FRI-ONLINE-1-BFT(R)-07

EFFECT OF PROCESSING WITH ALTERNATIVE NON-THERMAL TECHNOLOGIES AND EDIBLE PACKAGING ON FOOD SAFETY AND QUALITY

Prof. Stefan Stefanov, PhD
Department of Machines and apparatus for the food and flavour industry
University of Food Technologies, Plovdiv
E-mail: stvstefanov@yahoo.com

Ass. Prof. Yordanka Stefanova, PhD
Department General and Inorganic Chemistry with Chemistry Education
Plovdiv University "P. Hilendarski", Plovdiv
E-mail: jorpste@yahoo.com

Abstract: *New technologies for food processing and packaging are aimed at creating products for end customers with minimal loss of quality. In this regard, in the field of food science, processes are developed that spare raw materials and food products, with minimal impact on them and causing minor changes in their initial characteristics. They are considered non-traditional and alternative to the treatments used so far in mass food production. The effect of them is only now beginning to be studied in more depth. The results obtained so far show that they have a future.*

To ensure the safety of minimally processed raw materials and food products, as well as to preserve their properties for a longer period, a set of impacts is applied, which are known as technology with the application of more obstacles to spoilage reactions.

The article reviews literature sources that publish information on combined methods of food processing, for the packaging of which edible films or coatings are used. Results from the application of various barriers to specific food products are indicated. Based on the analysis, conclusions are made about the possibilities for practical implementation of the technology with obstacles in the food industry in combination with the use of edible films and coatings.

Keywords: *Edible Packaging, Edible Films, Edible Coatings, Non-thermal Processing,*

INTRODUCTION

There are many factors that influence the development of food science, technology and engineering. The food industry is faced with the task of meeting the growing needs of consumers for food that can be preserved for as long as possible, while maintaining the required quality. Developing effective scientific and commercial strategies to achieve these goals is not easy (Del Nobile and Conte, 2013). Improving food safety by eliminating risks or reducing their effects, improving their quality, extending the expiry date, reducing waste and creating conditions for sustainable development are the basis for the development of new methods for processing and packaging of food products.

In the processing of raw materials and food production, the initial characteristics are transformed in order to achieve appropriate changes, leading to more complete absorption of nutrients, improved taste and safety for a certain period.

Traditional technologies use physical, chemical, biotechnological and other methods for this. Thermal exposure methods are the most common for achieving structural changes and ensuring food safety. They simultaneously change the taste, improve the absorption of nutrients and ensure safety.

Conventional preservation technologies such as heat treatment ensure the safety and shelf life of fruit products, but can lead to a loss of physicochemical and nutritional qualities (Gómez et al, 2011). During heat treatment, many of the nutrients contained in the raw materials are lost or reduced in quantity, and some are transformed into unwanted ones. This reduces the quality of the

 Copyrights© 2020 ISBN 978-954-712-826-2 (Print)

food product produced by this method. Researches are focused in finding and developing new processing methods that have less impact on these changes. These are known as “minimal technologies methods”. A number of methods for minimal food processing are known (Ohlsson, 1994; Allende et al, 2006).

Technologies using methods for minimal impact on products are aimed at both the processing of raw materials and food processing, as well as their packaging.

In preparatory operations, such as cleaning, washing and disinfection of raw materials of plant origin, less and less traditional methods are prefered that use chemicals. Chlorine is widely accepted in disinfectant washing due to its low cost and high efficiency against a wide range of microorganisms. The problem is that it can promote the formation of putative carcinogenic compounds (De Corato U., 2020). In many countries, the use of chlorine-based detergents and disinfectants during the preparation of fruits and vegetables is prohibited. To ensure food safety, new methods are applied, alternative to the traditional ones, which reduce the risk of chemical contamination and achieve the necessary qualities.

Product quality and shelf life are often influenced more by storage conditions and barrier properties of the packaging material than by the processing itself (Bala et al, 2015). Packaging is the main tool for preventing product deterioration and extending its shelf life (Konte et al, 2012).

EXPOSITION

Food quality and safety

According to the Food and Agriculture Organization of the United Nations (FAO): **Food quality is "a complex characteristic of food that determines its value or acceptability to consumers."** *The nutritional value of food contributes to the perception of its qualities, as well as its organoleptic and functional properties.*

Safe food is one that does not contain any substances that can endanger human health.

Food spoilage

Food spoilage includes any physicochemical changes that make it unacceptable for human consumption and may include microbial toxicity, local enzymatic activities in consumed plant and animal tissues, non-microbial chemical changes, insect damage, physical injury due to pressure, freezing, drying, burning, irradiation, etc. (Beikzadeh et al., 2020).

Food spoilage directly affects the color, taste, smell and texture or structure of food and can be dangerous to consume. Spoiled food is not suitable for humans or its quality of edibleness decreases (Mamta and Bala, 2017). The length of time that food remains edible and has nutritional value depends on temperature, humidity, and other factors that affect the growth rates of the organisms that cause spoilage (Hammond et al., 2015).

Methods to prevent spoilage

To prevent microbial spoilage of food people use two main strategies: (1) preventing colonization by reducing access to susceptible foods, and (2) inhibiting population growth and limiting the population by creating an unfavorable environment (Hammond et al., 2015). Food preservation is an action or method designed to maintain food at the desired level of quality (Prokopov and Tanchev, 2007). Food preservation is defined as processes or techniques undertaken to eliminate internal and external factors that can cause food spoilage. The main purpose of food preservation is to increase the shelf life, preserving the original nutritional value, color, texture and taste (Amit et al., 2017).

Conventional or traditional canning methods have proven over the years to be effective in achieving food safety with certain quality characteristics. The food safety-quality ratio is a significant problem by modern traditional technologies. Due to aggressive technologies the loss of nutrients, which are useful to the human body, leads to reduction of food quality in terms of their nutritional value. Foods under stress lose vitamins, minerals, trace elements and more. Traditional food processing technologies rely on high energy impacts. This makes them energy inefficient.

A number of authors consider the principles of preservation with their advantages and disadvantages.

In recent years, methods to combat food spoilage have become increasingly sophisticated and are gradually changing, requiring the application of highly interdisciplinary science (Amit et al., 2017).

Alternative methods of food processing

Heat treatment is a traditional food processing method that can kill microorganisms, but also lead to physicochemical and sensory quality damage, especially to temperature-sensitive foods. Nowadays, the growing consumer interest in microbial safety products with first-class appearance, taste, high nutritional value and extended shelf life encourages the development of emerging technologies for non-thermal food processing as an alternative or replacement of traditional thermal methods (Zhao et al., 2019).

As a result of the growing consumer demand for minimally processed fresh food products with high sensory and nutritional qualities, there is a growing interest in non-thermal processes for food processing and canning (Knorr et al., 2002). Technologies such as high pressure, ultraviolet light, pulsed light, ozonation, powerful ultrasonic exposure and cold plasma (advanced oxidation processes) show promising results for inactivation of microorganisms (Van Impe, 2018). However, they are less agressive compared to traditional heat treatments and it is crucial to ensure complete inactivation of the microorganisms present. New processing technologies are increasingly attracting the attention of food processors, as they can provide food products with improved quality and reduced environmental footprint, while reducing processing costs and improving the added value of products (Pereira and Vicente, 2010).

High Pressure Processing (HPP), Cold Plasma (CP), Ultraviolette (UV), Irradiation (I - Irradiation) and Pulsed Electric Field (PEF) were studied for improvement of food quality and safety, including food of animal origin (Pexara and Govaris, 2020).

Non-thermally processed foods have unique quality parameters compared to conventional foods treated by heat treatment (Akbarian et al., 2014).

High hydrostatic pressure

High Hydrostatic Pressure (HHP) is a non-thermal, unconventional, emerging technology originally studied as a food preservation technique. The HHP process is based on the isostatic principle and the Le Chatelier principle; where the pressure is applied uniformly in all directions of the food, being responsible for the observed reaction. It can be used for liquid, pasty, solid or food with particles included in its structure. The process was interrupted (discrete) and carried out in the packaging (Augusto et al., 2018). High hydrostatic pressure (HHP) treatment is used to improve the microbiological safety and shelf life of ready-to-eat meat products, as a non-thermal decontamination technology in the meat industry applied before or after packaging (García-Gimeno and Izquierdo, 2020). High hydrostatic pressure (HHP) treatment is an effective technique for killing microorganisms and inactivating enzymes in order to increase food safety and shelf life. Multi-pulse treatment of foods with high hydrostatic pressure (mpHHP), with few exceptions, is more effective than conventional or single-pulse HHP (spHHP) treatment for inactivation of microorganisms in fruit juices, dairy products, raw eggs, meat products and seafood (Buzrul, 2015).

HHP has several advantages, such as transmitting less energy to food and even applying it to all sides of food, contrary to heat treatment (Buzrul and Hami, 2012). As the method does not use heat, the sensory and nutritional properties of the product remain practically unaffected. In this way, products with better quality are obtained than those processed by traditional methods. HHP has the ability to inactivate microorganisms as well as the enzymes responsible for shortening the shelf life of the product. In addition to extending the shelf life of food products, HHP can change the functional properties of macronutrients, such as proteins, which in turn can lead to the development of new products (San Martín et al., 2002).

 Copyrights© 2020 ISBN 978-954-712-826-2 (Print)

Pulsed (pulsating) light

Pulsed Light (PL) is a new non-thermal method of food processing that can decontaminate food or surfaces that come into contact with food using white light. Exposure to intense light pulses (in the infrared, visible, and ultraviolet (UV) regions) causes microbial cell death, making food safe at room temperature (Manda et al., 2020). This food technology involves the application of pulses with high intensity and short duration (100-400 μs) to continuous broad-spectrum light, in which about 40% of the emitted light corresponds to the UV region. These pulses have high peak energy, producing a light intensity per unit time approximately 20,000 times bigger than the intensity of sunlight at the sea level. The bactericidal effect was found to be due to the photochemical and photothermal effects. The technology not only decontaminates the food or the package, but also maintains its texture, nutrients and more (Abida et al., 2014).

The term “pulsed light” has been known since 1980 and was firstly used by the US Food and Drug Administration (FDA) for food processing in 1996 (FDA, 1996; Bhavya and Hebbr, 2017).

Pulsed light treatment is a successful, fast and environmentally friendly decontamination technology with many potential applications in the food industry, especially as a promising non-thermal technology that can be used for food safety purposes. PL treatments have been found to be suitable for microbial decontamination in transparent liquids and for surface contaminated foods that do not constitute complex microstructures (Mahendran et al., 2019).

Cold plasma

Cold plasma (CP) technology has proven to be very effective as an alternative tool for food decontamination and shelf life extension (Pankaj al., 2018). The term plasma is used in physics and chemistry to denote the state of an ionized gas. In order to produce plasma, it is necessary to supply energy to a gas to induce its ionization. Non Thermal Atmospheric Plasma (NTAP) is a promising food decontamination technology capable of inactivating bacteria, yeasts, molds, fungal and bacterial spores on both abiotic surfaces (eg packaging materials, media and equipment) and on foods (Lopez et al., 2019). Plasma treatment can effectively inactivate a wide range of microorganisms, including spores and viruses. The effectiveness of microbial inactivation depends on the surface type of the treated products, the plasma device, the gas composition and the route of exposure (Thirumdas et al., 2015).

A reduction of more than 5 logs can be obtained for pathogens such as *Salmonella, Escherichia coli* O157: H7, *Listeria monocytogenes* and *Staphylococcus aureus*. The effective processing time can vary from 120 s to less than 3 s, depending on the food, that’s being processed and the processing conditions.

Ultraviolet light

UV light has been shown to be effective against most bacterial microorganisms, as well as viruses and molds. Ultraviolet light with a wavelength of 254 nm destroys the DNA of all microorganisms, so that viruses, bacteria, yeast and fungi are deactivated in seconds. Its applications include pasteurization of juices, treatment of meat, treatment of food contact surfaces, and extension of the shelf life of fresh products (Koutchma, 2008).

UV light is divided into three areas:

• UVA - the longest wavelength from 320 to 400 nanometers (nm);
• UVB - wavelengths in the range from 280 to 320 nm;
• UVC - the shortest wavelengths between 100 and 280 nm.

Irradiation of food products with UV lamps is a completely safe process for sterilization of foods that are designed to emit wavelengths in the UVC range. As a method of physical storage, UV radiation has a positive image among consumers (Koutchma, 2008).

UV kills microorganisms by penetrating cell membranes and damaging DNA, making them unable to reproduce and therefore killing them (Vasuja and Kumar 2018).

Pulsed electric field

The pulsed electric field provides an alternative choice for a variety of foods, especially liquid foods, to better preserve and maintain the qualities of foods and keep them similar to fresh.

Pulsed electric field technology (PEF) is a non-thermal method of food storage that involves the use of short pulses of electricity to inactivate microbes while imposing minimal adverse effects on food quality (Syed et al. 2017).

There is no specific legislation in the European Union on foods processed with PEF. In general, the use of this technique is regulated by the Novel Food Regulation (EU) 2015/2283, but the introduction of PEF in manifacture does not automatically mean that the food becomes 'new'. Pursuant to Article 4 of Regulation (EC) № 258/97, a foodstuff may be considered as "new" if the manufacturing process applied causes significant changes in its composition or structure affecting the nutritional value, metabolism or level of undesirable substances (Nowosad et al., 2020).

PEF treatment improves several processes such as canning, softening and aging. PEF treatment can be used as a useful strategy to improve the water retention properties of fis products as well as to drying fish (Gómez et al., 2019).

Ozonation

Ozone is a strong oxidizer and a powerful disinfectant. Its application in the food industry attracts attention due to zero residues on the product and no aeration is required to remove the gas (Jegadeeshwar et al., 2017).

Ozone kills microorganisms through the progressive oxidation of vital cellular components (Nath et al., 2014). Some researchers suggest that there are probably two main mechanisms of inactivation of microorganisms by ozone. The first involves the oxidation of sulfhydryl groups and amino acids to enzymes, peptides, and proteins to produce smaller peptides during ozone exposure, while the second mechanism involves the oxidation of polyunsaturated fatty acids to acid peroxides (Nath et al., 2014; Brodowska et al., 2018).

Ionizing radiation

Irradiation has been used successfully to reduce pathogenic bacteria, eliminate parasites, reduce post-harvest germination, and extend the shelf life of fresh perishable foods (Andrews et al., 1998).

Ionizing radiation is transmitted by high-energy particles (alpha, protons, electrons and neutrons) or electromagnetic waves (X-rays and gamma rays). Only electromagnetic radiation (X-rays and gamma rays) and electron beam radiation are the two forms of ionizing radiation applied to food, among the various existing forms of ionizing radiation (Lima et al., 2018).

Based on experimental studies and theoretical assessments in 1980, the FAO / IAEA / WHO Expert Committee on the Completeness of Irradiated Foods recommended limiting the sources of radiation used in food processing to those with energy levels well below those that cause radioactivity in treated foods. Food processed by radiation in accordance with the Committee's recommendations shall not become radioactive. However, the chemical composition of food can be altered by radiation and the authorities responsible for assessing the safety of irradiated food must take into account the possibility that some of the chemical compounds formed during food irradiation may be harmful (WHO, 1981; WHO, 1988).

Microorganisms (especially Gram-negative bacteria such as Salmonella) can be killed by radiation. However, bacterial spores are killed only by high doses, which mean that the highly lethal food-borne disease, botulism, is not necessarily prevented by radiation (WHO, 1988).

The main source used for irradiation is cobalt-60. The radiation dose may vary depending on the purpose or the food type (Horita et al., 2018).

The high resistance of some enzymes and microorganisms to non-thermal processes, especially bacterial spores, limits their application. To expand the use of non-thermal processes in the food industry, combinations of these technologies with traditional or innovative food preservation techniques are being studied (Raso and Barbosa-Cánovas, 2003).

Packaging as a method of preventing food spoilage

Packaging is an essential component of the food system, ensuring the safe handling and delivery of fresh and processed food products from the point of production to the end user. The technological development of packaging offers new perspectives for reducing losses, maintaining quality, adding value and extending the shelf life of agricultural products and therefore ensuring the food system (Opara and Mditshwa, 2013).

Del Nobile and Conte (2013) address important issues related to the nature of packaging. Packaging can play a key role in preserving food.

The right choice of packaging system is essential for ensuring food safety, preserving their qualities and prolonging the shelf life. This includes suitable packaging material with characteristics corresponding to the food product, packaging environment and storage conditions.

From a passive barrier to stopping or significantly slowing down the processes of exchange of packaged foods with the environment, packages become active elements of the packaging system, as the components added to their structure slow down the processes of spoilage. Natural substances are increasingly used as active ingredients.

Antibacterial active packaging systems are being developed for various food products. The active components in them play a vital role in ensuring safety. Antibacterial active packaging systems can be passive or active. The passive ones have the property to repel microorganisms, and the active ones to kill them (Stefanov and Stefanova, 2017). The use of antimicrobial packaging materials in food packaging can minimize microbial contamination of food surfaces during storage, transportation, and handling (Sachin and Khan, 2017).

Although traditional food packaging technologies are still widely used, the future will undoubtedly belong to the innovation provided by the 21st century active packaging. The most important advantage resulting from their use is the reduction of food loss due to the extension of their shelf life (Wyrwa and Barska, 2017).

Current trends in food packaging researches are aimed at improving the quality and safety of food by increasing the use of environmental friendly materials and in the ideal case those that can be obtained from biological resources and present biodegradable characteristics. Edible films and coatings are the key area in the development of new multifunctional materials by their nature and properties to effectively protect food without waste production (Valdés et al., 2015).

The application of edible coatings on food products creates conditions for a change in the modern concept of packaging. By applying this even partial alternative to conventional packaging materials, it is possible to simplify the structure of the packages involved in the edible coating system. From multi-layered, packaging can become single-layered and even reduce its thickness, making it easier to recycle. Edible coatings may include active ingredients, such as antibacterial. The development of edible coatings with nanosystems allows the inclusion of antimicrobial and antioxidant ingredients (Zambrano-Zaragoza et al., 2018).

The direct surface application of antimicrobial substances to food is limited due to the rapid diffusion from the surface into the food mass. However, the use of packaging films containing antimicrobial agents is more effective due to the mechanism of slow migration from the packaging material to the food surface (Radusin et al., 2013).

Packaging in a modified atmosphere

Changing the environment in the package makes it possible to provide conditions that slow down the processes of food spoilage. Packaging in modified atmosphere is considered as an innovative technology, which is alternative to traditional packaging systems. Despite decades of application, it is constantly improving. The nomenclature of foods packaged in this technology is expanding. The developments are aimed at studying the mechanisms of impact of the environment in the packaging, the characteristics of packaging materials, storage conditions, the interactions between the elements in the packaging system to achieve the best results in terms of safety, quality and shelf life.

The application of minimal impact in the form of non-thermal food processing methods in many cases does not create the necessary level of safety. Combining them with appropriate packaging methods and tools significantly increases safety and shelf life. Providing appropriate conditions during storage, transport and distribution further adds a security element to the food system. When preserving food, different approaches are used, which create unfavorable conditions for the normal existence of the agents that cause spoilage - the water activity is reduced (drying), the pH is lowered, oxygen is removed, preservatives are added, etc. All these approaches can be combined. In practice, the application of a set of measures ensures the highest levels of safety with optimal quality indicators and a long period of storage of food products. This approach is known as the "obstacle effect" (Leistner, 1994). If the intensity of an obstacle in the food is too small, it should be increased, if it is to the detriment of the quality of the food, it should be reduced. Through this adjustment, food barriers can be maintained in the optimal range. Obstacle technology aims to improve the overall quality of food by applying an intelligent combination of obstacles (Leistner and Gorris, 1997); Leistner, 2000).

Combining food processing and packaging methods

Existing methods of non-thermal food processing can be combined in order to obtain optimal indicators of quality, shelf life and safety. The application of each of them creates an obstacle or a complex of such for the development of processes of decay. The use of edible coatings applied directly to food further enhances the effect. In many cases, it also manifests itself in the direction of improving the quality of edible coatings and films.

FIG. 1 shows the effect the combination of different methods of food packaging has on their shelf life, in which they maintain safety and high levels of quality indicators. At room temperature, the loss of quality will occur after a certain time, which is a function of the properties of the product and the packaging system that’s used. As the storage temperature decreases, the shelf life of the same measurable properties increases. This is in fact a second obstacle that is created for the causes of the ongoing processes of spoilage in food products. Adding a gas-specific atmosphere to the package will create a new barrier that will further increase the shelf life.

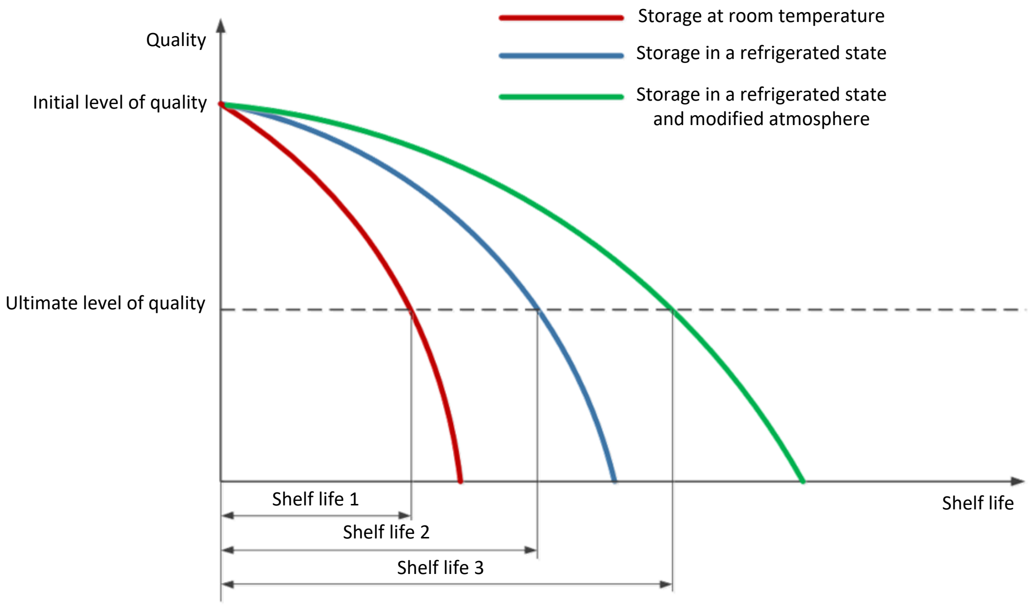

Fig. 1 Increase shelf life by adding barriers

In order to obtain maximum quality indicators for a certain shelf life, it is necessary to select appropriate barriers that do not create serious changes in the structure and composition of food products, manifested in the form of changes in taste, aroma, color, etc. The consistency of application of the obstacle methods is essential. When using edible films and coatings, treatment with non-thermal methods often changes their characteristics. This change is not always positive. There are cases in which the quality of edible packaging deteriorates, as a result of which the final effect is negative.

Edible films and coatings and MAP

Packaging foods in a modified atmosphere at low temperatures is usually not enough to significantly extend the shelf life of most freshly chopped fruits and vegetables.

 Copyrights© 2020 ISBN 978-954-712-826-2 (Print)

The combined use of edible packaging with modification of environment makes it possible to increase the protective function of the package. The combination of edible coatings with traditional MAP can reduce overall packaging costs (Turhan, 2010). Achieving a sufficient shelf life and ensuring the safety and quality of minimally processed fruits and vegetables requires a combination of treatments. An extension of the shelf life of minimally processed fruits and vegetables with edible coatings with natural additives and a modified atmosphere has been achieved (Ghidelli and Pérez-Gago, 2018).

The application of enriched edible films and coatings combined with MAP conditions slows the growth of microorganisms in hake fillets. The combination of edible whey protein-based coatings with oregano and essential oils and an atmosphere in a CO2-rich package can be a good alternative for preserving fish and fish products (Carrión-Granda et al., 2018).

Freshly chopped fruits and vegetables are at the top of the list of ready-to-eat foods and stimulate researches in this area (Porta et al., 2013). Packaging in microperforated polypropylene film using a passive or active modified atmosphere of sodium and alginate coated fresh and sliced carrots prevents dehydration and microbial proliferation, slows respiratory activity and enhances the quality of the product stored at 4° C (Mastromatteo et al., 2012). .

Mushrooms require special care and special packaging in the stages after harvest. Many methods have been proposed to increase the shelf life of edible mushrooms. Among the factors that contribute to the short life of the mushrooms, the most important are enzyme activity, darkening, loss of moisture, microbial attacks and very high respiration rates. The use of nano film and nano film plus packaging in a modified atmosphere has positive effects on the preservation of the physical, chemical and mechanical qualities of mushrooms during their storage and can also extend their shelf life. The use of nanofilm together with MAP is recommended for packaging of agricultural products and the food industry, especially for sensitive products such as mushrooms (Gholami et al., 2019).

The modified atmosphere packaging and soy protein coating maintain sensory, chemical and microbial quality indicators during storage at 4 ± 1° C of carp fish balls. The results show that the best gaseous media are 70% CO_2 / 20% N_2 / 10% O_2. They have a storage period of 27 days, followed by a gaseous medium of 50% CO_2 / 50% N_2 for 24 days. Edible coating without packaging in MA maintains quality for up to 18 days of storage (EL Din et al., 2018).

Edible coatings provide a semi-permeable barrier to gases and water vapor and also improve mechanical properties, thus slowing down natural aging, minimizing water loss and preserving the structural integrity of the coated product. The edible coating works to modify the internal gas composition of individual freshly chopped fruits or vegetables, and also reduces qualitative and quantitative changes, thus giving the effect of storage in a modified atmosphere. The quality and shelf life of freshly cut papaya cubes treated with alginate-based food coatings containing thyme and oregano essential oils in various concentrations (0.5 ml, 1.0 ml and 2.0 ml) as a lipid component of the coating, while the alginate concentration (2% w/v) is kept constant. The samples were analyzed for physicochemical changes, gas exchange, microbial stability and sensory quality for a 12-day storage period at 4° C. Increasing the concentration of essential oil increases the shelf life as well as the capacity to retain moisture, but shows negative reactions from the touch panel due to the strong odor of essential oils (Tabassum end Khan, 2020).

Edible packaging and pulsating light

The use of edible coatings in combination with pulsed light is a new approach to extend the shelf life of highly perishable but high value-added products, such as freshly sliced fruits and vegetables. By combining these two barriers, effective food storage methods can be developed using the different antimicrobial mechanisms of the two technologies and different time scales - pulsating light causes an immediate microbial reduction of the food surface, while active edible coatings provide inhibition of microbial growth over an extended period of time (Pirozzi et al., 2020).

PL treatments applied to freshly sliced apples coated with gellan-gum can be used to decontaminate the cut surface of the fruit without drastically affecting their properties, thus giving prebiotic potential and prolonging the shelf life (Moreira et al., 2015).

PL treatment with 20 pulses of broad-spectrum light (λ = 180 - 1100 nm) with a total energy of 8 $J{\cdot}cm^{-2}$ is most suitable for controlling the growth of L. Innocua on freshly sliced mango (Salinas-Roca et al., 2016).

The effects of edible coatings combined with repeated pulsed light (RPL) treatment on the microbiological stability, quality and physicochemical changes of freshly cut melons during storage at 4 ± 1° C were studied. Different cover materials were used. Microbiological quality, gas composition, physical quality (hardness, liquid and color loss), chemical quality (pH, titratable acidity, total soluble solids, total phenolic and ascorbic acid content) and homogeneity and adhesion of the coating were evaluated. The combination of treatment with alginate and RPL is the most effective treatment condition to extend the shelf life of freshly cut melons by maintaining microbiological quality for up to 28 days with significantly reduced fluid loss and increased hardness compared to samples treated with RPL alone (Koh et al., 2017).

The properties of freshly sliced strawberries dipped in AA-CaL and treated with pulsed light were studied. This has a positive effect on the overall quality of the sliced strawberries. The effect is achieved by reducing and / or inhibiting the development of mould and browning during refrigerated storage. No dramatic effects on antioxidant properties were found. Although PL treatment at 8 $J{\cdot}cm^{-2}$ retains 90% of the initial vitamin C content, the other studied properties remain unaffected (Avalos-Llano et al., 2018).

The combination of an edible coating based on modified chitosan with PL shows a slight antagonistic effect and has a slightly negative effect on color properties (Donsì et al., 2015).

Edible packaging in combination with high hydrostatic pressure

Combined treatments including edible packaging and high pressure can be used to preserve fish. The combined effect of gelatin coating on fish products and their treatment with high hydrostatic pressure during refrigeration was studied. The application of this combination imparts stability during storage of chilled fish (López de Lacey et al., 2012).

Studies have been performed and the effect of combining antimicrobial edible coating with other non-thermal treatments, including high hydrostatic pressure (HHP) or pulsed light (PL) has been evaluated. The coating is a modified chitosan, which contains a nanoemulsion of tangerine essential oil. The results show a significant reduction in *L. innocua* throughout the storage period, due to the development of significant synergism of antimicrobial effects (Donsì et al., 2015).

The changes occurring in the chemical and microbiological quality of fresh rainbow trout fillets at a storage temperature of 4 ± 1° C with applied edible film coating based on chitosan, vacuum packaging and high pressure processes have been determined. It has been found that high pressure and chitosan-based coating have a protective effect both chemically and microbiologically and that the most effective protection is obtained when both methods are used together (Günlü et al., 2014).

Edible packaging in combination with ionizing radiation (irradiation)

Polyphenol-chitosan coating combined with irradiation can maintain fish quality by preventing bacterial growth, oxidation, and color changes and sensory acceptability (Zhang et al., 2017).

A combination of lowland and irradiation can be used to extend the shelf life of minimally processed fish steaks when refrigerated. At a dose of 2 kGy, the increase in duration is from 7 to 34 days, and at a dose of 5 kGy – up to 42 days (Kakatkar et al., 2017).

Combined treatments of gamma irradiation at doses of 2, 4 and 6 kGy and edible coatings containing 2% ethanol extract of papaya leaves have been applied to improve the quality and safety of minced chicken legs through its effectiveness in eliminating bacteria and prolonging shelf life in cold storage. The extension was up to 30, 39 and 54 days for irradiated coated samples, respectively, compared to 6 days for uncoated control samples, without any adverse changes in

Copyrights© 2020 ISBN 978-954-712-826-2 (Print)

their chemical and sensory properties. The inclusion of ethanol extract of papaya leaves in edible roofing materials increases the bacterial inhibitory effect of gamma irradiation and is suitable for canning minced chicken (Abdeldaiem, 2014).

The effect of gamma irradiation of 0.5 and 1.0 kGy in addition to edible coating with paraffin oil and glycerol on the shelf life and quality of apples during storage at 0° C, 90-95% RH for 90 days was evaluated. Irradiation and edible coating during refrigerated storage strongly affect the storage quality of apples (Salem et al., 2019).

The effectiveness of gamma irradiation in low doses, combined with edible coatings for three types of products - shrimp, pizza and strawberries. Shelf life periods range from 3 to 10 days for shrimp and 7 to 20 days for pizza, compared to uncoated / non-irradiated products. No significant ($p > 0.05$) harmful effect of gamma radiation on sensory characteristics (smell, taste, appearance) was observed. In strawberries, coating with irradiated protein solutions leads to a significant reduction of mold (Ouattara et al., 2002).

Gamma irradiation and various edible coatings have been tested on fresh strawberries to maintain fruit quality and extend shelf life. The samples were irradiated with Co60. Irradiation of edible caseinate-based coatings is more effective than non-irradiated coatings (Vachon et al., 2003).

The red tomatoes are coated with gelatin / starch / glycerol in combination with irradiated supernatant lactic acid. The results show lower bacterial load, reduced weight loss, higher levels of ascorbic acid and more (Ola et al., 2020).

Mixtures of thin gilms based on different ratios of plasticized polyvinyl alcohol (PVA), carboxymethyl cellulose (CMC) and tannin compound are subjected to treatment with different doses of gamma rays. The effect of radiation on the thermal and mechanical characteristics of the films was studied. Gamma-ray-treated films are used to cover bananas. This has increased the shelf life from 9 to 19 days. On the 19th day, the banana maintains a good natural color and ripening level, while the control sample is completely damaged. Fruits covered with non-irradiated mixture cannot prevent maturation (Senna et al., 2014).

The combined effect of gamma irradiation and coatings containing 0.5% rosemary essential oil (Rosmarinus officinalis) on the chemical, microbiological and sensory properties of carp fish fillets (Hypophthalmichthys molitrix) during cold storage (4° C) was studied. The fillets are divided into three groups: uncoated (control samples), coated with edible coating (without additives) and γ-irradiated (0, 1, 3 and 5 kGy). The coating contains 0.5% rosemary. The increase in the bacterial inhibitory effect is caused by rosemary oil and radiation both. In coated samples irradiated at 1 kGy, a decrease in the number of Enterobacteriaceae, *Staphylococcus aureus* and *Bacillus cereus* was observed, as well as elimination of *Vibrio spp*. and *Salmonella spp*. Coated and irradiated samples at 3 and 5 kGy completely eliminated these bacteria (Abdeldaiem et al., 2018).

A study was performed to evaluate the combined effect of low-dose (2.5 kGy) gamma irradiation and edible chitosan coating (2%) containing grape seed extract (0.1%) on microbial, chemical and sensory qualities of chicken breast meat at storage 4° C. The shelf life is 21 days. The application of chitosan coating significantly improved the sensory properties of the samples and none of the evaluated sensory attributes was significantly affected by irradiation. Based on the results obtained in this study, the application of low-dose gamma irradiation and chitosan coating containing grape seed extract is effective in maintaining the quality of fresh chicken meat and is recommended for meat products (Hassanzadeh et al., 2017).

The combined effect of edible coating and gamma irradiation treatment on mold growth and storage quality of strawberry was studied. The coating is based on a solution of carboxymethylcellulose with a content of 0.5 and 1.0% (w/v). After application, the samples were irradiated with 2.0 kGy and cold stored for 21 days. Significant irradiation efficiency was found in combination with 1.0% w/v carboxymethylcellulose coating ($p \leq 0.05$) to slow down strawberries to grow mouldy for up to 18 days, to maintain quality and to slow down spoilage during refrigeration. The combined application of irradiation and coating can help for transportation of strawberries in distant markets far from the local market, which is in producers and consumers benefit (Hussain et al., 2012).).

The combined effect of gamma irradiation with gamma rays and commercial edible coating, Sta-Fresh 2505, on the quality after harvest of golden-yellow and purple-red tamarillo was studied. Weight loss, pH, hardness, soluble solids content, respiratory rate, pulp appearance, sensory hardness, aroma (including unpleasant smell) were analyzed. The self application of the two methods and the combination of them both has been studied. The combination of gamma irradiation and edible coating has a synergistic effect on the quality of tamarillos after harvest (Abad et al., 2017).

Edible packaging in combination with ionizing radiation (radiation) and modified atmosphere

The effect of applying a combination of edible coatings based on calcium caseinate with included trans-cinnamaldehyde, modified atmosphere (60% O_2, 30% CO_2 and 10% N_2) and irradiation with 0.25 or 0.5 kGy on the qualities of peeled mini carrots was studied. The samples were stored at 4 ± 1° C for 21 days. Results show that the combination of irradiation and storage conditions in MA plays an important role in the radiosensibilization of *L. innocua*. The combination of edible coating, MAP and irradiation can be used to maintain the safety of fresh minimally processed carrots. Irradiation can suppress food pathogens and subsequently extend the shelf life of peeled mini carrots. Complete inhibition of *L. innocua* is obtained with a combination of low doses of radiation (0.5 kGy) and MAP with or without coating. The number of *L. innocua* indicates that the combination of irradiation and MAP plays a role in bacterial radiosensibilization, producing a synergistic antimicrobial effect on bacterial growth in peeled mini carrots during storage (Caillet et al., 2006).

Edible coatings with ozone

The combined effect of edible coatings with added mixture of essential oils and citrus fruit extract with ozonation (Oz) or gamma irradiation (GI) on the shelf life of hake fillet stored at 4 ° C was studied. The fillets were coated with 1,6% w/v mixtures of essential oils prepared in 2% w/v alginate, followed by treatment with ozone (10 ppm for 15 minutes) or gamma rays (1.0 kGy). The shelf life of the fillets is 7 days for the control samples (fillets without any treatment), increased to 28 days for alginate-coated samples with essential oils included and gamma radiation treatment. The shelf life of the fillets is increased to 14 days when they have been treated only with an alginate coating with essential oils included and 21 days when they have been treated with an alginate coating with essential oils included and treated with ozone. Optimizing the combined dose for treatment can increase the shelf life of packaged fish to the desired duration (Shankar, et al).

Edible coatings with UV light

The effect of UV-C irradiation and edible coatings on longan fruits stored at ambient temperature (28 ± 1° C) was evaluated. For the UV-C irradiation is applied UV light with a wavelength of 254 nm and a dose of 11.4 kJ/m^2. Edible coatings are based on chitosan and carrageenan. When UV treatment precedes the coating, the effect is greater in combinations of UV plus chitosan coating than in UV plus carrageenan (Lin, et al., 2017).

UV-C treatment in combination with various edible coatings based on aloe, cinnamon oil and chitosan have a significant effect on the shelf life of white pepper stored at 8 ± 1° C with 80-85% RH. All treatments and combinations with edible coatings extend the shelf life. The application of UV-C rays for 5 minutes and 1.5% aloe gel maintains the quality of pepper better than the control samples and the term is extended to 24 days (Abbasi et al., 2015).

CONCLUSION

There are three possible effects of the barrier application in food systems: an additive, synergistic or antagonistic effect (Tsironi et al., 2020).

 Copyrights© 2020 ISBN 978-954-712-826-2 (Print)

The aim purpose when developing the technology and the packaging system is to achieve a synergistic effect that will fully meet modern trends - customers to receive safe and high quality products, retailers to obtain the necessary shelf life to deal in the products, and manufacturers to receive the added value.

The review analysis of the published results from a study of the food products behavior, which are non-thermally treated and coated with edible films shows their orientation to fresh, minimally processed fruits and vegetables intended for direct consumption - ready to eat (RTE). To some extent, this also applies to ready-to-eat foods, where the challenge is greater due to the presence of a wide variety of components with specific qualities. Researchers are focusing on products that have high added value. Obviously, the breakdown is most noticeable in terms of possible losses for the consumers, traders, distributors and producers.

More often, researchers turn to combining edible coatings with methods for non-thermal treatment based on radiation - ionizing radiation, UV and pulsed light. Despite the possible change in organoleptic qualities, most authors report a lack of tangible changes during the studies. They most often report a synergistic effect of combining edible coatings with non-thermal treatment methods. This is mainly due to the impact of these methods to improve the properties of the coatings.

The use of atmospheric modification packaging systems has found a worthy place in the supply chain of fresh fruits and vegetables, including sliced, ready to use at home and also by catering companies. The use of additional barrier by applying an edible coating, often with active ingredients based on natural materials (eg spices), gives the possibility of an additional or even synergistic effect on ensuring a longer shelf life. More often this does not require serious investment, and the effect is close to the ones obtained with expensive methods and equipment.

Parallel studies make it possible to make a comparative analysis of the applied minimum treatments and the resulting effect of extending the shelf life. In this way, it is noticed that results can be achieved by more easily feasible methods, close to the maximum obtained shelf life through significantly more expensive ones.

Reducing stress on processed raw materials of animal and plant origin and the production of minimally processed food products through a set of gentle effects also has an effect on the environment. It is related to reducing the energy intensity of the processes necessary to ensure the safety and quality of food in demand by consumers, the use of waste resources in edible coatings, which create a series of obstacles to the development of decay processes, and ultimately to significant reducing food and packaging waste. In this regard, it can be conluded that combining non-thermal technologies with edible films and coatings is a sustainable technology and a step towards a circular economy.

REFERENCES

Abad J., S. Valencia-Chamorro, A. Castro, C. Vasco (2017), Studying the effect of combining two nonconventional treatments, gamma irradiation and the application of an edible coating, on the postharvest quality of tamarillo (Solanum betaceum Cav.) fruits, Food Control, Vol. 72(B), pp. 319-323, ISSN 0956-7135, https://doi.org/10.1016/j.foodcont.2016.05.024.

Abbasi Nadeem Akhtar, Sonia Ashraf, Irfan Ali and Shahid Javed Butt (2015), Enhancing storage life of bell pepper by UV-C irradiation and edible coatings, Pak. J. Agri. Sci., Vol. 52(2), 403-411; ISSN (Print) 0552-9034, ISSN (Online) 2076-0906.
https://pakjas.com.pk/papers/2430.pdf.

Abdeldaiem M. H (2014), Using of Combined Treatment between Edible Coatings Containing Ethanolic Extract of Papaya (Carica Papaya L.) Leaves and Gamma Irradiation for Extending ShelfLife of Minced Chicken MeatAmerican Journal of Food Science and Technology, 2014, Vol. 2, No. 1, 6-16

Abdeldaiem Mohammad Hasan, Hoda Gamal Mohammad & Mohamed Fawzy Ramadan (2018) Improving the Quality of Silver Carp Fish Fillets by Gamma Irradiation and Coatings

Containing Rosemary Oil, Journal of Aquatic Food Product Technology, 27:5, 568-579, DOI: 10.1080/10498850.2018.1461157

Abida, J. & Rayees, B. & Masoodi, F. A. (2014). Pulsed light technology: A novel method for food preservation. International Food Research Journal. 21. 839-848.

Akbarian Mina, Banafsheh Aghamohammadi, Ava Akbarian, Zahra Poursharif, Nila Ghasemkhani and Fatemeh Moayedi (2014), Effect of different nonthermal processings on food packaging: a review, Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231-6345 (Online), An Open Access, Online International Journal, Vol. 4 (2) pp. 420-426.

Allende A., F. A. Tomás-Barberán, M. I.Gil (2006), Minimal processing for healthy traditional foods, Trends in Food Science & Technology, 17, 513–519.

Amit et al. (2017) A review on mechanisms and commercial aspects of food preservation and processing, Agric & Food Secur, pp. 2-22. DOI 10.1186/s40066-017-0130-8.

Andrews LS, Ahmedna M, Grodner RM, Liuzzo JA, Murano PS, Murano EA, Rao RM, Shane S, Wilson PW. Food preservation using ionizing radiation. Rev Environ Contam Toxicol. 1998; 154:1-53. doi: 10.1007/978-1-4612-2208-8_1. PMID: 9414630.

Avalos-Llano Karina R., Olga Martín-Belloso, Robert Soliva-Fortuny (2018), Effect of pulsed light treatments on quality and antioxidant properties of fresh-cut strawberries, Food Chemistry, Volume 264, pp. 393-400, ISSN 0308-8146, https:/doi.org/10.1016/j.foodchem.2018.05.028.

Beikzadeh S., M. Ghorbani, N. Shahbazi, F. Izadi, Z. Pilevar, A. Mortazavian (2020), The Effects of Novel Thermal and Nonthermal Technologies on the Properties of Edible Food Packaging, Food Engineering Reviews (2020) 12:333–345, https://doi.org/10.1007/s12393-020-09227-y

Bhavya M L, H Umesh Hebbar (2017), Pulsed light processing of foods for microbial safety, Food Quality and Safety, Vol. 1, 3, Pp. 187–202, https://doi.org/10.1093/fqsafe/fyx017

Brodowska Agnieszka Joanna, Agnieszka Nowak & Krzysztof Śmigielski (2018) Ozone in the food industry: Principles of ozone treatment, mechanisms of action, and applications: An overview, Critical Reviews in Food Science and Nutrition, 58:13, 2176-2201, DOI: 10.1080/10408398.2017.1308313.

Buzrul S. (2015). Multi-Pulsed High Hydrostatic Pressure Treatment of Foods. *Foods (Basel, Switzerland)*, *4*(2), 173–183. https://doi.org/10.3390/foods4020173

Buzrul, Sencer & Alpas, Hami. (2012). Treatment of Foods Using High Hydrostatic Pressure. 10.1002/9781119962045.ch18.

Caillet S., M. Millette, S. Salmiéri, M. Lacroix (2006), Combined Effects of Antimicrobial Coating, Modified Atmosphere Packaging, and Gamma Irradiation on *Listeria innocua* Present in Ready-to-Use Carrots (*Daucus carota*). *J Food Prot*, 69 (1): 80–85. doi: https://doi.org/10.4315/0362-028X-69.1.80

Carrión-Granda X., I. Fernández-Pan, J. Rovira, J. I. Maté (2018), "Effect of Antimicrobial Edible Coatings and Modified Atmosphere Packaging on the Microbiological Quality of Cold Stored Hake (Merluccius merluccius) Fillets", Journal of Food Quality, vol. 2018, Article ID 6194906, 12 pages, . https://doi.org/10.1155/2018/6194906

Christian Ghidelli & María B. Pérez-Gago (2018), Recent advances in modified atmosphere packaging and edible coatings to maintain quality of fresh-cut fruits and vegetables, Critical Reviews in Food Science and Nutrition, 58:4, 662-679, DOI: 10.1080/10408398.2016.1211087.

De Corato U (2019), The Market of the Minimally Processed Fresh Produce Needs of Safer Strategies for Improving Shelf Life and Quality: A Critical Overview of the Traditional Technologies. Open Access Journal of Agricultural Research, 4, 1, ISSN: 2474-8846,. DOI: 10.23880/oajar-16000216

Donsì Francesco, Enrico Marchese, Paola Maresca, Gianpiero Pataro, Khanh Dang Vu, Stephane Salmieri, Monique Lacroix, Giovanna Ferrari (2015), Green beans preservation by combination of a modified chitosan based-coating containing nanoemulsion of mandarin essential oil with high pressure or pulsed light processing, Postharvest Biology and Technology, Volume 106, pp. 21-32, ISSN 0925-5214, https://doi.org/10.1016/j.postharvbio.2015.02.006.

EL Din Hosam, Aboul Anean, Nagla El -Senousi, Safwat Abdel Ghfour, (2018), Effect of modified atmosphere packaging and edible films on the quality of carp fish patties, J Nutr Health Food Eng.;8(1):14–22.

García-Gimeno Rosa María and Guiomar Denisse Posada Izquierdo (2020), High Hydrostatic Pressure Treatment of Meat Products, DOI: 10.5772/intechopen.90858

Gholami, R., Ahmadi, E., & Ahmadi, S. (2019). Investigating the effect of chitosan, nanopackaging, and modified atmosphere packaging on physical, chemical, and mechanical properties of button mushroom during storage. *Food science & nutrition*, *8*(1), 224–236. https://doi.org/10.1002/fsn3.1294

Gómez Belen, Paulo E.S. Munekata, Mohsen Gavahian, Francisco J. Barba, Francisco J. Martí-Quijal, Tomás Bolumar, Paulo Cezar Bastianello Campagnol, Igor Tomasevic, Jose M. Lorenzo (2019), Application of pulsed electric fields in meat and fish processing industries: An overview, Food Research International, Volume 123, Pp. 95-105, ISSN 0963-9969, https://doi.org/10.1016/j.foodres.2019.04.047.

Günlü A., S. Sipahioğlu and H. Alpas (2014). The effect of chitosan-based edible film and high hydrostatic pressure process on the microbiological and chemical quality of rainbow trout (*Oncorhynchus mykiss* Walbaum) fillets during cold storage (4±1°C), High Pressure Research, 34:1, 110-121, DOI: 10.1080/08957959.2013.836643.

Günlü Ali, Sinem Sipahioğlu & Hami Alpas (2014) The effect of chitosan-based edible film and high hydrostatic pressure process on the microbiological and chemical quality of rainbow trout (*Oncorhynchus mykiss* Walbaum) fillets during cold storage (4±1°C), High Pressure Research, 34:1, 110-121, DOI: 10.1080/08957959.2013.836643

Hammond, Sean & Brown, James & Burger, Joseph & Flanagan, Tatiana & Fristoe, Trevor & Mercado-Silva, Norman & Nekola, Jeffrey & Okie, Jordan. (2015). Food Spoilage, Storage, and Transport: Implications for a Sustainable Future. BioScience. 1. 10.1093/biosci/biv081.

Hassanzadeh Parviz, Hossein Tajik, Seyed Mehdi Razavi Rohani, Mehran Moradi, Mohammad Hashemi, Javad Aliakbarlu (2017), Effect of functional chitosan coating and gamma irradiation on the shelf-life of chicken meat during refrigerated storage, Radiation Physics and Chemistry, Volume 141, Pages 103-109, ISSN 0969-806X, https://doi.org/10.1016/j.radphyschem.2017.06.014.

Horita Claudia N., Rafaela C. Baptista, Magdevis Y.R. Caturla, Jose Manuel Lorenzo, Francisco J. Barba, Anderson S. Sant'Ana (2018), Combining reformulation, active packaging and non-thermal post-packaging decontamination technologies to increase the microbiological quality and safety of cooked ready-to-eat meat products, Trends in Food Science & Technology, Volume 72, pp. 45-61, ISSN 0924-2244, https://doi.org/10.1016/j.tifs.2017.12.003.

Hurdle Technology in Fruit Processing, Paula Luisina Gómez, Jorge Welti-Chanes, Stella Maris Alzamora, Annual Review of Food Science and Technology 2011 2:1, 447-465

Hussain, P.R., Dar, M.A. and Wani, A.M. (2012), Effect of edible coating and gamma irradiation on inhibition of mould growth and quality retention of strawberry during refrigerated storage. Int J Food Sci Technol, 47: 2318-2324. https://doi.org/10.1111/j.1365-2621.2012.03105.x

Javier Raso and Gustavo V. Barbosa-Cánovas (2003), Nonthermal Preservation of Foods Using Combined Processing Techniques, Critical Reviews in Food Science and Nutrition, 43:3, 265-285, DOI: 10.1080/10408690390826527.

Jegadeeshwar, H & Shankar, Vijay & Kumar, Prem & thottiam Vasudevan, Ranganathan. (2017). A Review on Utilization of Ozone in Food preservation.

Joanna Wyrwa and Anetta Barska (2017), Innovations in the food packaging market: active packaging, Eur Food Res Technol 243:1681–1692 DOI 10.1007/s00217-017-2878-2.

Kakatkar Aarti S., Raj Kamal Gautam, Ravindranath Shashidhar (2017), Combination of glazing, nisin treatment and radiation processing for shelf-life extension of seer fish

(Scomberomorous guttatus) steaks, Radiation Physics and Chemistry, Volume 130, Pages 303-305, ISSN 0969-806X, https://doi.org/10.1016/j.radphyschem.2016.09.017.

Koutchma, Tatiana. (2008). UV Light for Processing Foods. Ozone Science and Engineering. 30. 93-98. 10.1080/01919510701816346.

Lee, SH, Choi, W. & Jun, S. (2016). Конвенционални и нововъзникващи комбинирани технологии за хранителна обработка. *Food Eng Rev* **8,** 414–434. https://doi.org/10.1007/s12393-016-9145-3.

Leistner L. (1994), Further developments in the utilization of hurdle technology for food preservation, Journal of Food Engineering, Volume 22, Issues 1–4, Pp. 421-432, ISSN 0260-8774.

Leistner L. (2000), Basic aspects of food preservation by hurdle technology, International Journal of Food Microbiology, Volume 55, Issues 1–3, Pp. 181-186, ISSN 0168-1605, https://doi.org/10.1016/S0168-1605(00)00161-6.

Leistner l. and l.G.M. Gorris (1997), Food preservation by combined processes, Final Report, EC Brussels European Commission Publikation EUR 15576, ISBN ISBN 90-900-7303-5

Lima Fabiana, Kássia Vieira, Miriam Santos and Poliana Mendes de Souza (2018), Effects of Radiation Technologies on Food Nutritional Quality, DOI: 10.5772/intechopen.80437

Lin Mee Gie, Ola Lasekan, Nazamid Saari, Siti Khairunniza-Bejo (2017), "The Effect of the Application of Edible Coatings on or before Ultraviolet Treatment on Postharvested Longan Fruits", Journal of Food Quality, vol. 2017, Article ID 5454263, 11 pages, https://doi.org/10.1155/2017/5454263

López de Lacey A.M., M.E. López-Caballero, J. Gómez-Estaca, M.C. Gómez-Guillén, P. Montero (2012), Functionality of Lactobacillus acidophilus and Bifidobacterium bifidum incorporated to edible coatings and films, Innovative Food Science & Emerging Technologies, Volume 16, pp. 277-282, ISSN 1466-8564, https://doi.org/10.1016/j.ifset.2012.07.001.

López Mercedes, Calvo Tamara, Prieto Miguel, Múgica-Vidal Rodolfo, Muro-Fraguas Ignacio, Alba-Elías Fernando, Alvarez-Ordóñez Avelino, A Review on Non-thermal Atmospheric Plasma for Food Preservation: Mode of Action, Determinants of Effectiveness, and Applications, Frontiers in Microbiology, ISSN=1664-302X, VOL.10, 2019, pp.622 DOI = 10.3389/fmicb.2019.00622.

Mahendran R., K. Ratish Ramanan, Francisco J. Barba, Jose M. Lorenzo, Olalla López-Fernández, Paulo E.S. Munekata, Shahin Roohinejad, Anderson S. Sant'Ana, Brijesh K. Tiwari (2019), Recent advances in the application of pulsed light processing for improving food safety and increasing shelf life, Trends in Food Science & Technology, Volume 88, pp. 67-79, ISSN 0924-2244, https://doi.org/10.1016/j.tifs.2019.03.010.

Maherani, B., Harich, M., Salmieri, S. *et al.* Антибактериални свойства на комбинираните нетермични процедури, базирани на биоактивно ядливо покритие, озониране и гама облъчване върху готови за консумация замразени зелени чушки: оценка на тяхната свежест и сензорни качества. *Eur Food Res Technol* 245**,** 1095–1111 (2019). https://doi.org/10.1007/s00217-018-3211-4

Mamta Sahu, Shashi Bala (2017), Food Processing, Food Spoilage and their Prevention: An Overview, Int. J. Life. Sci. Scienti. Res., 3(1): 753-759.

Mandal, Xanyar Mohammadi, Artur Wiktor, Anika Singh and Anubhav Pratap Singh (2020), Applications of Pulsed Light Decontamination Technology in Food Processing: An Overview Ronit, Appl. Sci., 10, 3606; doi:10.3390/app10103606

Mastromatteo Marianna, Amalia Conte, Matteo Alessandro Del Nobile (2012), Packaging strategies to prolong the shelf life of fresh carrots (Daucus carota L.), Innovative Food Science & Emerging Technologies, Volume 13, pp. 215-220, ISSN 1466-8564, https://doi.org/10.1016/j.ifset.2011.10.010.

Matteo Alessandro Del Nobile, Amalia Conte (2013), Packaging for Food Preservation**,** Online ISBN 978-1-4614-7684-9, DOI: https://doi.org/10.1007/978-1-4614-7684-9.

Moreira María R., Bárbara Tomadoni, Olga Martín-Belloso, Robert Soliva-Fortuny (2015), Preservation of fresh-cut apple quality attributes by pulsed light in combination with gellan gum-based prebiotic edible coatings, LWT - Food Science and Technology, Vol. 64, 2, pp. 1130-1137, ISSN 0023-6438, https://doi.org/10.1016/j.lwt.2015.07.002.

Natha A., K. Mukhimb, T. Swerb , Debashis Duttaa, N. Vermaa, B.C. Dekab and B. Gangwara (2014), A Review on Application of Ozone in the Food Processing and Packaging, Journal of Food Product Development and Packaging, Vol. 1, Pp. 07-21.

Nowosad, K., Sujka, M., Pankiewicz, U. *et al* (2020). Приложението на PEF технологията в преработката на храни и човешкото хранене. *J Food Sci Technol*. https://doi.org/10.1007/s13197-020-04512-4.

Ohlsson Th, Minimal processing-preservation methods of the future: an overview, Trends in Food Science & Technology, Volume 5, Issue 11, 1994, Pages 341-344, ISSN 0924-2244, https://doi.org/10.1016/0924-2244(94)90210-0.

Ola A. A. Khalil, Amr M. Mounir & Ramadan A. Hassanien (2020) Effect of gamma irradiated Lactobacillus bacteria as an edible coating on enhancing the storage of tomato under cold storage conditions, Journal of Radiation Research and Applied Sciences, 13:1, 317-329, DOI: 10.1080/16878507.2020.1723886

Ouattara B., S.F Sabato, M Lacroix (2002), Use of gamma-irradiation technology in combination with edible coating to produce shelf-stable foods, Radiation Physics and Chemistry, Volume 63, Issues 3–6, pp. 305-310, ISSN 0969-806X, https://doi.org/10.1016/S0969-806X(01)00517-5.

Pankaj, S. K., Wan, Z., & Keener, K. M. (2018). Effects of Cold Plasma on Food Quality: A Review. *Foods (Basel, Switzerland)*, *7*(1), 4. https://doi.org/10.3390/foods7010004

Pedro E.D. Augusto, Alline A.L. Tribst, Marcelo Cristianini (2018), Chapter 20 - High Hydrostatic Pressure and High-Pressure Homogenization Processing of Fruit Juices, Editor(s): Gaurav Rajauria, Brijesh K. Tiwari, Fruit Juices, Academic Press, 2018, Pages 393-421, ISBN 9780128022306, https://doi.org/10.1016/B978-0-12-802230-6.00020-5.

Pei Chen Koh, Mohd Adzahan Noranizan, Zainal Abedin Nur Hanani, Roselina Karim, Siti Zaharah Rosli (2017), Application of edible coatings and repetitive pulsed light for shelf life extension of fresh-cut cantaloupe (Cucumis melo L. reticulatus cv. Glamour), Postharvest Biology and Technology, Volume 129, Pages 64-78, ISSN 0925-5214, https:// doi.org/10.1016/j.postharvbio.2017.03.003.

Pereira R. N. and A. A. Vicente, Environmental impact of novel thermal and non-thermal technologies in food processing**,** Food Research International, Volume 43, Issue 7, August 2010, Pages 1936-1943, https://doi.org/10.1016/j.foodres.2009.09.013

Pexara Andreana and Alexander Govaris (2020), Foodborne Viruses and Innovative Non-Thermal Food-Processing Technologies, Foods, 9, 1520; doi:10.3390/foods9111520

Picart-Palmade, L., Cunault, C., Chevalier-Lucia, D., Belleville, M. P., & Marchesseau, S. (2019). Potentialities and Limits of Some Non-thermal Technologies to Improve Sustainability of Food Processing. *Frontiers in nutrition*, *5*, 130. https://doi.org/10.3389/fnut.2018.00130.

Pirozzi, A., Pataro, G., Donsì, F. *et al* (2020). Edible Coating and Pulsed Light to Increase the Shelf Life of Food Products. *Food Eng Rev*. https://doi.org/10.1007/s12393-020-09245-w

Porta R, Rossi-Marquez G, Mariniello L, Sorrentino A, Giosafatto V, et al. (2013) Edible Coating as Packaging Strategy to Extend the Shelf-life of Fresh-Cut Fruits and Vegetables. J Biotechnol Biomater 3:e124. doi:10.4172/2155-952X.1000e124

Prokopov, Tsvetko & Tanchev, Stoyan. (2007). Methods of Food Preservation. 10.1007/978-0-387-33957-3_1.

Radusin Tanja I., Marija M. Škrinjar, Ivana S. Čabarkapa, Branka M. Pilić, Aleksandra R. Novaković, Nevena M. Hromiš (2013), Actual and future trends in antimicrobial food packaging, *Agro FOOD Industry Hi Tech* - vol 24(4).

Sachin A Surwade, Khan Chand (2017), Antimicrobial food packaging: An overview, European Journal of Biotechnology and Bioscience, Volume 5; Issue 5; September 2017; Page No. 85-90.

Salem, E., Naweto, M., Mahmoud, M. (2019). Effect of Irradiation and Edible Coating as Safe Environmental Treatments on The Quality and The Marketability of " Anna " Apples During Cold Storage. Arab Journal of Nuclear Sciences and Applications, 52(1), 193-202. doi: 10.21608/ajnsa.2018.5418.1123

Salinas-Roca B., R. Soliva-Fortuny, J. Welti-Chanes, O. Martín-Belloso (2016), Combined effect of pulsed light, edible coating and malic acid dipping to improve fresh-cut mango safety and quality, Food Control, Volume 66, Pages 190-197, ISSN 0956-7135, https://doi.org/10.1016/j.foodcont.2016.02.005.

San Martín M. F., G. V. Barbosa-Cánovas & B. G. Swanson (2002) Food Processing by High Hydrostatic Pressure, Critical Reviews in Food Science and Nutrition, 42:6, 627-645, DOI: 10.1080/20024091054274.

Senna, M. , Al-Shamrani, K. and Al-Arifi, A. (2014) Edible Coating for Shelf-Life Extension of Fresh Banana Fruit Based on Gamma Irradiated Plasticized Poly(vinyl alcohol)/Carboxymethyl Cellulose/Tannin Composites. *Materials Sciences and Applications*, **5**, 395-415. doi: 10.4236/msa.2014.56045.

Shankar Shiv, Faustine Danneels, Monique Lacroix (2019), Coating with alginate containing a mixture of essential oils and citrus extract in combination with ozonation or gamma irradiation increased the shelf life of Merluccius sp. fillets, Food Packaging and Shelf Life, Volume 22, 100434, ISSN 2214-2894, https://doi.org/10.1016/j.fpsl.2019.100434.

Stefanov S. and J. Stefanova (2017). Nanotechnologies in the food industry. Nanosciences and nanotechnologies - Collection of review articles. (***Оригинално заглавие:*** Стефанов С. и Й. Стефанова (2017). Нанотехнологиите в хранителновкусовата промишленост. Нанонауки и нанотехнологии - Сборник с обзорни статии.) ISBN 978-619-202-282-2.

Swallow A.J. (1984) Preservation of Food by Ionizing Radiation, International Journal of Radiation Biology and Related Studies in Physics, Chemistry and Medicine, 46:1, 97, DOI: 10.1080/09553008414551121.

Syed QA, Ishaq A, Rahman UU, et al. (2017), Технология на импулсно електрическо поле при консервиране на храни: преглед. *J Nutr Health Food Eng*.; 6 (5): 168-172. DOI: 10.15406 / jnhfe.2017.06.00219

Tabassum Nazia, Mohammad Ali Khan (2020), Modified atmosphere packaging of fresh-cut papaya using alginate based edible coating: Quality evaluation and shelf life study, Scientia Horticulturae, Vol. 259, ISSN 0304-4238, https://doi.org/10.1016/j.scienta.2019.108853.

Thirumdas, R., Sarangapani, C. & Annapure, U.S. Cold Plasma: A novel Non-Thermal Technology for Food Processing. *Food Biophysics* **10,** 1–11 (2015). https://doi.org/10.1007/s11483-014-9382-z

Tsironi Theofania, Dimitra Houhoula, Petros Taoukis, Hurdle technology for fish preservation, Aquaculture and Fisheries, Volume 5, Issue 2, 2020, Pages 65-71, ISSN 2468-550X, https://doi.org/10.1016/j.aaf.2020.02.001.

Turhan, Kamile. (2010). Is edible coating an alternative to MAP for fresh and minimally processed fruits? Acta Horticulturae. 876. 299-305. 10.17660/ActaHortic.2010.876.40.

Ugo De Corato (2020) Improving the shelf-life and quality of fresh and minimally-processed fruits and vegetables for a modern food industry: A comprehensive critical review from the traditional technologies into the most promising advancements, Critical Reviews in Food Science and Nutrition, 60:6, 940-975, DOI: 10.1080/10408398.2018.1553025

Vachon, C., D'Aprano, G., Lacroix, M. and Letendre, M. (2003), Effect of Edible Coating Process and Irradiation Treatment of Strawberry *fragaria spp.* on Storage-keeping Quality. Journal of Food Science, 68: 608-611. https://doi.org/10.1111/j.1365-2621.2003.tb05718.x

Valdés, A.; Burgos, N.; Jiménez, A.; Garrigós, M.C. Natural Pectin Polysaccharides as Edible Coatings. *Coatings* 2015, *5*, 865-886.

Van Impe, J., Smet, C., Tiwari, B., Greiner, R., Ojha, S., Stulić, V., Vukušić, T. and Režek Jambrak, A. (2018), State of the art of nonthermal and thermal processing for inactivation of micro-organisms. J Appl Microbiol, 125: 16-35. https://doi.org/10.1111/jam.13751.

Vasuja, Shubham & Kumar, Venkat. (2018). Ultra Violet Irradiation and its applications in Food Processing Industries: A Review. International Journal of Trend in Research and Development, Volume 5(1), ISSN 2394-9333

WHO Technical Report Series, No. 659, 1981.

World Health Organization, Geneva (Switzerland) (1988). Food irradiation: A technique for preserving and improving the safety of food. World Health Organization (WHO): WHO.

Zambrano-Zaragoza M., R. González-Reza, N. Mendoza-Muñoz, V. Miranda-Linares, T. Bernal-Couoh, S. Mendoza-Elvira and D. Quintanar-Guerrero, (2018). Nanosystems in Edible Coatings: A Novel Strategy for Food Preservation, Int. J. Mol. Sci. 2018, 19, 705, pp. 2-24; doi:10.3390/ijms19030705.

Zhang, Q.Q., Rui, X., Guo, Y., He, M., Xu, X.L. and Dong, M.S. (2017), Combined Effect of Polyphenol-Chitosan Coating and Irradiation on the Microbial and Sensory Quality of Carp Fillets. Journal of Food Science, 82: 2121-2127. https://doi.org/10.1111/1750-3841.13810

Zhang, Z.-H., Wang, L.-H., Zeng, X.-A., Han, Z. and Brennan, C.S. (2019). Non-thermal technologies and its current and future application in the food industry: a review. Int J Food Sci Technol, 54: 1-13. doi:10.1111/ijfs.13903.

Zhao Yi-Ming, Maria de Alba, Da-Wen Sun & Brijesh Tiwari (2019) Principles and recent applications of novel non-thermal processing technologies for the fish industry—a review, Critical Reviews in Food Science and Nutrition, 59:5, 728-742, DOI: 10.1080/10408398.2018.1495613.

This work was supported/(partially supported) by the Bulgarian Ministry of Education and Science under the National Research Programme "Healthy Foods for a Strong Bio-Economy and Quality of Life" approved by DCM # 577 / 17.08.2018".