Food Chemistry Advances 2 (2023) 100304

Contents lists available at ScienceDirect

Food Chemistry Advances

journal homepage: www.elsevier.com/locate/focha

Recent advances in processing and preservation of minimally processed fruits and vegetables: A review – Part 2: Physical methods and global market outlook

Bianca Almada Ferreira Gomes[a], Ana Cláudia Silveira Alexandre[a], Guilherme Antônio Vieira de Andrade[b], Alice Pereira Zanzini[b], Hanna Elisia Araújo de Barros[a], Lara Maria dos Santos Ferraz e Silva[a], Paula Aparecida Costa[b], Eduardo Valério de Barros Vilas Boas[a,*]

[a] *Food Science Department, Federal University of Lavras, 37200-900, Lavras, MG, Brazil*
[b] *Agriculture Department, Federal University of Lavras, 37200-900, Lavras, MG, Brazil*

ARTICLE INFO

Keywords:
Storage life
Fresh-cut produce
Postharvest
Physical treatment
Packaging
Atmosphere conditions

ABSTRACT

In recent years, minimally processed fruits and vegetables have gained widespread consumer attention due to the need for a convenient yet healthy diet. As several factors can affect the shelf life of minimally processed products, it is essential to use preservation technologies that maintain the freshness of fruits and vegetables ensuring consumer health. In the second part of this review, the main physical preservation methods including heat treatments, refrigeration, irradiation, high pressure, ultraviolet radiation, and electrolyzed water are discussed in terms of their advantages, disadvantages, and applications. Advances in packaging for minimally processed products are also explored, such as active and intelligent packaging, edible films and coatings, and vacuum packaging. Defining the operational parameters related to treatment time and dose/intensity appropriate is one of the greatest difficulties in the application of physical methods. Therefore, these factors must be carefully evaluated, as must the sustainability and economic viability of each method.

1. Introduction

Minimal processing has become one of the fastest-growing segments of the food industry as a result of the emergence of a new consumer profile defined as “rich in cash, poor in time” (Ali, Yeoh, Forney & Siddiqui, 2017; De Corato, 2019). This modern lifestyle has increased the demand for practical, convenient, and healthy products that not only save time and effort but also offer the benefits of fresh produce, boosting the market for minimally processed fruits and vegetables (MPFVs) (Denoya et al., 2017). The main problem is that minimal processing of fruits and vegetables allows increased metabolism, resulting in faster spoilage, biochemical changes, and greater susceptibility to microbial contamination (Bansal, Siddiqui & Rahman, 2015). To this end, MPFVs require refrigerated storage, chemical and/or physical preservation methods, and an efficient packaging system that ensures a longer shelf life and greater consumer safety (De Corato, 2019; Ali, Yeoh, Forney & Siddiqui, 2017).

Physical preservation methods have gained great prominence in recent years since they minimize the impacts on health from the use of chemical methods and are eco-friendly technologies. In general, they can be divided into thermal technologies, such as the use of hot water and hot air, and nonthermal technologies, such as irradiation, high pressure, ultraviolet radiation, and electrolyzed water. Strategies related to the storage of MPFVs have also received considerable attention from researchers, leading to improvements in packaging (edible films and coatings, active and intelligent packaging) and changes in the atmosphere surrounding the products (modified atmosphere, controlled atmosphere, vacuums) (Angiolillo, Conte & Nobile, 2017; Belay, Caleb & Opara, 2019; Hassan, Chatha, Hussain, Zia & Akhtar, 2018).

In the first part of this review, some fundamental information about the implications of processing on MPFVs, the microbiological safety of these products, and the main chemical preservation methods used in the sector were reviewed. As the second part, this article explores the main physical preservation methods and the main packaging systems

---

* Corresponding author at: Department of Food Science, Federal University of Lavras, P.O. Box 3037, Zip code: 37200-900, Lavras, Minas Gerais, Brazil.
E-mail addresses: bianca.gomes3@estudante.ufla.br (B.A.F. Gomes), ana.alexandre@estudante.ufla.br (A.C.S. Alexandre), guilherme.andrade@estudante.ufla.br (G.A.V. de Andrade), lara.silva7@estudante.ufla.br (L.M.d.S. Ferraz e Silva), evbvboas@ufla.br (E.V.d.B.V. Boas).

https://doi.org/10.1016/j.focha.2023.100304
Received 19 December 2022; Received in revised form 12 April 2023; Accepted 6 May 2023

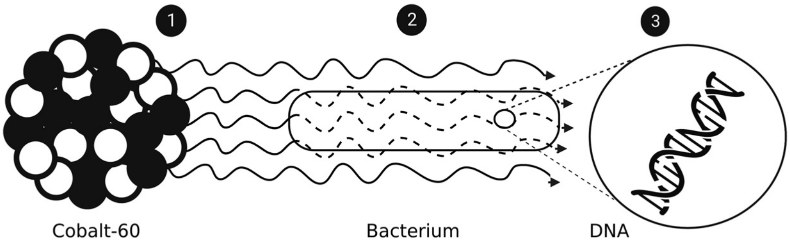

Fig. 1. Microbial inactivation mechanism of gamma irradiation (Rosario, Rodrigues, Bernardes & Conte-Junior, 2021).

suitable for MPFVs. It addresses the advantages, disadvantages, and applications of each technology, and it presents perspectives on the MPFV market.

2. Physical preservation methods

2.1. Irradiation

Electromagnetic waves, especially gamma-rays, are among the most important ionizing radiations arousing interest in food preservation. Gamma-irradiation of food usually involves exposure to gamma-rays, emitted by a cobalt-60 or cesium-137 source, inside shielded and hermetically sealed chambers (Baskaran et al., 2007). The irradiation source emits gamma rays that have capacity to penetrate structures and microorganisms. This process damage the microbial DNA inactivating the cell (Fig. 1). Irradiated foods do not become radioactive and are considered safe (Aleksieva & Yordanov, 2018). Although the highest dose allowed for commercial use is 10 kGy, substantially lower doses are sufficient for pathogen destruction (1–5 kGy) and delayed ripening and senescence of fruits and vegetables (0.2–0.5 kGy) (Loro, Botteon & Spoto, 2018; Frimpong, Kottoh, Ofosu & Larbi, 2015). In fact, dehydrated food products withstand high radiation doses without having compromised quality, while fresh fruits and vegetables usually cannot withstand very high doses (Wang & Meng, 2016). The optimal dose for ripening, senescence inhibition, and pathogen control and the highest dose that fruits can tolerate differ between species, cultivars, and developmental stages and depend on the edaphic and climatic conditions to which the crop has been subjected (Hussain, Omeera, Suradkar & Dar, 2014; Frimpong, Kottoh, Ofosu & Larbi, 2015).

Irradiation is an emerging physical preservation method for the treatment of MPFVs, being efficient at maintaining the quality and increasing the shelf life of produce, and can replace chemical products whose use is restricted (Vivek, Singh & RC, 2019). Despite the high cost of installing the equipment, there has been a significant increase in the commercialization of irradiated products, and the installation of the irradiation structure is regulated by the government and has well-established commercial standards due to the risks involved (Roberts, 2016). Irradiated products must be labeled as such on their packaging. Methods such as electron paramagnetic resonance spectroscopy can identify whether the food received ionizing radiation, providing greater consumer safety and facilitating the control of the technique (Aleksieva & Yordanov, 2018).

Irradiation is typically used after the cutting and packaging of MPFVs (Frimpong, Kottoh, Ofosu & Larbi, 2015). Gamma-irradiation doses lower than 10 kGy are effective, but the dose and the combination of irradiation with other methods depend on the vegetable species and the target pathogens (Arjeh, Barzegar & Sahari, 2015; Hussain, Omeera, Suradkar & Dar, 2014). The use of 2% ascorbic acid (w/v) and 1 kGy of gamma-irradiation in eggplant proved significantly ($p<0.05$) effective in inhibiting the PPO activity, surface browning, and maintaining the creamy white color of the vegetable for up to 6 days of storage (Hussain, Omeera, Suradkar & Dar, 2014). In minimally processed carrots and lettuce, the dose of 2 kGy was the most efficient at maintaining microbiological quality, reducing the counting of pathogenic organisms such as *Bacillus cereus, Cronobacter sakazakii, Staphylococcus aureus*, and *Klebsiella* spp (Frimpong, Kottoh, Ofosu & Larbi, 2015).

The main limitation of this technique is the high cost of implementation and the relationship between the consumer and the product. Frequently, consumers are conservative and reluctant to accept products processed by novel technologies, especially when they don't have enough information about the process. So, the limitation of information leads to a wrong perception of risks, culminating in a rejection of irradiated foods (Galati, Moavero & Crescimanno, 2019.

Although irradiation is safe because it inhibits food-contaminating microbiota, the process can induce reactions that lead to the formation of different compounds, and it is essential to determine the correct dose for each vegetable (Morehouse, Perez & McNeal, 2018). In pasteurized fruit juices, doses of 2 to 4 kGy generated higher-than-normal furan concentrations than were found in fresh unpasteurized juices (Morehouse, Perez & McNeal, 2018). Like furan, which can be carcinogenic if consumed in large quantities, other compounds harmful to health can be formed. It is important to determine the feasibility and safety of using irradiation alone and in combination with other methods (Carthew, DiNovi & Setzer, 2010; Morehouse, Perez & McNeal, 2018).

2.2. Ultraviolet radiation

The use of ultraviolet (UV) radiation in the preservation chain of fruits and vegetables is growing, and its main function is microorganism inactivation to decrease product contamination (Urban, Charles, de Miranda & Aarrouf, 2016). UV radiation is a type of electromagnetic radiation at a wavelength of 100–400 nm, and it can be divided into wavelength categories, such as UV-A (315 to 400 nm), UV-B (280 to 315 nm), and UV-C (100–280 nm) (Prakash, Inthajak, Huibregtse, Caporaso & Foley, 2000). Nonionizing UV-C radiation is the most commonly used for fruit and vegetable decontamination due to its sanitizing potential, and it can be applied to whole and minimally processed products (Tomás-Callejas, Otón, Artés & Artés-Hernández, 2012; Gutiérrez, Char, Escalona, Chaves & Rodríguez, 2015). For minimally processed products, UV-C radiation is used mainly in the sanitization step after cutting and slicing (Balbinot Filho & Borges, 2020; Gutiérrez, Char, Escalona, Chaves & Rodríguez, 2015).

The UV radiation technique is applied to various species of MPFVs, including arugula, lettuce, turnip, radish, apple, and pear (Balbinot Filho & Borges, 2020; Graça, Santo, Quintas & Nunes, 2017; Gutiérrez, Char, Escalona, Chaves & Rodríguez, 2015; Tomás-Callejas, Otón, Artés & Artés-Hernández, 2012). In lettuce leaves that have an irregular surface, UV-C can reduce the growth of pathogens and spoilage microorganisms, increasing preservation and maintaining the sensory quality attributes of the product (Balbinot Filho & Borges, 2020).

UV radiation acts on microorganisms, promoting changes in their membrane structures and nucleic acids, as well as activating vegetable defense pathways (Urban, Charles, de Miranda & Aarrouf, 2016). This method has several advantages over other fruit and vegetable decontamination methods, such as its ease of application and relatively low cost of installation and maintenance. In addition, it has no legal restrictions, is lethal to a wide range of pathogenic and deteriorating microorganisms, does not leave residues in food and causes low losses in sensory quality, with no changes in thermosensitive nutrients (Balbinot Filho & Borges, 2020). Like any technique, UV radiation has limitations be-

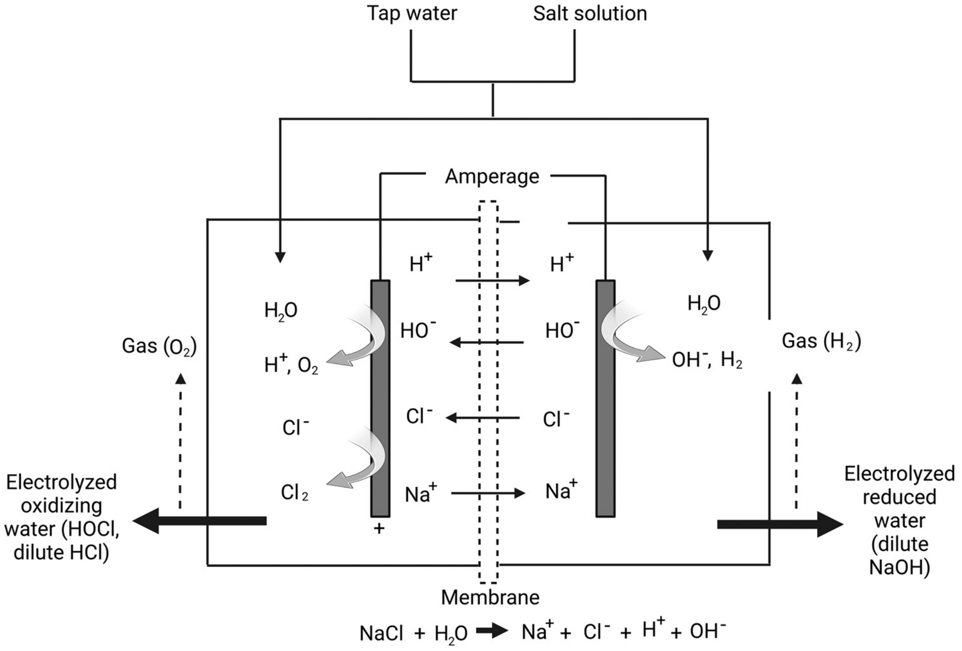

Fig. 2. Schematics of electrolyzed water generator and produced compounds (Huang et al., 2008).

cause it is a low-penetration surface treatment. In addition, irregularities and cracks in produce can protect microorganisms from the action of UV-C radiation, and solid surfaces such as packaging can interfere with produce exposure to the technique (Balbinot Filho & Borges, 2020). The main advantages and disadvantages of this method are presented in Table 1.

The efficiency of UV radiation depends on the dose used, since the use of inadequate dosages can cause negative impacts on the sensory characteristics of the product, requiring careful analysis for each vegetable (Zhang & Jiang, 2019). In MP Lollo Rosso and Red Oak Lea lettuce, doses between 2,37 and 8,14 kJ/m2 of UV radiation lead to a reduction of 1 and 2 logarithmic cycles (log UFC/g) of bacteria, including psychotropic, mesophyllic, Enterobacter, coliforms, and yeast (Allend et al., 2006). Also, there was a significant reduction of 1 to 2 log UFC/g at the counting of Enterobacter, molds, and yeasts in minimally processed apples using doses of 1,2 to 14,1 kJ/m2 and exposure times between 1 and 25 min Gómez et al. (2015). In minimally processed arugula leaves, doses of 10, 20, and 30 kJ m^{-2} reduced the oxygen (O_2) levels, the microbial activity, and the levels of total chlorophyll and carotenoids and increased the carbon dioxide (CO_2) levels inside packages over 8 days of storage in a modified atmosphere (Gutiérrez, Char, Escalona, Chaves & Rodríguez, 2015). In pear, microorganism growth and survival was also reduced by the use of UV-C radiation (Graça, Santo, Quintas & Nunes, 2017). High doses may raise the levels of phenolic compounds due to the stress on vegetable tissues, which may be desirable because it increases beneficial photochemical compounds (Gutiérrez, Char, Escalona, Chaves & Rodríguez, 2015; Zhang & Jiang, 2019).

2.3. Electrolyzed water

The use of electrolyzed water is the main physicochemical technology available for the treatment of minimally processed foods (Abadias, Usall, Oliveira, Alegre & Viñas, 2008; Rahman, Khan & Oh, 2016). This technique can be used to replace chemical treatments in the sanitization stages, uses only sodium chloride (NaCl) in its production, and is widely used for disinfecting vegetables after slicing and before packaging (Abadias, Usall, Oliveira, Alegre & Viñas, 2008; Graça, Abadias, Salazar & Nunes, 2011). The principle of this technology involves the electrolysis of dilute NaCl solutions as shown in Fig. 2, in which the anodes and cathodes can be separated or not by a diaphragm. Variations in the electrolysis process related to the possibility of using different diluted solutions are responsible for the generation of different types of electrolyzed water, such as acidic, basic, and neutral electrolyzed water (Rahman, Khan & Oh, 2016).

Although acid electrolyzed water is very efficient at reducing microbial loads, it has lower stability, and its low pH can cause greater wear of the processing structure (Cui, Shang, Shi, Xin & Cao, 2009). Neutral electrolyzed water is the most effective alternative to decontaminate produce without causing sensory losses due to its greater stability (Cui, Shang, Shi, Xin & Cao, 2009; Deza, Araujo & Garrido, 2003). The antimicrobial efficacy of this method is similar to those of chemical treatments, such as treatment with sodium hypochlorite, and is safer, as it reduces the amount of free chlorine present in minimally processed products after disinfection (Abadias, Usall, Oliveira, Alegre & Viñas, 2008). It does have some drawbacks, such as the reduction of antimicrobial activity over time due to the presence of organic matter that reduces the concentration of active chlorine, requiring the continuous replacement of the NaCl source in the electrolyzed water. In addition, the main limitation of this technique is the relatively high initial cost due to the acquisition cost of the equipment (Rahman, Khan & Oh, 2016). The efficiency of electrolyzed water treatments depends highly on the amount of available chlorine, and it varies according to the fruit or vegetable (Aday, 2016). In addition to active chlorine, other compounds are produced during electrolysis, such as reactive oxygen species that contribute to antimicrobial activity (Jeong, Kim & Yoon, 2009).

In apples inoculated with *Escherichia coli, Listeria innocua*, or *Salmonella choleraesuis*, electrolyzed water was efficient at reducing the microbial load (Graça, Abadias, Salazar & Nunes, 2011). In fresh-cut apples inoculated with yeast, UV-C radiation was more efficient at storage than electrolyzed water (Graça, Santo, Pires-Cabral & Quintas, 2020). In a study of minimally processed mango, electrolyzed water was more efficient at the control of *E. coli*, while UV-C radiation showed better control of *Cronobacter sakazakii* (Santo, Graça, Nunes & Quintas, 2018).

2.4. Cooling

Cooling is the main technique used to store and preserve perishable products because the decreased temperature reduces respiratory activity and ethylene synthesis, in addition to being good at keeping the micro-

Table 1
Advantages and disadvantages of using UV-C radiation as a conservation method.

Advantages	Disadvantages
Non-thermal treatment: thermosensitive nutrients are not altered.	Due to low penetration, treatments are limited to surfaces, films, and clear liquids.
UV-C radiation is non-ionizing: it does not change the chemical nature of food components and does not leave residues.	Irregularities, pores, cracks, and roughness can protect microorganisms from incident light.
UV-C rays are lethal to most spoilage and pathogenic microorganisms.	The presence of materials, such as packaging, between the light and the product interferes with the efficiency of the method.
Relatively low cost of implementation and maintenance.	

Adapted from Sethi et al. (2018).

bial load of the treated products low (Duan et al., 2020). Therefore, it is essential that efficient cooling systems be active during all minimal processing stages (De Corato, 2019).

Colas-Meda, Vinas, Alegre and Abadias (2017) evaluated the impact of the use of abusive temperatures on the growth and survival of *Listeria monocytogenes* and *Salmonella enterica* in minimally processed "Conference" pears during 8 days of storage (Colas-Meda, Vinas, Alegre & Abadias, 2017). The microorganisms were intentionally inoculated, and the product was immersed in antioxidant solution, packaged under a modified atmosphere, and stored under appropriate cooling conditions (4 °C) or an abusive temperatures (three days at 4 °C + five days at 8 °C). At the end of storage, a significant reduction in *S. enterica* populations was observed in both treatments. Regarding the growth of L. *monocytogenes*, in the first treatment there was a population increase of 1.6 logarithmic units, while in the second treatment there was an increase of 2.2 logarithmic units. This showed that L. *monocytogenes* could grow even under low-pH and cooling conditions and a modified atmosphere. In addition, that study reaffirmed the importance of low temperatures in maintaining low microbial loads.

Despite the beneficial effects of cooling, very low temperatures or refrigerated storage for long periods can lead to the development of chilling injury in produce, especially those of tropical and subtropical origin, which is a limitation of the method (Duan et al., 2020). However, chilling injury is not usually observed in MPFVs, since the short storage period (approximately 1–2 weeks) prevents them from reaching the limit or latency period for the manifestation of injury symptoms. In addition, symptoms usually manifest after the removal of the product from the refrigerated condition, which is definitely not recommended for MPFVs (Artes-Hernandez, Rivera-Cabrera & Kader, 2007). As minimal processing causes physical stress to tissues, making them more perishable than intact products, MPFVs should be stored at temperatures lower than those recommended for intact produce (Artes-Hernandez, Rivera-Cabrera & Kader, 2007).

2.5. *Thermal treatments*

Thermal or heat treatments are procedures based on high temperatures and are commonly used as an alternative to chemicals to control pathogens. Because heat is effective against microorganisms that have already penetrated the fruit or vegetable and those that are on the surface, it is a good option for food preservation, including of minimally processed foods (Chiabrando, Peano & Giacolone, 2018; Chiabrando & Giacolone, 2020). However, heat can negatively affect the physical and nutritional quality of fruits and vegetables, causing a decrease in the levels of thermosensitive vitamins and damage to the product, reinforcing the importance of the correct use of the technique (Avila, Medrano, Pardo, Gonzalez & Aguilar, 2018).

Heat treatment consists of exposing the product to temperatures ranging from 40 to 60 °C by immersion in hot water, steam, or hot air for periods that vary mainly according to the volume of the product (Leneveu-Jenvrin et al., 2019). Heat treatments have been widely used in the minimal processing industry, alone or combined with other preservation techniques (Barba et al., 2017). Good results were observed from immersion of kiwi, table grape, and garlic in hot water. The authors reported improved quality and prolonged shelf life of the products, reaffirming that the technique can be used as an emerging and sustainable process in the preservation of MPFVs (Zudaire et al., 2018; Chiabrando, Peano & Giacolone, 2018; Chiabrando & Giacolone, 2020). Hydrothermal treatment at 50 °C for 10 to 30 min can be used to maintain quality and minimize microbial growth in minimally processed 'Kimju' and 'Pan Srithong' guavas (Poubol, Techavuthiporn & Kanlayanarat, 2018). Sliced onions subjected to heat treatment at 55 °C for 60 s showed a significant reduction in mesophilic aerobic bacteria. Heat treatment reduced the loss of fresh mass and helped maintain visual characteristics, indicating that it is a good strategy for obtaining safe

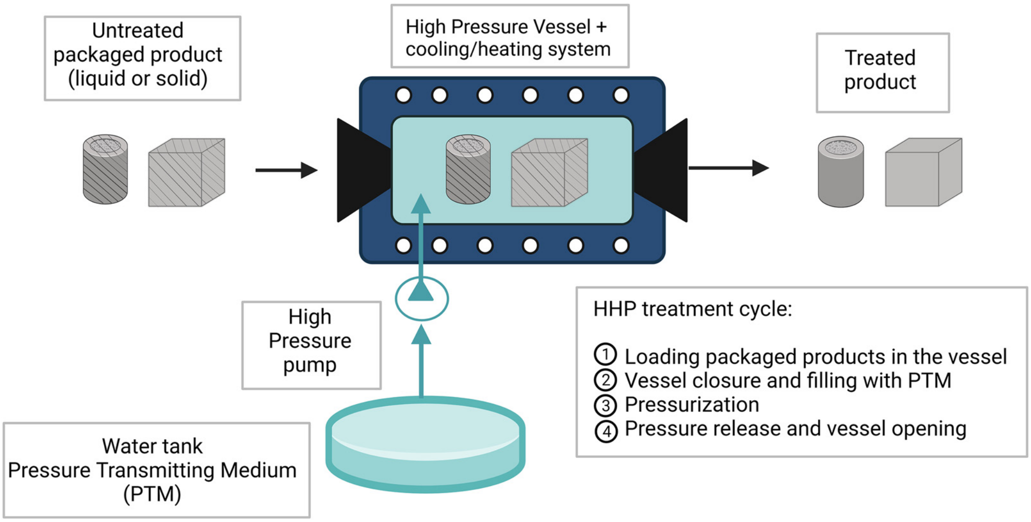

Fig. 3. Schematic layout for a High Hydrostatic Pressure treatment pilot (Picart-Palmade et al., 2019).

and high-quality MPFVs when combined with other sanitization techniques (Zudaire et al., 2018).

2.6. High pressure

High pressure is an emerging nonconventional and nonthermal technology that uses pressures of approximately 1000 to 7000 atm (100 to 700 MPa) to eliminate the microbial load and delay the enzymatic reactions responsible for food spoilage while keeping small molecules intact, such as vitamins and aromatic compounds. High-pressure treatment is conducted in a closed chamber (pressure vessel), in which water acts as a pressure transfer medium (Fig. 3). The hydrostatic method subjects liquid or solid foods (already packaged) to pressures ranging from 400 to 700 MPa, where pressurization is applied equally on all sides (Smelt, 1998).

Yeasts and other fungi are more sensitive to high pressure, being neutralized by pressures of 200 to 300 MPa, while bacteria are inactivated at higher pressures, between 400 and 600 MPa. Conversely, vegetative species, such as spores, can withstand pressures up to 1000 MPa. The factors that influence the use of high-pressure treatment are the required pressure level, the time, the temperature, the target microbiological species, and the shape of the bacterium, which can influence the cell's resistance to the process, bacilli being more sensitive than cocci (Mieszczakowska-Frac, Celejewska & Plocharski, 2021; Huang, Hsu & Wang, 2020)

The efficacy of the process against bacteria is due to the accumulation of damage inside the cells. The crystallization of membrane phospholipids is the main target of high-pressure application because it changes the cell permeability. Consequently, it compromises other cellular functions and attributes, such as by altering the morphology of the cell and its components, hindering DNA replication and ion exchange, changing the fatty acid composition, and causing denaturation of proteins and enzymes important for cellular functions (Vivek, Singh & RC, 2019).

The application of high-pressure technology can inactivate enzymes since it promotes disturbances in the medium and can influence the pH and substrate concentration and increase temperature. These disturbances can compromise the integrity of enzymes or result in changes in their conformational structures. With the application of pressures from 100 to 300 MPa, enzymes can be reactivated after decompression, while pressures above 300 MPa are recommended for total enzymatic inactivation (Vivek, Singh & RC, 2019). Such enzymes as polyphenol oxidases are not completely deactivated by high pressure, requiring the application of combined technologies for better efficiency of the technique. Packaging with low oxygen permeability is a great ally in the preservation of previously pressurized MPFVs; however, the use of vacuum in the product is not recommended due to the possibility of anaerobic respiration (Denoya et al., 2017).

Some technical factors hinder the use of high-pressure technology on a large scale, such as the difficulties defining the pressure intensity, the total treatment time (as well as the pressurization and decompression times), and the temperature distribution in the pressure vessel. In minimally processed peaches, high pressure combined with sanitization, bleaching, and vacuum packaging was efficient and maintained the color parameters of the product (Vivek, Singh & RC, 2019). Tests with pressures of 200 to 600 MPa for 3 min applied to nectarines and star fruit showed pigment stability at high pressure (Denoya et al., 2017).

3. Packaging

Packaging is used to maintain the freshness and quality of food products throughout the entire distribution chain until they are eaten. In addition to providing safety and ensuring the maintenance of the sensory characteristics of food, active compounds and intelligent technologies that can provide information to consumers about food quality and integrity can be added to packaging. New packaging types also offers more efficient oxygen, CO_2, and water vapor barrier properties, increasing the shelf life of the products (Kalpana, Priyadarshini, Leena, Moses & Anandharamakrishnan, 2019; Topuz & Uyar, 2020). Examples of packaging applied to MPFVs include modified atmosphere packaging (MAP), controlled atmosphere storage (CAS), active packaging, vacuum packaging, smart packaging, and edible films (EFs) and coatings (ECs).

3.1. Modified atmosphere packaging

MAP is a technology that has been widely applied postharvest for more than 90 years to preserve the quality of fresh and minimally processed products and prolong their shelf life under ideal processing and storage conditions (Belay, Caleb & Opara, 2016; Opara, Caleb & Belay, 2019). One of the main objectives of modifying the atmosphere is to promote an environment with low O_2 and high CO_2 levels to lower metabolism, respiration, oxidative stress, tissue senescence, and ethylene synthesis. A modified atmosphere can be achieved by passive or active techniques, passive MAP being more economical than active MAP (Belay, Caleb & Opara, 2017).

The gaseous equilibrium inside packaging with a passive modified atmosphere consists of a dynamic process determined by the permeability of the polymer film used, the metabolism of the packaged product, and the storage conditions (temperature and relative humidity). Packaging with an active modified atmosphere is based on the displacement or replacement of gasses inside the package or on the use of gas scavengers or absorbers to establish a desired initial mixture of O_2, CO_2, and nitrogen (N_2). The efficiency of this method can be influenced by the metabolism of the product, the initial composition of the gasses, and the permeability of the applied polymer film (Belay, Caleb & Opara, 2019; Hussein et al., 2015; Oliveira et al., 2015).

According to Oliveira et al. (2015), if the permeability of a film to O_2 and CO_2 is adapted to the product's respiration, an equilibrium-modified atmosphere is established inside the package, and the shelf life of the product increases. If ideal conditions are not applied, the opposite effect arises because inadequate gas concentrations can cause irreversible damage to the tissues of fruits and vegetables. O_2 concentrations below the critical limit (usually 1%) can induce anaerobic respiration and fermentation, resulting in the development of undesirable flavors and odors. Conversely, the presence or accumulation of CO_2 at high concentrations (usually above 15%) can have a negative effect on the quality of the processed products, causing the onset of physiological injury, accelerating changes in color and firmness, and increasing compound solubilization (Oliveira et al., 2015; Belay, Caleb & Opara, 2019; Teixeira, Cunha Júnior, Ferraudo & Durigan, 2016).

To reduce the risk of anaerobiosis during the storage of MPFVs, perforation-mediated MAP (PM-MAP) can be applied, further increasing the shelf life and maintaining the quality of the products. The sensory characteristics of minimally processed strawberry, mango, corn, melon, and banana were kept unchanged during storage with the application of PM-MAP (Hussein et al., 2015).

The use of passive MAP with organic acids may elicit a synergistic effect. In green pepper, the use of gibberellic acid (GA_3) combined with this technique improved the quality attributes and increased the shelf life of the product (Maurya, Ranjan, Gothandam & Pareek, 2020). In sweet persimmon, the combination of treatment with 1-methylcyclopropene (1-MCP) at 1.0 μL L^{-1} and active MAP with an O_2 transmission rate of 6000 ± 400 $cm^3\ m^{-2}\ day^{-1}$ and a CO_2 transmission rate of 30,000 ± 800 $cm^3\ m^{-2}\ day^{-1}$ delayed the advancement of ripening and inhibited the development of lesions during storage at 1 °C (Zhao et al., 2020). The application of passive MAP to ready-to-eat cherry tomato served to maintain the firmness and color of the product and reduced the respiratory rate during storage at 7 °C (Paulsen, Barrios & Lema, 2019). Passive MAP minimized the effects of temperature on the physicochemical and sensory quality of minimally processed broccoli stored at 8 °C (Paulsen et al., 2018), extending the shelf life of minimally processed d'Anjou pears by 21 days, in addition to reducing bacterial, yeast, and filamentous fungal populations (Siddiq et al., 2020). Despite the advantages of using MAP, physiological disturbances were observed in minimally processed romaine lettuce in active MAP (80% N_2 + 20% CO_2). The disorders may be a consequence of the increased ethylene production (almost 9-fold) during the first 4 days of storage (Koukounaras, Siomos, Gerasopoulos & Papachristodoulou, 2019).

Therefore, the application of passive or active MAP efficiently preserves fruits and vegetables. The initial gas concentrations, the type of film used, the storage temperature, and, especially, the metabolism of the product to be packaged should be analyzed to ensure the nutritional and sensory quality and the safety of the foods offered to consumers.

3.2. Controlled atmosphere storage

CAS is a process in which the concentrations of ambient gasses is rigorously controlled by correcting the gas levels when necessary. Thus, the controlled atmosphere requires a hermetically sealed storage environment with the presence of O_2 and CO_2 analyzers and gas removal and injection mechanisms. In this technique, the O_2 pressure is reduced by injecting N_2, while the CO_2 pressure is increased by injecting this gas using an adsorption by pressure oscillation gas separation system that absorbs O_2 through a membrane with a filtration system. In this case, the N_2-rich gas is exported, and the bound O_2 is released by depressurization of the packaging or the storage chamber. That is, the hollow fiber membrane system operates by heating the compressed air, which is forced through hollow fibers made of semipermeable membranes, promoting the continuously selective removal of CO_2, O_2, and N_2 in the storage space (Angiolillo, Conte & Nobile, 2017; Siqueira, Eça, de Aquino & da Silva, 2020).

Although CAS has been used for more than 200 years, it was only in the first half of the twentieth century that the technique was refined and applied commercially for the first time (Thompson, Prange, Bancroft & Puttongsiri, 2018). Generally, CAS costs more than MAP due to the need for constant maintenance of gas levels in chambers with large amounts of product and is therefore applied less often. However, when combined with strict temperature control and adequate postharvest handling procedures, CAS can effectively extend the shelf life of perishable foods, and it has been applied mainly to products with higher commercial value, such as apples and pears (Siqueira, Eça, de Aquino & da Silva, 2020). The main commercial systems used in CAS application are external gas generators, pulverized liquid nitrogen systems, and hyperbaric systems. In addition, CO_2 and ethylene control systems can be used for CAS application (Angiolillo, Conte & Nobile, 2017).

Mditshwa, Fawole and Opara (2018) found that CAS maintained the postharvest quality of apple, reducing the respiratory rate and ethylene production, as well as the onset of physiological disorders such as superficial scald. In immature flower stems of minimally processed onion shoots under CAS (1.0 kPa O_2 + 2.0 kPa CO_2) refrigerated at 1 °C, the physicochemical quality was preserved over 30 days of storage (Zudaire et al., 2020). The firmness values of minimally processed blueberries under CAS (5% O_2 + 15% CO_2 + 80% N_2) combined with cooling were maintained during storage (Concha-Meyer et al., 2015). CAS (1% O_2 + 5% CO_2) reduced the activity of peroxidase and polyphenol oxidases in lychee, reducing browning and red color loss in the pericarp and maintaining the levels of enzymatic and nonenzymatic antioxidants during storage (Ali, Khan, Malik & Shahid, 2016). In the case of minimally processed burdock, CAS composed only of CO_2 with a purity above 99.9% prolonged the shelf life of this unconventional vegetable in the short term, inhibiting its browning and improving its quality. Fresh-cut burdock treated with CO_2 for 4, 6, or 8 h showed better visual quality during 8 days of storage than that treated with air (Dong et al., 2015).

As with MAP, inadequate gas control can lead to physiological disorders in fresh MPFVs under CAS. Some examples are the irregular ripening of fruits, such as banana, mango, pear, and tomato, exposed to O_2 levels less than 2% and/or CO_2 levels greater than 5% for more than 1 month, and the development of unpleasant flavors and odors due to anaerobiosis and fermentative metabolism (Angiolillo, Conte & Nobile, 2017; Thompson, Prange, Bancroft & Puttongsiri, 2018).

3.3. Vacuum packaging

Vacuum packaging of MPFVs is a type of MAP. Vacuum packaging has advantages over common packaging, such as a gas barrier, microbial growth and oxidation–reduction, and prevention of product discoloration (Mantilla, Mano, Carvalho Vital & Franco, 2010).

The physicochemical characteristics of minimally processed vacuum-packed potato subjected to different doses of gamma-radiation were maintained after the application of the techniques (Pires et al., 2017). Rinaldi, Vieira and Fialho (2019) observed that the application of vacuum in the storage of minimally processed cassava conferred greater stability to the physicochemical components of the product and greater microbiological safety.

Despite the advantages of vacuum packaging, the results observed during the storage of MPFVs could be enhanced if this technique were combined with other technologies, such as active and intelligent packaging.

3.4. Edible films and coatings

EFs and ECs are two packaging strategies used to extend the shelf life of fresh MPFVs. Although EFs and ECs are usually considered synonymous, they are different concepts, mainly coming down to the way they are produced. ECs are applied in liquid form to food by immersing or spraying the products in the substance, generating a solution formed by the structural matrix (edible polymers). In turn, EFs are first molded as a solid sheet and then applied as packaging to food products (Guimarães, Abrunhosa, Pastrana & Cerqueira, 2018; Maringgal, Hashim, Mohamed Amin Tawakkal & Muda Mohamed, 2020).

Interest in EFs and ECs has increased in recent years due to their benefits over synthetic films, such as their biocompatibility, biodegradability, and compliance with chemical and biochemical changes (Hassan, Chatha, Hussain, Zia & Akhtar, 2018). Edible polymers are polymeric materials that can be consumed by humans, animals, or microorganisms without harmful effects on their health. They can be produced from polysaccharides, proteins, and lipids or their combination. Hydrocolloids, formed by the combination of polysaccharides and proteins, have good film formation capacity and good oxygen and aroma barrier characteristics. However, they are not indicated for storage in environments with high relative humidity due to their hydrophilic nature. Lipid-based coatings provide a better barrier to water vapor than those made with polysaccharides and proteins due to their hydrophobic nature. They have the disadvantage of not forming flexible films (Kouhi, Prabhakaran & Ramakrishna, 2020).

In the production of EFs or ECs, only water, ethanol, or a combination of them are used in order to maintain the edibility of the mixture. Other components can be added to the matrix of these materials to improve their functional properties, such as plasticizers (especially polyols such as glycerol, sorbitol, propylene glycol, sucrose, fatty acids, polyethylene glycol, and monoglycerides). These compounds increase the extensibility, dispensability, and flexibility of the developed film and decrease the cohesion and stiffness of the film. In addition, we can use crosslinking agents such as transglutaminase and genipin for proteins and citric or tannic acid for polysaccharides, reinforcements such as fibers and nanoreinforcements derived from polysaccharides such as cellulose nanofibers, starch nanocrystals to improve the mechanical properties, and emulsifiers to stabilize composite coatings and improve their adhesion (such as tweens, spans, fatty acid salts, and lecithins). Additives can also be added to improve the quality, stability, and safety of packaged foods, such as antioxidants, antimicrobial compounds, aromas, and pigments (Ballesteros-Mártinez, Pérez-Cerver & Andrade-Pizarro, 2020; Hassan, Chatha, Hussain, Zia & Akhtar, 2018; Kerch, 2015; Prakash, Baskaran, Paramasivam & Vadivel, 2018; Putnik et al., 2017, do Lago et al., 2020). The addition of oat straw cellulose nanofibers promoted improvements in the mechanical and barrier properties of cassava starch-based bionanocomposites by increasing stiffness and reducing water vapor permeability and water solubility. In addition, morphological analysis indicated a good interaction between the constituents of the bionanocomposites, indicating that this type of material has the potential to be applied as an EC of MPFVs as a sustainable alternative to traditional polymers (do Lago et al., 2020).

EFs and ECs are MAP methods that show promising results for the preservation of fruit and vegetable quality because they can act as a partial barrier to water vapor, leading to less surface moisture loss and modification of the atmosphere around the product, resulting in a barrier to gas exchange. In addition, they can reduce respiratory rates and senescence (without causing anaerobiosis), slow microbial growth, improve the exterior and nutritional value of fresh MPFVs, and maintain their firmness, color, vitamins, and bioactive compounds (Guimarães, Abrunhosa, Pastrana & Cerqueira, 2018; Jongsri, Wangsomboondee, Rojsitthisak & Seraypheap, 2016; Mostafidi, Sanjabi, Shirkhan & Zahedi, 2020; Prakash, Baskaran, Paramasivam & Vadivel, 2018). To be considered ideal, edible packaging (EF or EC) must meet some technological prerequisites, such as mechanical durability, permeability to water vapor and gasses (depending on the product to be packaged), good optical properties, and low susceptibility to chemical or microbiological changes, and neutral sensory profile (Hellebois, Tsevdou & Soukoulis, 2020).

Chitosan stands out among the polymers that can form the basis of EFs and ECs due to its biological and antimicrobial activity. Alginate is also widely used to maintain the quality and increase the shelf life of foods, promote the formation of a water barrier, and prevent microbial contamination. Waxes and other coatings act by delaying the ripening and aging of fresh products and may increase microbial stability and sustainability (Mostafidi, Sanjabi, Shirkhan & Zahedi, 2020). Gums have been used as excellent vehicles for active substances, controlling their speed of diffusion and improving the ripeness control of fresh MPFVs (Tahir et al., 2019).

Rodríguez, Sibaja, Espitia and Otoni (2020) observed that EFs developed using papaya puree and high-methoxyl pectin as binding agents, ascorbic and citric acids as browning inhibitors (antioxidants), and glycerol as a plasticizer prolonged the shelf life of foods susceptible to oxidation, such as minimally processed pears. An EC consisting of whey protein, pectin, transglutaminase, sorbitol, and water effectively reduced mass loss, prevented microbial growth, and preserved the antioxidant activity of minimally processed apple, potato, and carrot over 10 days of storage. They did not change the hardness or chewability of the products (Marquez et al., 2017).

Chitosan-based ECs containing nanoparticles decreased water vapor permeability during storage of fresh MPFVs. In addition, vitamin C and polyphenol losses were reduced during storage, indicating viability of the use of this packaging as long as the safety of the nanoparticles is confirmed (Kerch, 2015). Chitosan-based EFs containing glycerol showed excellent bactericidal and fungicidal activity in strawberry over 1 week, indicating an effect of chitosan against gram-positive and gram-negative bacteria, even after plasticization, in addition to protection of strawberry against fungal attack. Therefore, there is enormous potential in the development of ECs for fresh MPFVs (Pavinatto et al., 2020).

According to Hassan, Chatha, Hussain, Zia & Akhtar, 2018, nanoemulsions and nanoparticles may contribute to improving the barrier properties and functionality of coatings for application in minimally processed fresh fruits due to the greater distribution and homogeneity of the pores and skin of these products. Prakash, Baskaran, Paramasivam and Vadivel (2018) showed that the application of essential oil–based nanoemulsions as disinfectant washes or incorporated into ECs considerably improved the quality and microbial safety of MPFVs.

Therefore, EFs and ECs are extremely attractive for their efficiency in providing protection and stability to MPFVs. It is important to note that edible packaging does not completely replace conventional packaging materials, although their properties help improve the efficiency of food packaging and can help reduce the use of petroleum-derived polymers. Furthermore, the consumer's acceptance of EFs and ECs will depend on how well the packaging material is integrated with the food product (Aldred &Wansink. 2016).

3.5. Active packaging

In addition to protecting foods against the external environment, active packaging has the main purpose of increasing their shelf life, safety, and quality and/or improving their sensory characteristics (Ahmed et al., 2017). The most common types of active packaging are antimicrobial films, packaging with oxygen or ethylene absorbers, moisture regulators, and flavor and odor releasers and/or absorbers (Ramos, Jimenez, Peltzer & Garrigos, 2012; Ahmed et al., 2017).

Active packaging containing cysteine and sulfite was effective at inhibiting the enzymatic browning of sliced apples (Oliveira, Soares, de Paula & Viana, 2008). For this type of packaging system to be brought to market, studies are needed to ensure its functionality and the quality of the packaged product. The packaging system formed by polypropylene trays, biodegradable sachets containing 1-MCP, and biodegradable starch films applied to minimally processed lettuce did not increase the shelf life of the product, possibly due to the low 1-MCP concentration and the high permeability of the biodegradable film to this compound, preventing the maintenance of an adequate gas concentration inside the package (Marin, Montanucci, Benassi & Yamashita, 2010).

3.6. Smart packaging

Smart packaging is considered a modern packaging system capable of monitoring food and/or environmental conditions and transmitting the information to the consumer (Onwude et al., 2020). These packaging systems are composed of sensors and indicators based on chemical, enzymatic, immunochemical, or mechanical reactions (Wilson, 2007). In general, they can be categorized into two types, data carrier packages and indicator packages, both of which provide information about products to consumers (Spagnol, Silveira Junior, Pereira & Guimarães Filho, 2018). Data carrier packages are those with a bar code or radio frequency identification (RFID) tag. Mainetti et al. (2013) used RFID and near field communication technology in the traceability and monitoring of the supply chain of minimally processed vegetables, evaluating the product from production to supermarket shelf. In the future, RFID tags may be applied to the safe storage of minimally processed baby-leaf vegetables combined with other technologies that help maintain product quality (Saini, Ko & Keum, 2017).

Indicator packages provide data on time, temperature, the presence of gasses such as ethylene and oxygen, and the growth of pathogenic microorganisms and toxins, in addition to helping traders maintain favorable commercial conditions (Onwude et al., 2020; Pires et al., 2010; Sani et al., 2021). Temperature sensors were applied to minimally processed lettuce during storage, which indicating undesirable variations and conditions that were far from ideal, to ensure product safety (Saini, Ko & Keum, 2017). Most studies with smart packaging are performed on intact fruits and vegetables, although there is potential for their application in minimally processed fruits, as with the use of fruit ripeness sensors such as RipeSense^{TM} (Raynes, Carver, Gras & Gerrard, 2014), fluorescent dyes as sensors that signal increased O_2 inside the package (Hempel, Gillanders, Papkovsky & Kerry, 2012), molybdenum ions that change color in the presence of ethylene (Lang & Hübert, 2012), and bromophenol blue dye that changes color with the excess production of organic acid, indicating excess ripeness (Kuswandi et al., 2013).

4. Global market and prospects

There are reports that minimally processed foods have been available since the 1930s. However, the rise of this market began in the 1950s, in the United States, as a result of new eating habits, such as the emergence of fast food, which demanded agility in food preparation (Souza, de Almeida, Marques & Souza, 2020). In recent times, the minimally processed foods segment has grown due to changes in eating habits around the world. According to the new research report by Global Market Insights, the market for processed fruits and vegetables, including ready-to-eat salads, will exceed US $392 billion by 2025. This advance is attributed to several factors, such as the expansion of the middle class, supporting the expansion of the industry, and technological innovations in production that have enabled the development of products with greater nutritional value and longer shelf lives (Global Market Insights Inc., 2019).

Consumers today opt for high-quality, natural, nutritious, safe, convenient products. Globalization and modern lifestyles are factors directly related to the demand for MPFVs. In addition, the greater participation of women in the labor market, the fewer people per household, and the increased number of individuals living alone, among other factors, drive consumers to seek out these products and further reinforce the promising prospects of this sector. Therefore, the production and consumption of MPFVs has the potential to meet the needs of the population, and its rise shows an increasingly significant trend (Ngadi, Bajwa & Alakali, 2012; Bansal, Siddiqui & Rahman, 2015; Lavilla & Gayan, 2018).

The emerging technologies applied to MPFVs are an alternative to consumers demands for convenience, freshness, safety, and more natural products with fewer additives and preservatives that maintain the quality attributes of the food product. To meet this criterion, the alternative processes and preservation technologies should also be environmentally friendly and low in cost. Despite their importance, these factors alone don’t guarantee its success in the global market, because the success of a new technology for MPFVs depends on consumer acceptance. For example, irradiation and genetically modified organisms, despite their efficiency in quality preservation, resulted in the greatest negative effect on likely use, while nonthermal technologies produced the most positive effect (Galati, Moavero & Crescimanno, 2019). So, the biggest challenge for food engineers and scientists around the world is to develop the emerging technologies that guarantee the safety and quality of products while considering the consumer’s opinion and acceptance (Sillani & Nassivera, 2015; Lavilla & Gayan, 2018).

So, the application of physical preservation methods has a great prospective for maintaining the food quality and bioactive compounds unaltered. The major challenge for this technology is its introduction in the industry because it is difficult to achieve full control over the variables associated with process operation. Furthermore, new studies are required to assess how emerging technologies will affect the structural and functional characteristics of food components across a variety of food groups. Finally, to guarantee success in the market, it is fundamental to create a relationship of trust with the consumer. The market acceptability of a new food technology depends on effective communication between industry and consumers during the development and implementation of the technology (Lavilla & Gayan, 2018).

5. Conclusions

The expansion of the market for minimally processed foods has guided the development and improvement of physical preservation methods that are efficient at maintaining the sensory, nutritional, and microbiological quality of MPFVs and could be used with low temperatures throughout processing, transportation, and shelving. The main physical preservation methods that can be used in the food industry are thermal treatments, irradiation, high pressure, UV radiation, and electrolyzed water. In addition to the physical methods cited, technological advances in the development of packaging that interacts with consumers and products, promoting desirable changes, are a new frontier in the MPFV sector. The choice of the most appropriate method must be made judiciously for each raw material that will be subjected to minimal processing and must take into account factors related to sustainability, the economic viability of each technology, and consumer acceptance. So, the main advantages, disadvantages, and applications of each physical preservation method were summarized in this review, helping food engineers and researchers to choose the best method for their market or study applications.

Declaration of Competing Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be constructed as a potential conflict of interest.

Data availability

Data will be made available on request.

Acknowledgments

The authors are grateful for the financial support of Brazilian sponsors Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, Bolsas de Produtividade em Pesquisa 302259/2018-0, 302699/2019-8), Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG, PPM-00458-15), and Higher Education Personnel Improvement Coordination (CAPES: 88881.068456/2014-01), as well as to the Federal University of Lavras (UFLA, Lavras, Minas Gerais, Brazil).

References

Abadias, M., Usall, J., Oliveira, M., Alegre, I., & Viñas, I. (2008). Efficacy of neutral electrolyzed water (NEW) for reducing microbial contamination on minimally-processed vegetables. *International Journal of Food Microbiology, 123*(1–2), 151–158. 10.1016/j.ijfoodmicro.2007.12.008.

Aday, M. S. (2016). Application of electrolyzed water for improving postharvest quality of mushroom. *LWT-Food Science and Technology, 68*, 44–51. 10.1016/j.lwt.2015.12.014.

Ahmed, I., Lin, H., Zou, L., Brody, A. L., Li, Z. X., Qazi, I. M., et al., (2017). A comprehensive review on the application of active packaging technologies to muscle foods. *Food Control, 82*, 163–178. 10.1016/j.foodcont.2017.06.009.

Aleksieva, K. I., & Yordanov, N. D. (2018). Various approaches in EPR identification of gamma-irradiated plant foodstuffs: A review. *Food Research International, 105*, 1019–1028. 10.1016/j.foodres.2017.11.072.

Ali, S., Khan, A. S., Malik, A. U., & Shahid, M. (2016). Effect of controlled atmosphere storage on pericarp browning, bioactive compounds and antioxidant enzymes of litchi fruits. *Food Chemistry, 206*, 18–29. 10.1016/j.foodchem.2016.03.021.

Ali, A., Yeoh, W. K., Forney, C., & Siddiqui, M. W. (2017). Advances in postharvest technologies to extend the storage life of minimally processed fruits and vegetables. *Critical Reviews in Food Science and Nutrition, 58*, 2632–2649. 10.1080/10408398.2017.1339180.

Angiolillo, L., Conte, A., & Del Nobile, M. A. (2017). Biotechnologicak approach to preserve fresh pasta quality. *Journal of Food Protection, 12*(80), 2006–2013. 10.4315/0362-028X.JFP-16-382.

Arjeh, E., Barzegar, M., & Sahari, M. A. (2015). Effects of gamma irradiation on physicochemical properties, antioxidant and microbial activities of sour cherry juice. *Radiation Physics and Chemistry, 114*, 18–24. 10.1016/j.radphyschem.2015.05.017.

Artes-Hernandez, F., Rivera-Cabrera, F., & Kader, A. A. (2007). Quality retention and potential shelf-life of fresh-cut lemons as affected by cut type and temperature. *Postharvest Biology and Technology, 43*(2), 245–254. 10.1016/j.postharvbio.2006.09.009.

Avila, J. A. D., Medrano, A. W., Pardo, C. A. R., Gonzalez, E. M., & Aguilar, G. A. G. (2018). Use of nonthermal technologies in the production of functional beverages from vegetable ingredients to preserve heat-labile phytochemicals. *Journal of Food Processing and Preservation, 42*(2), 1–12. 10.1111/jfpp.13506.

Balbinot Filho, C. A., & Borges, C. D. (2020). Effects of UV-C radiation on minimally processed lettuce and apple: A review. *Brazilian Journal of Food Technology, 23*, 1–13. 10.1590/1981-6723.32118.

Bansal, V., Siddiqui, M.W., & Rahman, M.S. (2015). Minimally processed foods: Overview. Minimally processed foods: Technologies for safety, quality, and convenience, 1-15. 10.1007/978-3-319-10677-9_1

Barba, F. J., Mariutti, L. R., Bragagnolo, N., Mercadante, A. Z., Barbosa-Canovas, G. V., & Orlien, V. (2017). Bioaccessibility of bioactive compounds from fruits and vegetables after thermal and nonthermal processing. *Trends in Food Science & Technology, 67*, 195–206. 10.1016/j.tifs.2017.07.006.

Ballesteros-Mártinez, L., Pérez-Cervera, C., & Andrade-Pizarro, R. (2020). Effect of glycerol and sorbitol concentrations on mechanical, optical, and barrier properties of sweet potato starch film. *NFS Journal, 20*, 1–9. 10.1016/j.nfs.2020.06.002.

Baskaran, R., Devi, A. U., Nayak, C. A., Kudachikar, V., Prakash, M. K., Prakash, M., et al., (2007). Effect of low-dose γ-irradiation on the shelf life and quality characteristics of minimally processed potato cubes under modified atmosphere packaging. *Radiation Physics and Chemistry, 76*(6), 1042–1049. 10.1016/j.radphyschem.2006.10.004.

Belay, Z. A., Caleb, O. J., & Opara, U. L. (2016). Modelling approaches for designing and evaluating the performance of modified atmosphere packaging (MAP) systems for fresh produce: A review. *Food Packaging and Shelf Life, 10*, 1–15. 10.1016/j.fpsl.2016.08.001.

Belay, Z. A., Caleb, O. J., & Opara, U. L. (2017). Impacts of low and super-atmospheric oxygen concentrations on quality attributes, phytonutrient content and volatile compounds of minimally processed pomegranate arils (cv. Wonderful). *Postharvest Biology and Technology, 124*, 119–127. 10.1016/j.postharvbio.2016.10.007.

Belay, Z. A., Caleb, O. J., & Opara, U. L. (2019). Influence of initial gas modification on physicochemical quality attributes and molecular changes in fresh and fresh-cut fruit during modified atmosphere packaging. *Food Packaging and Shelf Life, 21*, 1–11. 10.1016/j.fpsl.2019.100359.

Carthew, P., DiNovi, M., & Setzer, R. W. (2010). Application of the margin of exposure (MoE) approach to substances in food that are genotoxic and carcinogenic: Example: Furan (CAS No. 110-00-9. *Food and Chemical Toxicology, 48*, 69–74. 10.1016/j.fct.2009.10.017.

Chiabrando, V., & Giacalone, G. (2020). Efficacy of hot water treatment as sanitizer for minimally processed table grape. *Journal of Cleaner Production, 257*, 1–2. 10.1016/j.jclepro.2020.120364.

Chiabrando, V., Peano, C., & Giacalone, G. (2018). Influence of hot water treatments on postharvest physicochemical characteristics of Hayward and Jintao kiwifruit slices. *Journal of Food Processing and Preservation, 42*(3), 1–9. 10.1111/jfpp.13563.

Colas-Meda, P., Vinas, I., Alegre, I., & Abadias, M. (2017). The impact of a cold chain break on the survival of Salmonella enterica and Listeria monocytogenes on minimally processed "Conference" pears during their shelf life. *Journal of the Science of Food and Agriculture, 97*(9), 3077–3080. 10.1002/jsfa.8127.

Concha-Meyer, A., Eifert, J. D., Williams, R. C., Marcy, J. E., & Welbaum, G. E. (2015). Shelf life determination of fresh blueberries (Vaccinium corymbosum) stored under controlled atmosphere and ozone. *International Journal of Food Science, 2015*, 1–9. 10.1155/2015/164143.

Cui, X., Shang, Y., Shi, Z., Xin, H., & Cao, W. (2009). Physicochemical properties and bactericidal efficiency of neutral and acidic electrolyzed water under different storage conditions. *Journal of Food Engineering, 91*(4), 582–586. 10.1016/j.jfoodeng.2008.10.006.

De Corato, U. (2019). 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. 10.1080/10408398.2018.1553025.

Denoya, G. I., Vaudagna, S. R., Chamorro, V. C., Godoy, M. F., Budde, C. O., & Polenta, G. A. (2017). Suitability of different varieties of peaches for producing minimally processed peaches preserved by high hydrostatic pressure and selection of process parameters. *Lwt-Food Science and Technology, 78*, 367–372. 10.1016/j.lwt.2017.01.006.

Deza, M., Araujo, M., & Garrido, M. (2003). Inactivation of Escherichia coli O157: H7, Salmonella enteritidis and Listeria monocytogenes on the surface of tomatoes by neutral electrolyzed water. *Letters in Applied Microbiology, 37*(6), 482–487. 10.1046/j.1472-765X.2003.01433.x.

do Lago, R. C., de Oliveira, A. L. M., Cordasso Dias, M., de Carvalho, E. E. N., Denzin Tonoli, G. H., & de Barros Vilas Boas, E. V (2020). Obtaining cellulosic nanofibrils from oat straw for biocomposite reinforcement: Mechanical and barrier properties. *Industrial Crops and Products, 148*, Article 112264. 10.1016/j.indcrop.2020.112264.

Dong, T., Shi, J., Jiang, C.-Z., Feng, Y., Cao, Y., & Wang, Q. (2015). A short-term carbon dioxide treatment inhibits the browning of fresh-cut burdock. *Postharvest Biology and Technology, 110*, 96–102. 10.1016/j.postharvbio.2015.07.014.

Duan, Y., Wang, G. B., Fawole, O. A., Verboven, P., Zhang, X. R., Wu, D., et al., (2020). Postharvest precooling of fruit and vegetables: A review. *Trends in Food Science & Technology, 100*, 278–291. 10.1016/j.tifs.2020.04.027.

Frimpong, G., Kottoh, I., Ofosu, D., & Larbi, D. (2015). Effect of gamma irradiation on microbial quality of minimally processed carrot and lettuce: A case study in Greater Accra region of Ghana. *Radiation Physics and Chemistry, 110*, 12–16. 10.1016/j.radphyschem.2015.01.011.

Galati, A., Moavero, P., & Crescimanno, M. (2019). Consumer awareness and acceptance of irradiated foods: The case of Italian consumers. *British Food Journal*. 10.1108/bfj-05-2018-0336.

Global Market Insights. (2019). Processed Fruits and Vegetables Market to hit $392 billion by 2025: Global Market Insights, Inc. Selbyville, Delaware, April 15, 2019 (GLOBE NEWSWIRE). Retrieved July 12, 2021, from https://www.globenewswire.com/news-release/2019/04/15/1803744/0/en/Processed-Fruits-and-Vegetables-Market-to-hit-392-billion-by-2025-Global-Market-Insights-Inc.html

Gómez, P. L., Schenk, M. L., Salvatori, D. M., & Alzamora, S. M. (2015). Potential of UV-C light for preservation of cut apples fortified with calcium: Assessment of optical and rheological properties and native flora dynamics. *Food and Bioprocess Technology, 8*(9), 1890–1903. http://doi.org/10.1007/s11947-015-1545-5.

Graça, A., Abadias, M., Salazar, M., & Nunes, C. (2011). The use of electrolyzed water as a disinfectant for minimally processed apples. *Postharvest Biology and Technology, 61*(2–3), 172–177. 10.1016/j.postharvbio.2011.04.001.

Graça, A., Santo, D., Pires-Cabral, P., & Quintas, C. (2020). The effect of UV-C and electrolyzed water on yeasts on fresh-cut apple at 4 °C. *Journal of Food Engineering, 282*. 10.1016/j.jfoodeng.2020.110034.

Graça, A., Santo, D., Quintas, C., & Nunes, C. (2017). Growth of Escherichia coli, Salmonella enterica and Listeria spp., and their inactivation using ultraviolet energy and electrolyzed water, on 'Rocha'fresh-cut pears. *Food Control, 77*, 41–49. 10.1016/j.foodcont.2017.01.017.

Guimarães, A., Abrunhosa, L., Pastrana, L. M., & Cerqueira, M. A. (2018). Edible Films and Coatings as Carriers of Living Microorganisms: A New Strategy Towards Biopreservation and Healthier Foods. *Comprehensive Reviews in Food Science and Food Safety, 17*(3), 594–614. 10.1111/1541-4337.12345.

Gutiérrez, D. R., Char, C., Escalona, V. H., Chaves, A. R., & Rodríguez, S. d. C. (2015). Application of UV-C radiation in the conservation of minimally processed rocket (Eruca sativa Mill.). *Journal of Food Processing and Preservation, 39*(6), 3117–3127. 10.1111/jfpp.12577.

Hassan, B., Chatha, S. A. S., Hussain, A. I., Zia, K. M., & Akhtar, N. (2018). Recent advances on polysaccharides, lipids and protein based edible films and coatings: A review. *International Journal of Biological Macromolecules, 109*, 1095–1107. 10.1016/j.ijbiomac.2017.11.097.

Hellebois, T., Tsevdou, M., & Soukoulis, C. (2020). Functionalizing and bio-preserving process food products via probiotic and synbiotic edible films and coatings. *Advances in Food and Nutrition Research, 94*, 162–212. 10.1016/bs.afnr.2020.06.004.

Hempel, A. W., Gillanders, R. N., Papkovsky, D. B., & Kerry, J. P. (2012). Detection of cheese packaging containment failures using reversible optical oxygen sensors. *International Journal of Dairy Technology, 65*(3), 456–460. 10.1111/j.1471-0307.2012.00849.x.

Huang, Y., Hung, Y., Hsu, S., Huang, Y., & Hwang, D. (2008). Application of electrolyzed water in the food industry. *Food Control, 19*(4), 329–345. 10.1016/j.foodcont.2007.08.01.

Huang, H. W., Hsu, C. P., & Wang, C. Y. (2020). Healthy expectations of high hydrostatic pressure treatment in food processing industry. *Journal of Food and Drug Analysis, 28*(1), 1–13. 10.1016/j.jfda.2019.10.002.

Hussain, P. R., Omeera, A., Suradkar, P. P., & Dar, M. A. (2014). Effect of combination treatment of gamma irradiation and ascorbic acid on physicochemical and microbial quality of minimally processed eggplant (Solanum melongena L.). *Radiation Physics and Chemistry, 103*, 131–141. 10.1016/j.radphyschem.2014.05.063.

Hussein, Z., Caleb, O. J., Jacobs, K., Manley, M., & Opara, U. L. (2015). Effect of perforation-mediated modified atmosphere packaging and storage duration on physicochemical properties and microbial quality of fresh minimally processed ‘Acco’ pomegranate arils. *LWT - Food Science and Technology, 64*(2), 911–918. 10.1016/j.lwt.2015.06.040.

Jeong, J., Kim, C., & Yoon, J. (2009). The effect of electrode material on the generation of oxidants and microbial inactivation in the electrochemical disinfection processes. *Water Research, 43*(4), 895–901. 10.1016/j.watres.2008.11.033.

Jongsri, P., Wangsomboondee, T., Rojsitthisak, P., & Seraypheap, K. (2016). Effect of molecular weights of chitosan coating on postharvest quality and physicochemical characteristics of mango fruit. *LWT, 73*, 28–36. 10.1016/j.lwt.2016.05.038.

Kalpana, S., Priyadarshini, S. R., Maria Leena, M., Moses, J. A., & Anandharamakrishnan, C. (2019). Intelligent packaging: Trends and applications in food systems. *Trends in Food Science & Technology, 93*, 145–157. 10.1016/j.tifs.2019.09.008.

Kerch, G. (2015). Chitosan films and coatings prevent losses of fresh fruit nutritional quality: A review. *Trends in Food Science & Technology, 46*(2), 159–166. 10.1016/j.tifs.2015.10.010.

Kouhi, M., Prabhakaran, M. P., & Ramakrishna, S. (2020). Edible polymers: An insight into its application in food, biomedicine and cosmetics. *Trends in Food Science & Technology, 103*, 248–263. 10.1016/j.tifs.2020.05.025.

Koukounaras, A., Siomos, A. S., Gerasopoulos, D., & Papachristodoulou, M. (2019). Active modified atmosphere package induced a new physiological disorder of minimally processed romaine lettuce leaves. *Food Packaging and Shelf Life, 22* 100411-100411. 10.1016/j.fpsl.2019.100411.

Kuswandi, B., Maryska, C., Jayus Abdullah, A., & Heng, L. Y (2013). Real time on-package freshness indicator for guavas packaging. *Journal of Food Measurement and Characterization, 7*(1), 29–39. 10.1007/s11694-013-9136-5.

Lang, C., & Hubert, T. (2012). A Colour Ripeness Indicator for Apples. *Food and Bioprocess Technology, 5*(8), 3244–3249. 10.1007/s11947-011-0694-4.

Lavilla, M., & Gayan, E. (2018). Consumer acceptance and marketing of foods processed through emerging technologies. In *Innovative technologies for food preservation* (pp. 233–253). Academic Press. 10.1016/b978-0-12-81.

Leneveu-Jenvrin, C., Charles, F., Barba, F. J., & Remize, F. (2019). Role of biological control agents and physical treatments in maintaining the quality of fresh and minimally-processed fruit and vegetables. *Critical Reviews in Food Science and Nutrition, 19*, 1–19. 10.1080/10408398.2019.1664979.

Loro, A. C., Botteon, V. W., & Spoto, M. H. F. (2018). Quality parameters of tomatoes submitted to different doses of gamma radiation. *Brazilian Journal of Food Technology, 21*. 10.1590/1981-6723.16817.

Mainetti, L., Mele, F., Patrono, L., Simone, F., Stefanizzi, M. L., & Vergallo, R. (2013). An RFID-Based Tracing and Tracking System for the Fresh Vegetables Supply Chain. *International Journal of Antennas and Propagation, 15*, 1–15. 10.1155/2013/531364.

Mantilla, S. P. S., Mano, S. B., Carvalho Vital, H., & Franco, R. M. (2010). Modified atmosphere in food preservation. *Revista Acadêmica Ciência Animal, 8*, 437–448. 10.7213/cienciaanimal.v8i4.11000.

Marin, T., Montanucci, J. R., Benassi, M. D., & Yamashita, F. (2010). Active packaging for fresh-cut iceberg lettuce (Lactuca sativa L. *Semina-Ciencias Agrarias, 31*(3), 653–660. 10.5433/1679-0359.2010v31n3p653.

Maringgal, B., Hashim, N., Mohamed Amin Tawakkal, I. S., & Muda Mohamed, M. T. (2020). Recent advance in edible coating and its effect on fresh/fresh-cut fruits quality. *Trends in Food Science & Technology, 96*, 253–267. 10.1016/j.tifs.2019.12.024.

Marquez, G. R., Pierro, P. D., Mariniello, L., Esposito, M., Giosafatto, C. V. L., & Porta, R. (2017). Fresh-cut fruit and vegetable coatings by transglutaminase-crosslinked whey protein/pectin edible films. *LWT, 75*, 124–130. 10.1016/j.lwt.2016.08.017.

Maurya, V. K., Ranjan, V., Gothandam, K. M., & Pareek, S. (2020). Exogenous gibberellic acid treatment extends green chili shelf life and maintain quality under modified atmosphere packaging. *Scientia Horticulturae, 269* 108934-108934. 10.1016/j.scienta.2019.108934.

Mditshwa, A., Fawole, O. A., & Opara, U. L. (2018). Recent developments on dynamic controlled atmosphere storage of apples—A review. *Food Packaging and Shelf Life, 16*, 59–68. 10.1016/j.fpsl.2018.01.011.

Mieszczakowska-Frac, M., Celejewska, K., & Plocharski, W. (2021). Impact of innovative technologies on the content of vitamin C and its bioavailability from processed fruit and vegetable products. *Antioxidants, 10*(1), 1–19. 10.3390/antiox10010054.

Morehouse, K. M., Perez, G., & McNeal, T. P. (2018). Identification and quantitation of furan in irradiated fruit and vegetable juice. *Radiation Physics and Chemistry, 152*, 81–88. 10.1016/j.radphyschem.2018.06.044.

Mostafidi, M., Sanjabi, M. R., Shirkhan, F., & Zahedi, M. T. (2020). A review of recent trends in the development of the microbial safety of fruits and vegetables. *Trends in Food Science & Technology, 103*, 321–332. 10.1016/j.tifs.2020.07.009.

Ngadi, M. O., Bajwa, S. S., & Alakali, J. (2012). Minimally processed foods. *Food Biochemistry and Food Processing, 39*, 746–763 *second edition*. 10.1002/9781118308035.ch39.

Oliveira, M., Abadias, M., Usall, J., Torres, R., Teixidó, N., & Viñas, I. (2015). Application of modified atmosphere packaging as a safety approach to fresh-cut fruits and vegetables – A review. *Trends in Food Science & Technology, 46*(1), 13–26. 10.1016/j.tifs.2015.07.017.

Oliveira, T. M., Soares, N. D. F., de Paula, C. D., & Viana, G. A. (2008). Active packaging use to inhibit enzymatic browning of apples. *Semina-Ciencias Agrarias, 29*(1), 117–128. 10.5433/1679-0359.2008v29n1p117.

Onwude, D. I., Chen, G. N., Eke-emezie, N., Kabutey, A., Khaled, A. Y., & Sturm, B. (2020). Recent advances in reducing food losses in the supply chain of fresh agricultural produce. *Processes, 8*(11). 10.3390/pr8111431.

Opara, U. L., Caleb, O. J., & Belay, Z. A. (2019). *Modified atmosphere packaging for food preservation* (pp. 235–259). Elsevier.

Picart-Palmade, L., Cunault, C., Chevalier-Lucia, D., Belleville, M., & Marchesseau, S. (2019). Potentialities and Limits of some Non-thermal Technologies to improve sustainability of Food Processing. *Frontiers in Nutrition, 5*(130). 10.3389/fnut.2018.00130.

Paulsen, E., Barrios, S., & Lema, P. (2019). Ready-to-eat cherry tomatoes: Passive modified atmosphere packaging conditions for shelf life extension. *Food Packaging and Shelf Life, 22* 100407-100407. 10.1016/j.fpsl.2019.100407.

Paulsen, E., Barrios, S., Baenas, N., Moreno, D. A., Heinzen, H., & Lema, P. (2018). Effect of temperature on glucosinolate content and shelf life of ready-to-eat broccoli florets packaged in passive modified atmosphere. *Postharvest Biology and Technology, 138*, 125–133. 10.1016/j.postharvbio.2018.01.006.

Pavinatto, A., de Almeida Mattos, A. V., Malpass, A. C. G., Okura, M. H., Balogh, D. T., & Sanfelice, R. C. (2020). Coating with chitosan-based edible films for mechanical/biological protection of strawberries. *International Journal of Biological Macromolecules, 151*, 1004–1011. 10.1016/j.ijbiomac.2019.11.076.

Pires, A. C. D., Soares, N. D. F., da Silva, L. H. M., de Andrade, N. J., Silveira, M. F. A., & de Carvalho, A. F. (2010). Polydiacetylene as a Biosensor: Fundamentals and Applications in the Food Industry. *Food and Bioprocess Technology, 3*(2), 172–181. 10.1007/s11947-008-0171-x.

Pires, J. A., Lima, D. C., Silva, L. C. A. S., Arthur, V., & Harder, M. N. C. (2017). Efeito da Irradiação (Co^{60}) nas propriedades físico-químicas de batata minimamente processada. *Brazilian Journal of Food Research, 8*(1), 72–79. 10.3895/rebrapa.v8n1.3721.

Poubol, J., Techavuthiporn, C., & Kanlayanarat, S. (2018). Guava fruit treated with hot water on microbiological quality of fresh-cut ’Kimju’ and ’Pan Srithong’ guava. *International Food Research Journal, 25*(3), 903–907.

Prakash, A., Baskaran, R., Paramasivam, N., & Vadivel, V. (2018). Essential oil based nanoemulsions to improve the microbial quality of minimally processed fruits and vegetables: A review. *Food Research International, 111*, 509–523. 10.1016/j.foodres.2018.05.066.

Prakash, A., Inthajak, P., Huibregtse, H., Caporaso, F., & Foley, D. (2000). Effects of low-dose gamma irradiation and conventional treatments on shelf life and quality characteristics of diced celery. *Journal of Food Science, 65*(6), 1070–1075. 10.1111/j.1365-2621.2000.tb09420.x.

Putnik, P., Bursać Kovačević, D., Herceg, K., Roohinejad, S., Greiner, R., Bekhit, A. E.-D. A., et al., (2017). Modelling the shelf-life of minimally-processed fresh-cut apples packaged in a modified atmosphere using food quality parameters. *Food Control, 81*, 55–64. 10.1016/j.foodcont.2017.05.026.

Rahman, S., Khan, I., & Oh, D. H. (2016). Electrolyzed water as a novel sanitizer in the food industry: Current trends and future perspectives. *Comprehensive Reviews in Food Science and Food Safety, 15*(3), 471–490. 10.1111/1541-4337.12200.

Ramos, M., Jimenez, A., Peltzer, M., & Garrigos, M. C. (2012). Characterization and antimicrobial activity studies of polypropylene films with carvacrol and thymol for active packaging. *Journal of Food Engineering, 109*(3), 513–519. 10.1016/j.jfoodeng.2011.10.031.

Raynes, J. K., Carver, J. A., Gras, S. L., & Gerrard, J. A. (2014). Protein nanostructures in food - Should we be worried? *Trends in Food Science & Technology, 37*(1), 42–50. 10.1016/j.tifs.2014.02.003.

Rinaldi, M. M., Vieira, E. A., & Fialho, J. F. (2019). Postharvest conservation of minimally processed cassava roots subjected to different packaging systems. *Científica, 47*(2), 144–155. 10.15361/1984-5529.2019v47n2p144-155.

Roberts, P. B. (2016). Food irradiation: Standards, regulations and world-wide trade. *Radiation Physics and Chemistry, 129*, 30–34. 10.1016/j.radphyschem.2016.06.005.

Rodríguez, G. M., Sibaja, J. C., Espitia, P. J. P., & Otoni, C. G. (2020). Antioxidant active packaging based on papaya edible films incorporated with Moringa oleifera and ascorbic acid for food preservation. *Food Hydrocolloids, 103* 105630-105630. 10.1016/j.foodhyd.2019.105630.

Rosario, D. K. A., Rodrigues, B. L., Bernardes, P. C., & Conte-Junior, C. A. (2021). Principles and applications of non-thermal technologies and alternative chemical compounds in meat and fish. *Critical Reviews in Food Science and Nutrition, 61*(7), 1163–1183. 10.1080/10408398.2020.1754755.

Saini, R. K., Ko, E. Y., & Keum, Y. S. (2017). Minimally processed ready-to-eat baby-leaf vegetables: Production, processing, storage, microbial safety, and nutritional potential. *Food Reviews International, 33*(6), 644–663. 10.1080/87559129.2016.1204614.

Sani, M. A., Azizi-Lalabadi, M., Tavassoli, M., Mohammadi, K., & McClements, D. J. (2021). Recent advances in the development of smart and active biodegradabe packaging materials. *Nanomaterials, 11*(5), 1331–1362. 10.3390/nano11051331.

Santo, D., Graça, A., Nunes, C., & Quintas, C. (2018). Escherichia coli and Cronobacter sakazakii in ‘Tommy Atkins’ minimally processed mangos: Survival, growth and effect of UV-C and electrolyzed water. *Food Microbiology, 70*, 49–54. 10.1016/j.fm.2017.09.008.

Sethi, S., Joshi, A., & Arora, B. (2018). UV treatment of fresh fruits and vegetables. In M. W. Siddiqui (Ed.), *Postharvest disinfection of fruits and vegetables* (pp. 137–157). Cambridge: Academic Press. Chap. 7, pp.. 10.1016/B978-0-12-812698-1.00007-8.

Siddiq, R., Auras, R., Siddiq, M., Dolan, K. D., & Harte, B. (2020). Effect of modified atmosphere packaging (MAP) and NatureSeal® treatment on the physico-chemical, microbiological, and sensory quality of fresh-cut d’Anjou pears. *Food Packaging and Shelf Life, 23* 100454-100454. 10.1016/j.fpsl.2019.100454.

Sillani, S., & Nassivera, F. (2015). Consumer behavior in choice of minimally processed vegetables and implications for marketing strategies. *Trends in Food Science & Technology, 46*(2), 339–345. 10.1016/j.tifs.2015.07.004.

Siqueira, L. O., Eça, K. S., de Aquino, A. C., & da Silva, L. M. R. (2020). Modified and controlled atmosphere packaging. *Fresh-Cut Fruits and Vegetables*, 151–164. 10.1016/b978-0-12-816184-5.00007-0.

Smelt, J. P. P. M. (1998). Recent advances in the microbiology of high pressure processing. *Trends in Food Science & Technology, 9*(4), 152–158. 10.1016/s0924-2244(98)00030-2.

Souza, A. C. F., de Almeida, A. T., Marques, M. J. L., & Souza, J. F. (2020). Microbiological analysis of minimally processed fruits and vegetables marketed in supermarkets in the city of Macapá-Amapá. *Research, Society and Development, 9*(6), Article 148963751. 10.33448/rsd-v9i6.3751.

Spagnol, W. A., Silveira Junior, V., Pereira, E., & Guimarães Filho, N. (2018). Reducing losses in the fruit and vegetable chains by the analysis of shelf life dynamics. *Brazilian Journal of Food Technology, 21*. 10.1590/1981-6723.07016.

Tahir, H. E., Xiaobo, Z., Mahunu, G. K., Arslan, M., Abdalhai, M., & Zhihua, L. (2019). Recent developments in gum edible coating applications for fruits and vegetables preservation: A review. *Carbohydrate Polymers, 224* 115141-115141. 10.1016/j.carbpol.2019.115141.

Teixeira, G. H. A., Cunha Júnior, L. C., Ferraudo, A. S., & Durigan, J. F. (2016). Quality of guava (Psidium guajava L. cv. Pedro Sato) fruit stored in low-O2 controlled atmospheres is negatively affected by increasing levels of CO2. *Postharvest Biology and Technology, 111*, 62–68. 10.1016/j.postharvbio.2015.07.022.

Thompson, A. K., Prange, R. K., Bancroft, R. D., & Puttongsiri, T. (2018). *Controlled atmosphere storage of fruit and vegetables*. Boston, MA 3 ed..

Tomás-Callejas, A., Otón, M., Artés, F., & Artés-Hernández, F. (2012). Combined effect of UV-C pretreatment and high oxygen packaging for keeping the quality of fresh-cut Tatsoi baby leaves. *Innovative Food Science & Emerging Technologies, 14*, 115–121. 10.1016/j.ifset.2011.11.007.

Topuz, F., & Uyar, T. (2020). Antioxidant, antibacterial and antifungal electrospun nanofibers for food packaging applications. *Food Research International, 130* 108927-108927. 10.1016/j.foodres.2019.108927.

Urban, L., Charles, F., de Miranda, M. R. A., & Aarrouf, J. (2016). Understanding the physiological effects of UV-C light and exploiting its agronomic potential before and after harvest. *Plant Physiology and Biochemistry, 105*, 1–11. 10.1016/j.plaphy.2016.04.004.

Vivek, K., Singh, S. S., & RC, P. (2019). A review on postharvest management and advances in the minimal processing of fresh-cut fruits and vegetables. Journal of Microbiology. *Biotechnology and Food Sciences*, 1178–1187. 10.15414/jmbfs.2019.8.5.1178-1187.

Wang, C., & Meng, X. (2016). Effect of 60Co γ-irradiation on storage quality and cell wall ultra-structure of blueberry fruit during cold storage. *Innovative Food Science & Emerging Technologies, 38*, 91–97. 10.1016/j.ifset.2016.09.010.

Wilson, C. L. (2007). *Intelligent and active packaging for fruits and vegetables*. CRC Press.

Zhang, W., & Jiang, W. (2019). UV treatment improved the quality of postharvest fruits and vegetables by inducing resistance. *Trends in Food Science & Technology, 92*, 71–80. 10.1016/j.tifs.2019.08.012.

Zhao, Q., Jin, M., Guo, L., Pei, H., Nan, Y., & Rao, J. (2020). Modified atmosphere packaging and 1-methylcyclopropene alleviate chilling injury of 'Youhou' sweet persimmon during cold storage. *Food Packaging and Shelf Life, 24* 100479-100479. 10.1016/j.fpsl.2020.100479.

Zudaire, L., Viñas, I., Abadias, M., Lafarga, T., Bobo, G., Simó, J., et al., (2020). Effects of long-term controlled atmosphere storage, minimal processing, and packaging on quality attributes of calçots (Allium cepa L. *Food Science and Technology International, 26*(5), 403–412. 10.1177/1082013219891007.

Zudaire, L., Vinas, I., Abadias, M., Simo, J., & Aguilo-Aguayo, I. (2018). Efficacy of chlorine, peroxyacetic acid and mild-heat treatment on the reduction of natural microflora and maintenance of quality of fresh-cut calçots (Allium cepa L.). *LWT-Food science and technology, 95*, 339–345. 10.1016/j.lwt.2018.05.005.