic, chemical and physical (Atuonwu et al., 2018). In order to fulfil the new industry and consumer requirements, several sustainable methods of food preservation have been developed (Cercel et al., 2017). These innovative methods include physical technologies (high pressure treatment), electromagnetic technologies (pulsed electric field treatment, ohmic heating, microwave, radio frequency and ultraviolet treatment), ultrasound and others, such as membrane filtration and modified atmosphere packaging (Milani et al., 2016).

Traditional thermal processes have been used as preservation methods for a long time, in order to reduce the microbial load or enzymatic reactions in food products, mainly based on the thermal effect.

The main problem is that they have a negative impact on the nutritional value and sensory qualities of the treated food products, so in recent times, novel non-thermal technologies have been developed (Harasym et al., 2020). Among them, the most used ones are high pressure CO_2 treatments, gas-plasma treatments, ultrasound, UV radiation, high-hydrostatic pressure, high-intensity electric pulsed fields, cold plasma and others (Arshad et al., 2021).

MATERIALS AND METHODS

For a better understanding of this topic, Web of Science, Elsevier, Wiley Online and Springer databases were electronically searched for research articles published in the last 10 years. The literature search comprised of research articles and reviews on the following topics: innovative preservation techniques (thermal and non-thermal) and sustainable food systems. The content analysis of the reviewed papers was aimed at defining the scope of analysis, evaluate the content and in the end to state the pros and cons of using novel and sustainable preservation techniques of food products. The literature search included as document type: research article and review, on the topics: "innovative preservation techniques", "sustainability" "food systems", "food packaging challenges", "thermal processing technologies", "non-thermal processing technologies".

RESULTS AND DISCUSSIONS

Novel treatments like osmotic pre-concentration, ultrasound, high-pressure, ultraviolet radiation and others have been used in the food industry in order to preserve and maintain the nutrients levels in food products. It has been stated that some of these innovative food processing techniques may have disadvantages, because their impact can produce interactions between food components (Li et al., 2021).

One of the sustainable preservation technologies that are being used nowadays is osmotic processing alone or combined with other preservation techniques (as chilling, drying and others). The major advantage of this technique is that water particles are osmotically removed (natural process) in liquid form at ambient temperatures, thus the treated product being protected against oxygen and heat stress. Osmotic processing is used on fruits and vegetables, because it provides low energy consumption rate and it preserves the quality of the treated products (Petrotos & Lazarides, 2001).

Non-thermal processing technologies

Cold plasma

A new technique for non-thermal food processing is plasma treatment, which has attracted attention in recent years as an alternative method for chemical and thermal disinfection of food and uses moderate temperatures and short processing times. Non-thermal plasma is generated by subjecting a gas to a strong electric field, so it is a partially ionized gas (Costello et al., 2021). Oh et al. (2016) stated in a study that cold plasma technology is an environmentally friendly processing that offers many potential applications for food packaging. The efficiency of decontamination of dry and heat-sensitive products with athermic plasma was investigated by Hertwing et al. (2015). He noted that this treatment was able to inactivate bacterial spores, vegetative bacteria, moulds and yeasts, in environmental conditions, on different types of herbs and spices with different surface-volume ratios.

Low-temperature plasma treatments on different food products have been developed in recent years, because of the effectiveness over the inactivation effect over some microorganisms that are present on the surface of the food product (Ojha et al., 2021).

The way that this treatment works is by arise of the UV radiation, radicals and other reactive species from the plasma in order to inactivate microorganisms (Muranyi et al., 2007; Wan et al., 2009).

Ultraviolet radiation (UV)

A new and alternative preservation techniques is ultraviolet (UV) radiation treatment, which is being used in order to improve food safety characteristics. The electromagnetic spectrum used for UV radiation treatment is at wavelengths ranging from 100 to 400 nm (Mansor et al., 2014). The UV radiation spectrum is comprised of four different wavelengths intervals spectrums: UV-A (315-400 nm), UV-B (280-315 nm), UV-C (200-280 nm) and vacuum UV (100-200 nm), of which, only the UV-C (254 nm) can be used as an antimicrobial treatment (Koutchma, 2014). As advantages, UV-C radiation is not a thermal method and does not form toxic by-products during treatment. Moreover, it can remove certain organic contaminants, while not producing odorous substances (Rocha et al., 2015). The use of ultraviolet radiation has been proposed for pasteurization and sterilization of food surfaces due to its potential to destroy a number of bacteria, viruses and parasites

(Lelieveld & Andersen, 2019; Kim et al., 2021). Currently, UV-C is used to pasteurize liquid foods, such as juices and nectars, to inactivate microorganisms such as *E. coli*, *Salmonella*, *Shigella*, *Zygosaccharomyces bailii* and *Saccharomyces cerevisiae* and protozoa, such as *Cryptosporidium parvum*; enzymes such as polyphenol oxidase, adenosine triphosphate, acid phosphatase, carboxypeptidase A and trypsin (Golombek et al., 2021).

Mansor et al. (2014) studied the effect of UV-C treatment technology in order to inactivate the presence of *Salmonella typhimurium* TISTR 292 in pineapple juice at three different frequencies (30, 35 and 40 Hz). While the UV-C dosage was increased, the microbial count of *Salmonella typhimurium* decreased. A reduction of 5-log10 CFU/ml was achieved at a dosage of 13.75 mJ/cm^2, while the pump frequency was at 30 Hz.

High Pressure Processing (HPP)

High pressure processing is a food processing technique in which food products are treated with high pressures (up to about 600 MPa), with or without additional heating, to inactivate the microbial flora or to modify the sensory characteristics of food in order to achieve qualities desired by the consumer (Huang et al., 2014). HPP processing is a non-thermal technology and has good potential compared to traditional preservation methods, such as heat treatment. HPP processing is widely used for vegetables, meat and seafood due to the inactivation of microorganisms and enzymes, while maintaining the nutritional and sensory characteristics of food (Bhoite, 2016). HPP treatment is used to inactivate enzymes in food, mainly to inactivate polyphenol oxidase (PPO), peroxidase (POD), lipoxidase (LOX) and protease in fruits and vegetables (Norton & Sun, 2008).

The effectiveness of treatment on overall food quality and safety is influenced not only by extrinsic (process-related) factors such as treatment time, pressure/decompression rate, pressure/temperature levels and number of pulses, but also by intrinsic factors (related to the processed food) such as the food composition and the physiological state of the microorganisms (Koutchma, 2012).

A study undergone by Bhoite (2016) confirms that the HPP treatment is a very good innovative processing technique for fish and shell-fish products like crab, shrimp, crawfish and lobsters, because of the elimination of vegetative pathogens, like *Salmonella* and *Listeria monocytogenes*, both of which have zero-defect action levels in ready-to-eat products.

New packaging technologies

In recent years, the new concept of active and intelligent packaging has significantly influenced the marketing of food. An active packaging can be defined as a system that modifies the condition of the food to extend its shelf life or to improve its sensory properties while providing food safety (Firouz et al., 2021), thus attracting more and more attention from manufacturers due to its benefits. The active packaging is a products friendly technology, based on the use of the active compounds (in the most of cases are used natural compounds), such as antioxidants and antimicrobial agents, which are incorporated or coated on packaging materials (Göksen et al., 2021).

Active packaging systems can be classified into active release systems (emitters) that add compounds to packaged foods or active absorption systems (absorbents) that remove unwanted compounds from food or the environment (Göksen et al., 2021).

Modified atmosphere packaging (MAP)

Modified atmosphere packaging (MAP) is an innovative packaging technology that consists of replacing the air inside the package with a mixture of gases (Van den Broek et al., 2015), in which the proportion of each gas is well known, but no additional control can be performed during storage. In the process of packing food in a modified atmosphere, three types of gases are mainly used: oxygen (O_2), nitrogen (N_2) and carbon dioxide (CO_2).

For the modified atmosphere packaging of food products, two or three types of gases are used in combination, chosen in such a way as to contribute as much as possible to increase the shelf life of the chosen product (Sandhya, 2018). This type of packaging has been applied to fish, fresh produce, pasta, pizza, other bakery products and dry products such as nuts and snacks.

Active packaging systems with oxygen absorbers
The most widely used active packaging technology for food today is the use of oxygen-absorbing agents inside food packaging. The presence of oxygen in food packaging accelerates the oxidative damage of packaged products (Carina et al., 2021). The presence of oxygen facilitates the growth of aerobic microorganisms, the unwanted development of certain flavours, odours, colour changes, the depreciation of the nutritional value and the decrease of the storage time of food products (Dey et al., 2019). Therefore controlling the oxygen level in food packaging is important to increase the shelf life of food.

Active packaging systems using carbon dioxide (CO_2) emitters
Carbon dioxide can be introduced into the packaging medium to slow microbial growth in certain foods such as: fresh meat, fish products, cheeses, baking products and pastries (Lopez-Rubio et al., 2006). For these reasons, the method of active packaging by introducing CO_2 inside food packaging is used more and more often, thus slowing down the metabolic processes of food, thus increasing their shelf life (Sivertsvik et al., 2004). In the case of active packaging with a mixture of gases including CO_2 and O_2, CO_2 dissolves in the product creating a partial vacuum due to the solubility of CO_2 at lower temperatures (Kerry et al., 2006).

Thermal processing technologies

Radio frequency (RF) treatment

Dielectric heating uses electromagnetic radiation in the frequency range of 300 kHz to 300 GHz. Radio frequency (RF) uses frequencies higher than microwaves between 300 kHz and 300 MHz therefore only selected frequencies (13.56, 27.12 and 40.68 MHz) are allowed for household, industrial, scientific and medical applications (Jiao et al., 2014). The principles of radio frequency heating are very similar to microwave heating. Heat is uniformly generated in dielectric materials (food, in this case) when the electromagnetic field reverses the polarity of the molecules or stimulates the migration of ions inside the material as it undergoes treatment (Marra et al., 2009).

RF wave heating is used to defrost eggs, fruits, vegetables and fish. Radiofrequency dielectric heating is now widely used in industrial applications, such as textile drying, paper final drying, biscuit final dehydration after baking, and honey melting (Bedane et al., 2021).

RF wave treatment offers a considerable advantage over conventional heating methods through a very short time and highly uniform heating. Despite the major advantages and the fact that this technology has been available for many years, its development at the industrial level has been relatively slow (Wang et al., 2007).

Orsat and Raghavan (2005) studied radiofrequency sterilization for macaroni and cheese. Their findings showed that the process (27.12 MHz wavelength) led to products with a better shelf-life, using less energy than the conventional method.

Radiofrequency drying of food products has been used mainly for post-baking drying of cookies, biscuits and pasta. Cookies and biscuits, fresh from the oven, have an uneven distribution of moisture that can lead to their crushing during handling. RF heating can even help distribute moisture after baking by directing the amount of water remaining (Zhong et al., 2003; Bedane et al., 2018).

Microwave treatment

In order to maintain the original characteristics of food products and reduce production costs, alternative methods for conventional thermal heating such as microwaves treatments have been investigated as potential technologies to inactivate peroxidases in vegetables (Lopes et al., 2015).

Gomez et al. (2019) studied the microwave treatment process on banana samples. The study showed that the treated banana samples were dry and crunchy with moisture content, water activity, physical and mechanical properties similar to those observed for fruits obtained by lyophilisation (Hassan et al., 2019).

The results of a study carried out by Hashemi et al. (2017) demonstrate that microwave heating causes significant losses in terms of quality and nutritional value of oils extracted from Mashhadi melon, Iranian watermelon, pumpkin and yellow apple seeds. The degradation was directly proportional to the increase in processing time. Tocopherols, phenols, chlorophylls and carotenoids are thermosensitive molecules, indicating low values with increasing exposure time.

In a study by Jouquand et al. (2015) was demonstrated that optimizing microwave processing equipment to prepare beef can retain its nutritional, sensory, and phenolic properties as much as traditional cooking, although several studies have shown that microwave processing has tended to degrade the texture of meat, to form carboxymethylisine and to destroy essential amino acids by the Maillard reaction.

Some of the advantages and disadvantages of innovative preservation techniques have been evidenced by different researchers, and are presented in Table 1.

Table 1. Advantages and disadvantages of innovative preservation techniques

Preservation technique	Advantages	Disadvantages	Source
High pressure processing (HPP)	Microorganisms and enzymes inactivation effect Colour and flavour preservation Food products can be treated, despite their size or shape Covalent bonds are not broken (no interaction between different compounds) Application at ambient temperature	A very expensive processing method Processed foods need to be stored at low temperature	Bhoite, 2016 Norton & Sun, 2008 Koutchma, 2012 Agregan et al., 2021
Ultrasound processing	Beneficial effect on physicochemical and functional properties of food components Ultrasound waves are chemical free, safe, and eco-friendly Ultrasound treatment can be combined with other thermal and non-thermal methods in order to inactivate microorganism growth	Free radicals formed during cavitation may cause harmful effect on the consumers High initial investment	Zhu et al., 2018 Abdullah & Chin, 2014 McClements, 1995 Ravihumar et al., 2017
Microwave treatment	Microwave treatment resulted in higher water-holding capacity, but lower sarcoplasmic protein solubility in thigh The times to get to the desired treating temperature is faster than other conventional treatments The heat is generated rapidly and uniform in the food product	Fragmentation in both sarcoplasmic and myofibrillar proteins Microwave-cooked rice showed a significantly higher percentage of equilibrium starch hydrolysis, and the crystalline patterns Significant losses in terms of quality and nutritional value, when treating thermosensitive molecules Lack of experimental data regarding microwave model heating	Taskıran et al., 2020 Thuengtung et al., 2019 Hashemi et al., 2017
Modified atmosphere packaging (MAP)	Reduction of economic losses due to longer storage time Lower transportation costs, products can be delivered over longer distances, requiring fewer shipments Improved presentation – clear visibility on the food No interaction with the products	High production costs Temperature control is required Different gas combinations for each type of product Use of special equipment and employee training	Oliveira et al., 2015 Opara et al., 2019 Antmann et al., 2008 González-Buesa et al., 2014 Tano et al., 2007

Radio frequency treatment (RF)	Great potential for rapid and uniform heating of food products Provides safe and high-quality food More uniform heating because of the deeper wave penetration of the food product No need to be in direct contact with the food product (no electrodes needed)	Higher equipment and operating costs Reduced power density, when compared to microwave heating More efficient than microwave heating	Bedane et al., 2021 Marra et al., 2009 Wang et al., 2007 Zhong et al., 2003 Bedane et al., 2018
Osmotic dehydration	Moisture is withdrawn from the product at ambient temperature by diffusion, so phase change has been avoided Improves the nutritional and sensory attributes of food products Requires less energy compared to other drying techniques Used to extend the shelf-life of fruits and vegetables	Higher equipment and operating costs	Ahmed et al., 2016 Nastaj & Witkiewicz, 2004 Sutar et al., 2012 Ciurzyńska et al., 2016

CONCLUSIONS

Novel and innovative preservation technologies for a sustainable food system are being developed, which can be used in order to meet the requirements of consumers and manufacturers. The use of innovative preservation technologies like high-pressure treatment, RF treatment, and new packaging technologies can be applied for extending the shelf life, improving the quality and safety of food in a sustainable way. Despite these major advantages and the fact that the mechanisms are well known, further researches and effort are needed to be made in order to fully take advantage of these novel preservation techniques at the industrial level in order to obtain a sustainable food system.

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