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Cutting-edge physical techniques in postharvest for fruits and vegetables: Unveiling their power, inclusion in 'hurdle' approach, and latest applications

Maria Lucia Valeria de Chiara[a,*], Juan Manuel Castagnini[b], Vittorio Capozzi[a]

[a] Institute of Sciences of Food Production, National Research Council of Italy (CNR), C/o CS-DAT, Via Michele Protano, 71121, Foggia, Italy
[b] Research Group in Innovative Technologies for Sustainable Food (ALISOST). Department of Preventive Medicine and Public Health, Food Science, Toxicology and Forensic Medicine, Faculty of Pharmacy, Universitat de València, Avda. Vicent Andrés Estellés, s/n, 46100, Burjassot, Valencia, Spain

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ABSTRACT

Background: Minimal processing and postharvest technologies are crucial for promoting the consumption of fruit/vegetables but can have detrimental effects on the quality of fresh produce, encouraging faster deteriorative modification. Innovative approaches are finalized to reduce nutrient losses, increasing consumer acceptability while guaranteeing minimal environmental impact. Recent evolution of physical approaches aims at reducing side effects and water consumption in fresh and minimally processed fruit and vegetables, acting as an alternative to the use of high-temperature or synthetic compounds.

Scope and approach: Emerging physical technologies such as vacuum cooling and hydrocooling, microwave heating, pulsed electric field, cold plasma, and high hydrostatic pressure have been studied to reduce microbial load and spoilage phenomena while maintaining fresh-like characteristics and nutritive active compounds in fruits and vegetables postharvest. The effect of each treatment, focusing on the variability of the matrices, and the combination of more treatments in a hurdle technology approach, on the quality and safety of final products is reported. This review aims to represent a comprehensive collection of the emerging and most important physical technologies that have been applied to fresh and minimally processed horticultural products during the last years, focusing, for each processing, on its mode of action and practical application on the different categories of horticultural products.

Key findings and conclusions: The study highlights the effectiveness of these treatments in improving safety while preserving freshness and quality products, providing an overview of their key advantages and disadvantages. A selection of case studies *i)* supports information on the diversity of treatments with respect to the variability of matrices and *ii)* illustrates the application of physical solutions in the framework of hurdle technology approaches to enhance synergistic effects by combining multiple techniques. Future challenges to optimise final product quality standards by adopting cost-effective methods are also discussed.

1. Introduction

The consciousness and interest in a healthy lifestyle, combined with high consumption of fruit and vegetables, has constantly increased in the last few years. Fresh-cut produce represents a ready-to-eat, appealing, nutritionally balanced, and safe source of fresh fruit and vegetables that conciliate the instances for a healthy diet with the needs connected to modern lifestyles. Minimal processing of fruits and vegetables generally includes washing, peeling, cutting, size reduction, and disinfection operations (Gomes et al., 2023). The industrial interest led to concrete attention to developing innovative approaches to avoid the adverse effects of these technological treatments while retaining the fresh-like properties of the horticultural produce. Washing under clean and running water is the best way to control the turgor of fresh-cut produce after cutting, although a further sanitizing step is also required. Fruits and vegetables are susceptible to many postharvest diseases caused by spoiling and pathogenic microorganisms due to their high water and nutrient content (De Simone et al., 2020; Karoney et al., 2024). The traditional strategy to control diseases is the use of high-temperature or synthetic compounds such as sodium hypochlorite

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* Corresponding author.
E-mail address: marialucia.dechiara@ispa.cnr.it (M.L.V. de Chiara).

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(NaOCl), which can be potentially harmful to the environment and to the human body (Martínez-Hernández et al., 2017). Consequently, their application has recently been limited due to consumer and administration concerns about human and environmental health, and the increasing attention to organic products increased the demand for residue-free fruit and vegetables (Zhang et al., 2023). Most of the postharvest technologies can cause adverse consequences on the quality of food and are highly water-consuming (Palumbo et al., 2022). Also, minimal processing encourages faster deteriorative modification in fruits and vegetables. Therefore, emerging physical techniques have been spotlighted over the last few years. These innovative approaches are defined as various mechanical and structural methods used to handle and process horticultural products after harvesting. This encompasses a wide range of techniques and equipment designed to maintain the quality, extend the shelf life, and reduce microbial contamination and quality losses of fruits and vegetables. Cutting-edge physical techniques are primarily aimed at replacing thermal processing/chemical solutions, thus reducing nutrient losses, improving sustainability and increasing consumer acceptability. Physical, non-thermal treatments guarantee the total absence of residues in the treated product and minimal environmental impact. From the point of view strictly related to environmental issues, increasing the production volume should be done sustainably, introducing best practices, and reducing the adverse impact on the environment of the production process. Research and future food systems should meet three main challenges without compromising food security: *i)* sustainably improve the food systems, *ii)* reduce food losses and waste, and *iii)* move towards a plant-based diet (Faber et al., 2024; Onyeaka et al., 2024). Therefore, the development of non-chemical and non-thermal techniques to control fresh produce diseases is increasing in many research programs to investigate their potentiality and/or limitations for postharvest application. Emerging technologies such as vacuum cooling and hydrocooling, microwave heating, pulsed electric field (PEF), cold plasma (CP), high hydrostatic pressure (HHP), UV irradiation and pulsed light, and ionizing radiation have been studied as promising approaches to reduce microbial load while maintaining fresh-like characteristics and nutritional active compounds of fruit and vegetables. However, these techniques showed advantages and disadvantages to be investigated in a matrix-dependent manner to achieve a suitable quality standard by adopting cost-effective methods (Ganesan et al., 2021). In a panorama of highly specialized reviews on a single technology, this review aims to represent quite a comprehensive collection of the emerging and most important physical technologies that have been applied to fresh and minimally processed horticultural products during the last few years, providing a comparative scenario and focusing on their synergistic effect when applied as hurdle technology in combination with further physical and chemical techniques. No recent review in the field focused on evaluating the matrices-dependent effectiveness of the physical treatment. Hence, a particular emphasis is given to the variability of the matrix, mainly represented by fresh-cut produce, providing an original collection of information compared to the existing literature. By highlighting the diverse matrices encountered in horticultural products and their implications for technology application, this review offers valuable insights into optimising preservation strategies tailored to specific product characteristics, promoting the design of adaptable and flexible technological solutions. Advanced systems with capabilities to detect and adjust to these variations can significantly enhance the efficiency, quality, and safety of postharvest handling and processing. For each technology, identified as relevant in the postharvest sector (vacuum and hydrocooling, microwave heating, PEF, CP, HHP) a specific paragraph concerning its mode of action and its application during postharvest processing is reported, and then particular attention is paid to the beneficial and detrimental effects of the treatment on the quality and safety of fresh and minimally processed fruit and vegetables (Fig. 1).

2. Physical emerging techniques

2.1. Temperature management

2.1.1. Vacuum and hydrocooling

2.1.1.1. General aspects. Vacuum cooling (VC) technology is based on liquid evaporation to produce a cooling effect on food matrices. When a portion of a liquid is evaporated due to the low surrounding pressure, an amount of heat equal to the latent heat of evaporation must be absorbed by the evaporated portion either from the liquid body or from the surroundings, resulting in the reduction of the temperature of the liquid body or surroundings. Any product with free water whose structure cannot be damaged by water removal can be subjected to vacuum cooling. The ratio between evaporation surface area and the mass of foods influences the effectiveness of the treatment. Water-immersed treatment (hydrocooling) resulted in better quality maintenance. Hydrocooling (HC) shows the advantage of a faster and more uniform cooling than air for a wide range of fruits and vegetables since the surface heat transfer coefficient of produce-to-water is much higher than that of air, leading to a reduction of tissues postharvest deterioration. However, produce that undergoes hydrocooling must have a high resistance to wetting and low vulnerability to physical damage caused by water (Ding & Mat, 2021), to avoid the main disadvantages associated with this technology, such as tissue damage and mass loss,

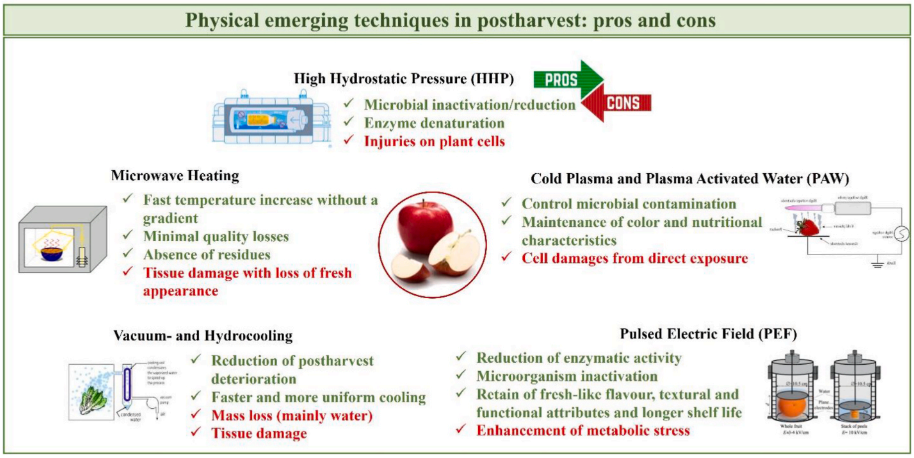

Fig. 1. Pros and cons of the main physical technologies when applied to fresh and minimally processed horticultural products to prolong their postharvest life and enhance their safety.

primarily represented by water.

2.1.1.2. Postharvest application on fresh and minimally processed fruits and vegetables. The rapid removal of field heat reduces plant tissue's respiration rate and physiological activities, which may hasten senescence during post-processing handling operations. Therefore, it is crucial to remove this heat as quickly as possible. Different pre-cooling methods (such as vacuum or hydrocooling) may be applied to fresh produce, resulting in faster cooling than conventional solutions. The scientific literature of the last few years reports that rapid cooling was efficiently applied to pre-cool several fresh fruits and vegetables. Research has been extensively carried out to investigate vacuum cooling and hydrocooling applications in several varieties of whole fruits and vegetables (Table 1), since the intact fresh product, not subjected to any preliminary process, is more suitable for this type of technology, including leafy vegetables (Alabi et al., 2023; Garrido et al., 2015; Kongwong et al., 2019), amla (Tomar & Pradhan, 2023), cashew apple (Oliveira et al., 2019), fresh sweet corn (Ding & Mat, 2021; Zhang et al., 2023, 2023b, 2023c) and pears (Mahajan et al., 2023) confirming that precooling application, both hydro or vacuum, is highly effective in maintaining the quality of these products, extending their shelf life. On the other hand, vacuum cooling has also been reported to cause approximately an inevitable mass loss (mostly water) that can be avoided when preliminary wetting of produce is applied. Thus, hydrocooling can overcome this issue and is commonly practiced for many commodities, such as asparagus and broccoli, also contributing as a cleaning strategy (Ding & Mat, 2021). The application of vacuum and hydrocooling is most effective for freshly harvested products, ensuring optimal quality and freshness before processing. Selecting the appropriate cooling method can significantly enhance the postharvest quality and shelf life of various produce, with each method offering specific benefits tailored to different types of fruits and vegetables.

2.1.2. *Microwave heating*

2.1.2.1. General aspects. High-frequency microwave (MW) oscillations are produced by an electronic tube, a magnetron, that only needs a power supply for its self-oscillation. Innovation in microwave generation is represented by solid-state sources based on transistor amplifiers. Microwave heating is related to the capability of the product to absorb microwave energy, transforming it into heat. Due to its polar nature, the main cause of dielectric heating is the presence of water or moisture within fresh plant tissue. Well-sized microwaving could ensure a rapid and sound heat treatment with the advantage of reducing the risk of tissue damage, thus avoiding the reduction of nutritive substances (de Chiara et al., 2023). From a microbiological point of view, food irradiation causes damage to DNA with consequent cell inactivation. The main advantages of this mild heating technique are represented by a fast temperature increase of plant tissue without a gradient, leading to minimal quality losses, and the absence of chemical residues. Nevertheless, the attainment of excessively high temperatures resulting from overly intense treatments may cause tissue damage with loss of its freshness-related characteristics.

2.1.2.2. Postharvest application on fresh and minimally processed fruits and vegetables. Conventional heating processes can result in the thermal destruction of essential antioxidant and flavour-related compounds, which is a significant side effect due to slow convection or conduction of heat. Microwave heating represents a valuable alternative to traditional thermal processing for minimally processed fruit and vegetable production, mildly treating them, ensuring at the same time minimal environmental impact and absence of residues in the treated product (Usall et al., 2016). To date, little information is available concerning the application of this innovative physical technology to control postharvest diseases on minimally processed fruits and vegetables and fresh

Table 1
The main application of physical technologies aimed at temperature management (vacuum- and hydrocooling and microwave heating) on fresh and minimally processed fruit and vegetables of the last five years.

Experimental condition	Food Matrix	Effects	Reference
		Cooling	
VC: air velocity 1.4 m s^{-1} at 4 ± 1 °C and 80–85% RH. Final holding pressure: 0.6 and 0.65 kPa for 15, 20, and 25 min.	Baby cos lettuce cv. Baby Star^{W}	VC slowed down the ascorbic acid and chlorophyll losses over storage time, enhancing antioxidant and phenolic accumulation. The cells remained intact, and their senescence was delayed, ensuring 16 days of high-quality produce.	Kongwong et al. (2019)
HC: immersion in chlorinated water at 1, 3, 5, and 7 °C.	Cashew apple^{W}	5 °C-HC fruits showed higher freshness, firmness, and acidity, and lower weight loss, vitamin C content, and enzymatic activity compared with control samples. Total phenolic contents decreased during storage, but little treatment effect on the decline rate was detected.	Oliveira et al. (2019)
HC: water temperature 4 °C, up to 17 and 7.25 °C of the core.	Fresh sweet corn^{W}	Cooling up to 7.25 °C and storage at 12 ± 2 °C retain higher soluble solids concentration and pH with significantly lower weight loss.	Ding and Mat (2021)
Three levels of magnetic field HC (MFHC) (at 534.1 mT, 458.0 mT, and 396.8 mT) on hydrocooling.	Jute mallow, fluted pumpkin, and bitter leaf^{W}	The MFHC at 396.8 mT provided higher cooling rates, significantly reducing microbial loads in all treated products and more effective in maintaining the integrity of microstructures.	Alabi et al. (2023)
HC: sprinkle of chilled water at 5 °C. Forced Air Cooling (FAC): cold air at a speed of 3.0–3.5 m s^{-1}. Evaporative Cooling (EC): fruits were exposed to cold air produced from the dessert cooler.	Pear^{W}	The lowest weight loss was observed in FAC-treated fruits, followed by HC method. Fruit firmness, overall sensory score, TSS, ascorbic acid, and phenolic content were higher for FAC method, while the highest decay incidence was observed for control samples.	Mahajan et al. (2023)
HC: the product was hydro cooled using immersion in chlorinated water (200 ppm) at 3, 5, and 8 °C.	Amla^{W}	The HC process of amla fruits showed significantly lower weight loss, with higher firmness and slower ascorbic acid reduction. A not significant effect of HC and cold room cooling process was observed for titratable	Tomar and Pradhan (2023)

(continued on next page)

Table 1 (*continued*)

Experimental condition	Food Matrix	Effects	Reference
		acidity and TSS during product storage.	
Strong wind pre-cooling (SWPC): pre-cooling in a 0 °C freezer; ice water pre-cooling (IWPC): pre-cooling with a mixture of 0 °C ice water; vacuum pre-cooling (VPC): vacuum cooling chamber with the vacuum at 600 Pa; natural convection pre-cooling (NCPC) (control): thermotank at 4 °C; slurry ice pre-cooling (SIPC): fluidized ice with a 3:1 ratio if ice to sweet corn.	Fresh sweet corn^{W}	SWPC had the fastest speed, removing the sweet corn's latent heat in 31 min. SWPC and IWPC reduced fruit quality losses, thus extending product shelf life up to 28 days, 14 days longer than SIPC and VPC treated samples, and 7 days longer than NCPC technique.	Zhang et al. (2023)
		Heating	
MW at 300-100 W/ 35-10 s	Apples^{FC}	The strongest microwave treatment after washing and packaging achieved the greatest microbial reduction for mesophiles, and psychrophiles count, while samples did not show significant differences for yeast and moulds.	Colelli et al. (2021)
MW at different power densities (4.4, 7.7, and 11.0 W g^{-1}), with three cook values levels (0.36, 10, 24 min) for each power density	Peach^{P}	PPO of peach puree significantly decreased while increasing the cook value level, and PME significantly decreased when power density raised from 4.4 to 11.0 W g^{-1} at cook value 24 min. MW treatment did not affect the flow behaviour of the puree. The apparent viscosity values and L* values increased with MW treatment. MW treatment retained total polyphenol, flavonoid and antioxidant capacity.	Zhou et al. (2022b)
MW at 75 °C for 0–5 min	Kiwifruit^{P}	MW treatment significantly increased the total antioxidant activity of kiwifruit juice, improving its peptide content and digestibility of fruit protein. An 80% reduction in allergen content was observed with the longest treatment. However, negative effects on sugar content and colour parameters were observed.	Wang et al. (2023)
Central Composite Design (10 combinations of treatment time and MW power)	Table grape^{RtU}	MW energies above 8000 kJ affected the sensory parameters of the product detrimentally. The physicochemical aspect did not show significant differences. 100 W for 80 s led to a better visual appearance of the product maintaining an intermediate level of mesophilic bacterial load and no significant differences in nutritional parameters.	de Chiara et al. (2023)

The superscript letters in the table indicate the following: *W* = fresh, whole unprocessed product, intended for storage; *RtU* = fresh ready-to-use product, unprocessed, intended for sale; *FC* = fresh-cut product, which has undergone minimal processing; P = processed fresh produce, reduced to puree or juice.

fruit-based smoothies (Colelli et al., 2021) (Table 1). Minimally processed apples (Colelli et al., 2021), ready-to-use table grape (de Chiara et al., 2023), and kiwifruit puree (Wang et al., 2023) were subjected to high power/short time treatments showing promising results from a microbiological point of view. The effect of microwave pasteurization on fresh juice or purees was also reported for peach (Zhou et al., 2022b), confirming the effectiveness of the short-time heating obtained through continuous or batch microwaving in enzyme inactivation and maintenance of nutritional and organoleptic quality of fresh puree, even if their freshness is however compromised being a pasteurized product. However, this research may represent a line to be extended to smoothies and other fresh fruits and vegetables-based products. In this sense, there is a need to combine additional treatments to ensure product quality and safety throughout the storage time. The future of microwave application is increasingly focused on minimally processed produce (as seen in Table 1), rather than whole fruits. Literature shows that microwave treatment could represent, as a part of a hurdle technology approach, a good, effective, and sustainable alternative to conventional heating and sanitizing procedures in terms of reduction of chemicals and water consumption. However, an excessive duration or intensity of treatment can induce excessive temperature increase, damaging the fresh tissue. For this reason, there is a need to overcome several challenges to obtain a successful industrial-scale microwave process on fresh and minimally processed products, paying particular attention to the use of generators based on solid-state sources technology.

2.2. *Pulsed electric field*

2.2.1. *General aspects*

The basic principle of Pulsed Electric Field (PEF) technology involves applying a series of high-voltage pulses, consisting of pulses characterized by higher electric fields for a few micro-milliseconds, with a range intensity of 10–80 kV cm^{-1}, to a food product placed between two electrodes. The short electric pulses induce an electric field across the cellular membranes of microorganisms causing a phenomenon known as electroporation. As a result, the integrity of the cell membrane is disrupted, leading to the formation of pores. When the electric field strength exceeds a critical threshold, these pores cannot reseal, resulting in cell death or loss of cell functionality. The extent of microbial inactivation depends on several factors, including the electric field strength, pulse duration, number of pulses, and the properties of the food matrix.

The distance between the electrodes is characteristic of the treatment chamber. The electric field can be applied in various forms, such as exponentially decaying, monopolar, or bipolar waves. The process can also be carried out at different temperatures. During PEF processing, high-voltage application results in the inactivation of microorganisms. This technique is preferably used for liquid foods, most frequently milk, juices, yoghurt, liquid eggs, and soups, because electric current flows more efficiently, and the transfer of pulses from one point to another becomes quite easier due to the presence of charged molecules (Abbas Syed, 2017). The typical system is composed of a pulse generator that produces high-voltage pulses and a treatment chamber associated with controlling and monitoring devices. The chamber is made of nonconductive material, preventing electricity flow between the electrodes. PEF treatment induces instability of microbial membranes by electrical field application and electromechanical compression that leads to the creation of pores in the membrane, resulting in a significant increase in the membrane rupture and permeability, termed electro-permeabilization, which ends up in the destruction of the cell. The main advantages of this technology, as also detailed in Table 2 considering the variability of the matrices subjected to the treatment, can be described as the reduction of enzymatic activity, microorganism inactivation and maintenance of fresh-like flavour, textural and functional attributes and longer shelf life.

2.2.2. *Postharvest application on fresh and minimally processed fruits and vegetables*

Pulsed electric field (PEF) technology is a non-thermal food preservation method that is valuable for postharvest applications to inactivate microorganisms while having minimal detrimental effects on product quality and maintaining the physical and sensory attributes of food. PEF technology has gained much attention during the last decade because it can obtain safe food by applying short treatment time with minimal heat production (Vanga et al., 2021). PEF technology has a wide range of applications ranging from liquid or semi-solid foods to solid foods; in the postharvest field, this translates into the possibility of using this technology for fresh fruit and vegetable smoothies and juices. Electric field strength, treatment time, pulse frequency, pulse polarity, and pulse shape represent the parameters that should be monitored and tailored to obtain microbial and enzymatic inactivation in fresh produce. Table 2 reports the effect of PEF application on whole and fresh-cut apples (Li et al., 2023; Ribas-Agustí et al., 2019), fresh-cut lotus roots (Li et al., 2020), carrots (López-Gámez et al., 2020a, 2020b, 2021), tomatoes and kiwifruits (Giancaterino & Jaeger, 2023), and fresh Barhi date (Younis et al., 2023). PEF-treated products better retained fresh-like flavour, textural and functional attributes, longer shelf life, and microbiological safety. In recent years, PEF technology has also been applied for different purposes, including enhancement of drying efficiency, modification of various enzymatic activities, treatment of solid food, wastewater treatment, and improvement of extraction efficiency (Abbas Syed, 2017). PEF effects on the mechanical and sorption properties were studied in apples (Castagnini et al., 2020), carrots, and potatoes (Iaccheri et al., 2022), as well as its effects in the glass transition temperature (Iaccheri et al., 2021). PEF-induced metabolic stress of cells could lead to undesired effects on the quality of the final products, thus representing a limit to the application of this technology in fresh-cut products. PEF application on minimally processed produce can ease the mass exchange between the dipping solution and the tissue if this further processing is planned (Tylewicz et al., 2022); on the other, it can enhance further stress responses. Few works have been published concerning the effects of PEF on metabolism and postharvest quality of whole and fresh-cut produce. However, short electric pulses induce an enhancement of metabolic stress of plant cells; for this reason, this technology is mainly applied to unprocessed products, and there is a need for further optimization.

Table 2
The main application of pulsed electric field (PEF) on fresh and minimally processed fruit and vegetable-based products for the last five years.

Experimental condition	Food matrix	Effects	Reference
i) 0.4 kV cm^{-1}, 5 pulses (0.01 kJ kg^{-1}, 20μs); ii) 2.0 kV cm^{-1}, 35 pulses (1.8 kJ kg^{-1}, 140 μs) and iii) 3.0 kV cm^{-1}, 65 pulses (7.3 kJ kg^{-1}, 260 μs)	Apple^{W}	Treatments at 1.8 and 7.3 kJ kg^{-1} induced discolouration and firmness loss, while overall phenolic contents decreased, except those of flavonols. However, 24 h after treatment at 0.01 kJ kg^{-1} the main apple phenolic compounds were higher, as well as total phenolics and flavan-3-ols contents, while physicochemical quality attributes were unaffected.	Ribas-Agustí et al. (2019)
10,000 pulses at 0.5, 1.0, and 1.5 kV cm^{-1}, with specific energy levels 5.56, 22.20, and 50.00 kJ kg^{-1}	Lotus root^{FC}	PEF treatment decreased the reducing sugar content in fresh samples, lowering the browning index and reducing acrylamide content after frying. Membrane disintegration resulted in soft tissue structure and reduced oil inhalation by 15 %.	Li et al. (2020)
5 pulses of 350 kVm^{-1} (580 ± 80 J kg^{-1})	Carrot^{W}	The highest production of CO_2 and volatile organic compounds was observed 12 h after PEF treatment, whereas the largest increases in total phenolic content occurred 24 h after treatment, most probably related to a stress-induced biosynthesis of hydroxycinnamic and hydroxybenzoic acids.	López-Gámez et al. (2020b)
0.8, 2, and 3.5 kV cm^{-1} electric field strength and 5, 12, and 30 number of pulses	Carrot^{W}	The largest increases in phenolic content were reached 24 h after applying 30 pulses of 0.8 kV cm^{-1} and 5 pulses of 3.5 kV cm^{-1}. Colour was not affected, but softening occurred after applying the highest strength. Total and individual carotenoid contents increased just after applying $E \geq 2$ kV cm^{-1}, whereas lutein decreased, and α-carotene remained similar to untreated carrots. After applying 2 and 3.5 kV cm^{-1}, TSS and pH remained unaltered, but the cortical browning index increased, which was correlated to carotenoid content.	(López-Gámez et al., 2020a, 2021)

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Table 2 (*continued*)

Experimental condition	Food matrix	Effects	Reference
Electric field 1 kV cm^{-1}, number of pulses 10–500, and the applied frequency 2 Hz. Resulting in 0.25–5.0 and 0.63–12.6 kJ kg^{-1} total energy for tomatoes and kiwi fruit.	Tomato and kiwifruit^{W}	PEF treatment could reduce weight losses and the detrimental effects of thermal peeling on the colour and bioactive compounds of the tested product.	Giancaterino and Jaeger (2023)
PEF at 1, 3, and 5 kV cm^{-1}, 200 μs, and 500 Hz	Apple^{FC}	The apples treated with 3 kV cm^{-1} and 5 kV cm^{-1} showed higher quality during storage time with lower weight loss, browning index, enzyme activity, and microbial load.	Li et al. (2023)
Five-factor mixed-level central composite rotating design (CCRD): PEF intensity, PEF exposure time, PEF numbers, storage temperature, and storage time	Barhi date^{W}	Optimal PEF treatment and storage conditions to prolong the shelf life of fresh Barhi dates were PEF intensity 10.3 kV cm^{-1}; PEF duration 46.73 ms; number of PEF 169.9; storage temperature 18.7 °C up to 21 days. Applying these conditions TSS value, firmness, DE, total viable count, total phenolic content, antioxidant activity, and glucose and fructose content resulted to be comparable to the predicted values (Desirability value = 1).	Younis et al. (2023)

The superscript letters in the table indicate the following: *W* = fresh, whole unprocessed product, intended for storage; *RtU* = fresh ready-to-use product, unprocessed, intended for sale; *FC* = fresh-cut product, which has undergone minimal processing; P = processed fresh produce, reduced to puree or juice.

2.3. *High hydrostatic pressure*

2.3.1. *General aspects*

High hydrostatic pressure (HHP) is a non-thermal batch process consisting of applying high-pressure treatments to products already packaged in their final container. Commercial-scale types of equipment have internal volumes ranging from 35 to 525 L. Semi-continuous HHP systems are instead used to process food products before packaging (Koutchma et al., 2016). HHP processing uses hydrostatic pressures commonly in the range of 100–800 MPa, with a duration of the treatment ranging from 30 s to a few minutes to treat various food products. The inactivation of microorganisms is due to pressure-induced damage to the cell membrane and cellular integrity, which results in altered cell permeability, loss of osmotic regulation and genetic functions, and altered biochemical reactions (Barba et al., 2015). HHP can completely or partially inactivate microorganisms and enzymes, depending on the processing conditions such as pressure, temperature, and exposure time. This treatment is effective at a minimum pressure of 400 MPa at ambient temperature. Biological systems begin to show molecular bond cleavage at this pressure level and above, leading to minimal side effects on food tissue. However, for temperatures ranging from 0 to 40 °C, typically, HHP has minimal effects on the quality parameters of fresh products, slightly affecting antioxidants and vitamin content, colour, and flavour (Koutchma et al., 2016). Similarly to all treatments that affect cellular integrity, HHP has the advantage of inactivating/reducing microbial content, and denaturing enzymes, but on the other hand, it can also cause injuries to the cells of the product itself, damaging its overall quality.

2.3.2. *Postharvest application on fresh and minimally processed fruits and vegetables*

HHP is mostly used for microbial inactivation or reduction and enzyme denaturation in processed and packaged ready-to-eat fruit- and vegetable-based products. Among HHP effects, inactivation microorganisms, including pathogenic bacteria, endogenous microflora, and yeast and moulds, are the most interesting for postharvest application, enhancing safety and extending the shelf life of fresh and minimally processed products (Fan & Wang, 2021). However, high pressure, inducing injuries on microbial cellular structure, might have a similar effect on plant tissue, thus is needed an in-depth study for treatment optimization on various fresh systems (Wang et al., 2016). Table 3 reports the most recent application on whole fresh horticultural produce (Paciulli et al., 2019a; Paciulli et al., 2019b; Rux et al., 2020; Hu et al., 2021), minimally processed products (Denoya et al., 2022; Hu et al., 2020; Kundukulangara Pulissery et al., 2021; Paciulli et al., 2021; Ramos-Parra et al., 2019; Rinaldi et al., 2023) and fruits and vegetables-based juice or purees (Fernández et al., 2020; González-Tejedor et al., 2023; Koo et al., 2023; Raj et al., 2022). Results show that this technique significantly affects microbial inactivation; however, it also affects the functionality of proteins such as enzymes and tissue structure specifically and differentially due to the wide variety of product types (Rux et al., 2020). As can be seen from the table below, many applications of HHP technology are reported on fresh-cut products and fresh smoothies. Physicochemical quality maintenance and efficiently reducing microbial growth are reported as the main results.

2.4. *Cold plasma and plasma-activated water*

2.4.1. *General aspects*

Plasma is known as the fourth state of matter, generated by the induction of energy into a gas mixture, ending in the formation of charged particles, free radicals and electrons, UV radiations, ions, reactive atoms, neutral molecules, and photons in a metastable state with a roughly zero net electrical charge (Pan & Jun-Hu Cheng, 2019; Bagheri & Abbaszadeh, 2020). Plasma produced at room temperature, known as cold plasma (CP), typically has a temperature range of 30–60 °C. This type of plasma is primarily used in food processing. Cold plasma can be generated using microwave, radio frequency, and direct or alternating current. It is one of the most modern technologies tested for microbial inactivation or destruction. Bacterial cell surfaces exposed to the intense radicals' attack are subjected to rapid lysis due to DNA and chemical bond denaturation. At the base of the phenomenon of lesion formation, there is the accumulation of electrostatic forces on the external surface of the living cell. Dielectric barrier discharge (DBD) plasma is the most used, and it is generated by placing an insulating or dielectric material between two electrodes, which is responsible for a self-pulsing operation. The identities of produced atoms depend on the characteristics of the original gaseous mixture and the polarity of discharge, while electron energies rely on the method of generating the corona along with the gas characteristics (Bussiahn et al., 2010). Cold plasma is generally produced by mixed gases such as helium, oxygen, argon, nitrogen, and air with varying frequency and power (Ganesan et al., 2021). The ionization process is a significant event that generates multiple particles with strong oxidizing abilities. This is especially evident with reactive oxygen species (ROS) such as O and –OH, and reactive nitrogen species (RNS) such as NO, NO_2, and $–NO_3$.Plasma-activated water (PAW) represents a cold plasma-derived strategy to be used as an alternative to traditional preservation and antimicrobial methods, having milder operating conditions (Guo et al., 2021). PAW is obtained by direct or indirect exposure of distilled or tap water to non-thermal plasma (NTP)

Table 3
The main application of High hydrostatic pressure (HHP) on fresh and minimally processed fruit and vegetable-based products of the last five years.

Experimental condition	Food matrix	Effects	Reference
HHP at 400–600 MPa; 1–5 min	Blueberry^{RtU}	HHP led to higher tissue damage than blanching, resulting in leakage of intracellular components, such as bioactive molecules and enzymes. Antioxidant activity was higher for samples treated for longer times (5 min). Pectin methyl esterase was more active in blueberries treated with more intense high pressure conditions.	(Paciulli et al., 2019a)
HHP at 200, 400, 600 MPa for 5 min	Pumpkin^{FC}	400 MPa and thermal treatment were the most effective in inactivating pectin methylesterase of pumpkin cubes. Colourimetric parameters decreased after all treatments. Antioxidant activity showed a significant increase during storage, especially for the samples treated at 200 MPa.	Paciulli et al. (2019b)
HHP at 50–400 MPa for 3–60 min	Papaya fruit^{FC}	HHP treatment increased carotenoid precursors and carotenes contents following processing and storage: lycopene levels increased up to 11-fold compared to the non-treated samples, and H_2O_2 and lipid peroxidation were concomitantly increased.	Ramos-Parra et al. (2019)
HHP at 630 MPa/6 min	Vegetable smoothie^{P}	HHP reduced native microbiota to values below the detection limit and reduced enzyme initial activities significantly. Greater retention of colour and nutritional indicators was noted on treated samples during storage.	Fernández et al. (2020)
HHP at 100–600 MPa for 2 min	Pumpkin^{FC}	HHP treatment could better maintain the original histology properties of the samples than heated ones based on the colour parameter, firmness, relative electrical conductance, and degree of pectin esterification, among which moderate pressure (300–400 MPa) exerted more positive effects.	Hu et al. (2020)
HHP at red cabbage: 150–200 MPa at 35–55 °C for 5–20 min. Radish: 100–200 MPa, at 20–40 °C for 5–10 min	Red cabbage leaves and radish tubers^{W}	Intensity, duration and temperature of HHP treatments interactively, pronouncedly, and directly affected cell turgor and tissue integrity. Never at or below 100 MPa, turgor losses become irreversible. Both occurred at any HHP treatment with pressures above 150 MPa and at temperatures higher than 45 °C.	Rux et al. (2020)
Mild HHP at 20–80 MPa for 10 min	Mango^{W}	HHP promoted the capacity of cell wall macromolecules to bind water and prevented structural damage to mango tissues during postharvest storage. It reduced the respiration rate and the consumption of sugars and acids, and in most cases, increased bioactive substances and increased carotenoid biosynthesis at the transcriptional level.	Hu et al. (2021)
HHP at 100–300 MPa for 5–20 min	Pineapple^{FC}	HHP significantly affects the firmness, total flavonoids, total polyphenols, vitamin C, and colour values, while not-treated samples exhibited a major degradation. Treatment at 300 MPa for 10 min was found to be suitable for preserving products quality.	Kundukulangara Pulissery et al. (2021)
HHP at 400,600 MPa; 1,5 min	Zucchini^{FC}	5 min-treatment led to more extended cell lysis and dehydration. High-pressure treatments were less effective than blanching on PME inactivation, with the best results obtained at 400 MPa for 1 min. Moreover, high pressure led to a general browning of zucchini parenchyma and DPPH drop.	Paciulli et al. (2021)
HHP at 100, 300, and 500 MPa with different holding times (1,5 min).	Peach^{FC}	300 and 500 MPa significantly affected the product's antioxidant properties, mainly	Denoya et al. (2022)

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Table 3 (*continued*)

Experimental condition	Food matrix	Effects	Reference
		associated with the modification in the microstructure that enhances compound extractability. HHP treatment at 300 MPa for 1 min did not detrimentally affect the fresh tissue.	
HHP at 300, 350, 400 and 450 MPa	Fresh purple smoothie^{P}	A strong positive correlation was observed between the pressure level and the inactivation rate. Quality was mostly unaffected by the HHP treatments, except for the vitamin C content, which reported reductions of 26 and 21% after 300 and 350 MPa, respectively.	González-Tejedor et al. (2023)
HHP at 200–400 MPa, up to 5 m	Carrot-orange juice^{P}	HHP at 300 MPa for 2 m, 400 MPa for 1 m, and 400 MPa for 3 m achieved more than 6-log reduction of *Listeria innocua* in pH 4, 5, and pH 6 blends, respectively. Chemical parameters and colour attributes did not significantly change after HHP treatments. The natural microbiota was kept below 2-log CFU mL^{-1} for 28 d of storage.	Raj et al. (2022)
HHP at 600 MPa and 5 °C, and seven pressure holding times: 0, 2.5, 5, 7.5, 10, 15, and 20 min	Bok choi juice^{P}	PPO and POD activity was still retained after 20 min. Increasing the time to enhance enzyme inactivation did not affect vitamin C, K, and carotenoid retention, antioxidant capacity, and isothiocyanates content.	Koo et al. (2023)
Six different pressures (100 (HHP100) to 600 MPa (HHP600)) for 3 min	Pumpkin^{FC}	HHP200 led to a higher available amount of pectin and starch, while HHP200 and HHP400 showed the highest antioxidant capacity. Treatments HHP 400 to 600 strongly affected bacterial load by giving the highest destruction of microorganisms but destroying at the same time the structural quality of the product.	Rinaldi et al. (2023)

The superscript letters in the table indicate the following: *W* = fresh, whole unprocessed product, intended for storage; *RtU* = fresh ready-to-use product, unprocessed, intended for sale; *FC* = fresh-cut product, which has undergone minimal processing; P = processed fresh produce, reduced to puree or juice.

to let the reactive species from the NTP be transferred to the water through diffusion and many other plasma-water chemical processes. Their concentrations depend on plasma activation time, gas composition, voltage, and water flow rate (Perinban et al., 2022). The advantages of these widely used technologies include control of the microbial load, maintenance of colour and of the nutritional characteristics of fresh horticultural produce. A poorly sized treatment can, however, cause cell damage from direct exposure.

2.4.2. *Postharvest application on minimally processed fruits and vegetables*

According to Niemira and Gutsol (2011), the cold atmospheric plasma can be applied in the postharvest field in three ways. The product is placed separately from the plasma-generating source in the remote exposure method, producing secondary chemical species from the air and other gases. In the direct exposure method, the food material is located near the plasma generation source, called active plasma, which contains short- and long-lived chemical species. In the electrode contact method, the food material is placed in the plasma-generating electrode field, which discharges chemical species, producing ion bombardment. To ensure method efficiency, the space of the target material and the treatment time should be considered. The application of cold plasma technology is widely studied in the fresh and fresh-cut fruits and vegetable industry as a novel technology to control microbial contamination (Bagheri & Abbaszadeh, 2020) to replace conventional sanitation treatments and improve, at the same time, the nutritional and antioxidant properties of food matrix. Based on the application method (gaseous or aqueous), the techniques of cold plasma and plasma-activated water can be applied to all types of products (whole unprocessed product intended for storage; ready-to-use product, unprocessed, intended for sale; fresh-cut product, which has undergone minimal processing; processed fresh produce, reduced to puree or juice) with beneficial effects on safety aspects. Many studies extensively reviewed the decontamination effect of non-thermal plasma on different food matrices, and many reviews have been published concerning the plasma application on fresh horticultural products. Thus, the present review mainly reports the most recent application of cold plasma on minimally processed/ready-to-use fruits and vegetables. The literature reported in Table 4 points out general treatment efficiency for different raw materials. Several fruits and vegetables based on fresh-cut produce were subjected to plasma treatment with beneficial effects concerning maintaining quality parameters and inhibiting microbial growth. Effects on enzymatic activity, antioxidant content, and microorganism inactivation (Denoya et al., 2023; Perinban et al., 2022; Segura-Ponce et al., 2018; Zhou et al., 2020) are reported for fresh-cut apples. Cold plasma treatments effectively inhibited mesophilic aerobic bacteria, yeast, and mould growth and proliferation during storage in minimally processed pears (Zhang et al., 2021). For different minimally processed matrices, a general behaviour can be described which has as its main effect the reduction of the bacterial load often combined with the maintenance of colour and nutritional characteristics both for fresh-cut fruit and vegetables (Li et al., 2019a; Li et al., 2019b; Mahnot et al., 2020; Rana et al., 2020; Yi et al., 2022; Zhou et al., 2022a) and fresh-cut leafy greens (Giannoglou et al., 2020; Liu et al., 2023; Silvetti et al., 2021; Sudarsan & Keener, 2022; Tan & Karwe, 2021). PAW application has been increasingly studied during the last few years. Avoiding the cell damage caused by direct exposure to cold plasma, this technique could represent a valuable alternative to the conventional washing solution during fresh-cut processing for several products. To date, the effects of PAW washing are reported for fresh-cut pears (Chen et al., 2019), fresh-cut apples (Liu et al., 2020; Perinban et al., 2022), fresh-cut kiwifruit (Zhao et al., 2019) and fresh-cut banana slices (Zhang et al., 2023, 2023b, 2023c), minimally processed green leafy vegetables (Abouelenein et al., 2023; Chamorro et al., 2023; Laurita et al., 2021; Schnabel

Table 4
The main application of cold plasma and plasma activated water (PAW) on minimally processed fruit and vegetables in the last five years.

Experimental condition	Food matrix	Effects	Reference
Dielectric barrier discharge plasma at 45 kV/1 min	Strawberries^{FC}	Plasma treatment was able to retain strawberry texture properties and inhibit microbial growth. It also promoted phenolics, flavonoids, and anthocyanins accumulation.	(Li et al., 2019a)
Dielectric barrier discharge cold plasma at 60 kV/5 min	Pitaya^{FC}	Cold plasma treatment significantly inhibited the growth of total aerobic bacterial counts, increased phenolic accumulation, and enhanced antioxidant activity in fresh-cut pitaya fruit.	Li et al. (2019b)
Double barrier discharge generated plasma for 30 and 60 min	Apples^{FC}	A noticeable reduction of superficial browning was observed in all cultivars. The effect on PPO activity was very variable, according to the cultivar considered.	Tappi et al. (2019)
Cold atmospheric dielectric barrier discharge plasma for 5, 10, 15, and 20 min	Rocket leafy salad^{RtU}	A reduction of microbial load from 0.57 to 1.02 log CFU g^{-1} was observed after processing times ranging from 5 to 20 min, with 10 min considered as optimum for a sufficient reduction of the microbial load while maintaining colour and texture.	Giannoglou et al. (2020)
Atmospheric double barrier discharge plasma at 60, 80, and 100 kV for 1, 2, 3, 4, and 5 min	Carrots^{FC}	About 2 $\log_{10}$ CFU g^{-1} reductions in the population of total aerobic mesophiles, yeast, and mould were observed in carrot discs treated at 100 kV for 5 min. Voltages between 80 and 100 kV and treatment times between 4 and 5 min are recommended to maximise the reduction in spoilage microflora and quality retention.	Mahnot et al. (2020)
Atmospheric cold plasma (ACP) at 60 kV for 10, 15 and 30 min	Strawberry^{RtU}	The shelf-life of ACP-treated strawberries was extended to 5 days at 25 °C and 9 days at 4 °C in a sealed ACP package. 15-min treatment resulted in a 2-log reduction of microbial load and enhanced the phenolic content and antioxidant activity. Total soluble solids, pH, and moisture were not affected.	Rana et al. (2020)
Gas phase surface discharge plasma (SDP) for 30, 60, 90, and 120 s	Apple^{FC}	Microbial load reduction of the fresh-cut apples was found to be strongly dependent on the storage time and preservation method, e.g. refrigeration (control), SDP-room temperature, and SDP-refrigeration (SDP-RF). After 6 d of storage, SDF-RF treated groups were found to have a significantly lower contamination level compared to the refrigeration-stored (4 °C) and the SDP-processed groups, with the lowest bacterial load on the 120 s SDP-RF stored apple pieces (1.76 CFU g^{-1}).	Zhou et al. (2020)
Atmospheric pressure plasma jet (APPJ) at 7.5 kV of applied voltage, 20 kHz of pulses frequency, and 20 L min^{-1} of air flow for 15 s	Salad^{FC}	APPJ induced a fast microbial decontamination (1.3 $\log_{10}$ CFU g^{-1}) of the salad surface and retarded bacterial growth during storage. No significant effects were observed on electrolyte leakage, pH, and dry matter content.	Silvetti et al. (2021)
Dielectric barrier discharge plasma-activated mist (PAM) for 5–20 min.	Purple lettuce, kale, and baby spinach leaves^{RtU}	The leaves were either dip-inoculated or spot-inoculated. The longer the PAM treatment time, the more microbial reduction on dip-inoculated leaves on purple lettuce, kale, and baby spinach leaves.	Tan and Karwe (2021)
Atmospheric double barrier discharge plasma for 1 or 5 min at 45 and 65 kV	Pears^{FC}	Treatments were effective in inhibiting the growth of mesophilic aerobic bacteria, yeast, and mould. Moreover, 65 kV/1 min treatment retard respiration and maintain organoleptic and quality properties. Peroxidase and pectin methylesterase activities were reduced immediately after treatments.	Zhang et al. (2021)
High voltage atmospheric cold plasma (HVACP) for 2 and 5 min	Baby spinach leaves^{RtU}	Up to 2.6 and 3.5, $\log_{10}$ CFU/sample of microbiota were eliminated until 7 days of refrigerated storage after 2 and 5 min of cold plasma exposure, respectively. A 5-min, indirect, 80 kV HVACP treatment showed no effect on the leaves texture profile, color, or moisture content.	Sudarsan and Keener (2022)
CP at 75 kV for 3 min using a dielectric barrier discharge (DBD) generator	Mango^{FC}	CP treatment could delay the loss of nutritional and organoleptic qualities by retaining physicochemical parameters while also	Yi et al. (2022)

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Table 4 (*continued*)

Experimental condition	Food matrix	Effects	Reference
		inhibiting microbial growth. The most important quality losses were reduced by CP treatment, which reduced the ROS-triggered membrane lipid peroxidation and the phenolic oxidation, enhancing the activity of antioxidant enzymes.	
CP at 40 kV/90 s	Cantaloupe^{FC}	Treatment significantly inhibited the growth and reproduction of bacteria and mould during 10 d storage. Fresh-cut cantaloupe showed higher quality and sensory attributes and flesh firmness. Floral- and fruity-note aromas were significantly enhanced.	(Zhou et al., 2022a)
In-package CP. Product exposure time: 0, 1, and 3 min; storage times were 1, 4, and 7 days.	Apple^{FC}	Cold plasma treatments within the storage bags could prolong the quality of the fruit over time, preserving the structure of the plant tissue. 1 min-exposure allowed to have the highest antioxidant content at day 1. PPO activity was reduced but not enough to stabilise the antioxidant properties of the product over storage time.	Denoya et al. (2023)
CP at 50 kV/30 s	Bamboo shoots^{FC}	CP-treated bamboo showed a higher firmness than control groups, and less yellowing occurrence was also observed for treated samples. Six key flavour compounds (odour activity value (OAV) > 1) were detected. 4-Hydroxybenzaldehyde was the most abundant compound, accounting for 45.53%–78.46% in bamboo shoots. As for flavour compounds, ester, aldehyde, and ketone content was enhanced by CP treatment, and alcohols and alkenes were reduced. Moreover, CP induced higher microbiological diversity within four days.	Liu et al. (2023)
PAW 6, 8, and 10 kV for 5 min	Pears^{FC}	All treatments significantly inhibited the growth of aerobic bacteria, yeast, and mould during storage, with the 8-kV PAW treatment maintaining the lowest growth rate. Treatment with 6-kV significantly slowed down the softening of fresh-cut pears, and 8-kV treatment reduced the mass loss and the total phenolic content ($P < 0.05$).	Chen et al. (2019)
Use of PPtW during washing steps, including pre-rinsing, pre-washing, main washing, and post-rinsing.	Endive lettuce^{FC}	Inactivation efficiency depends on the single or combined usage of PPtW at different steps of the washing process. The usage of PPtW at 3 different steps led to the highest reductions.	Schnabel et al. (2019)
Spraying with 1-mL PAW on each slice	Kiwifruit^{FC}	The microbial population was reduced by approximately 1.8 log CFU g^{-1} after the PAW treatment. The activities of superoxide dismutase, peroxidase, and catalase were improved.	Zhao et al. (2019)
20-min DBD treatment and 20-min PAW immersion	Shiitake mushroom^{W}	After 7 days of storage, the total bacteria count of PAW- and DBD-treated samples was 0.89 ± 0.01 and 0.6 ± 0.05 log CFU g^{-1} lower than those of control samples, respectively. Furthermore, both DBD and PAW treatments reduced the overall colour changes of samples, and PAW-treated samples had the highest firmness value.	Gavahian et al. (2020)
7.0 kHz with amplitudes of 6 kV, 8 kV (PAW-8), and 10 kV for 5 min	Apples^{FC}	Microorganisms growth was inhibited by PAW treatments during storage, especially the microbial inactivation with PAW-8. The bacterial counts of fresh-cut apples treated with PAW were<5 $\log_{10}$ CFU g^{-1} during 12 days of storage. PAW treatments reduced superficial browning without affecting firmness, titratable acidity, antioxidant content, and radical scavenging activity-	Liu et al. (2020)
Washing with PAW for 2, 5, 10 and 20 min	Rocket leaves^{RtU}	PAW allowed an average reduction of 1.7–3 Log CFU g^{-1} for total mesophilic and psychrotrophic bacteria and Enterobacteriaceae following 2–5 min washing with minimal variation of qualitative and nutritional parameters.	(Abouelenein et al., 2023; Laurita et al., 2021)
PAW at different activation times	Button mushrooms^{W}	The pH value, electrical conductivity, and	Zhao et al. (2021)

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Table 4 (*continued*)

Experimental condition	Food matrix	Effects	Reference
(15, 20, and 25 min) for 10 min		PAW's oxidation-reduction potential significantly depended on plasma activation time. The PAW treatment effectively inactivated *Escherichia coli* and delayed the browning process. 20-PAW-treated groups showed the highest firmness and total soluble solid content and the lowest browning index and relative electrical conductivity during the whole storage duration.	
PAW with activation times of 10 min, 20 min, 30 min, 45 min and 60 min, 5 min produce washing	Apples^{FC}	PAW treatments showed variable effects on enzyme activity. No significant changes in the total phenolic content and antioxidant activity were observed. 45 and 60 min activation had adverse effects on produce quality. Significant reductions in the total aerobic bacteria and total yeast and moulds were observed in 20, 30, 45, and 60 PAW treatments.	Perinban et al. (2022)
PAW was prepared using a frequency of 10 kHz and 200 Hz	Potato^{FC}	PAW was able to inactivate the enzyme related to browning occurrence, thus lowering the browning index. Moreover, PAW promoted phenolic synthesis and increased antioxidant activity in the treated sample. 200 Hz-PAW-treated samples showed the lowest weight loss, electrolyte leakage, and microbial loads during storage.	Aihaiti et al. (2023)
PAW immersion for 1 and 5 min	Lettuce^{FC}	PAW treatments slowed the chlorophyll degradation kinetics from day 3 of storage. As for microbiological aspects, mesophilic and psychrotroph bacteria and Enterobacteriaceae were lower in PAW-treated samples. Moreover, PAW treatments enhanced antioxidant capacity and total phenolic content.	Chamorro et al. (2023)
PAW treatment for 15 s, 30 s, 60 s and 90 s	Banana^{FC}	PAW treatments on banana slices increased intracellular reactive oxygen species and enhanced the activity of PPO while decreasing POD activity with positive effects on fruit colour and quality retention.	Zhang et al. (2023)
PAW treatment for 30 and 60 min	Chili^{W}	Reduction of 80% and 65% of carbendazim and chlorpyrifos after 30 and 60 min of PAW treatment, respectively. *E. coli* populations were reduced by 2.8 Log CFU g^{-1}. 100% of inhibition of fungal spore germination. PAW treatment demonstrated significantly higher efficiency in controlling Anthracnose in chili by about 83% compared to other treatments.	Sawangrat et al. (2022)

The superscript letters in the table indicate the following: *W* = fresh, whole unprocessed product, intended for storage; *RtU* = fresh ready-to-use product, unprocessed, intended for sale; *FC* = fresh-cut product, which has undergone minimal processing; P = processed fresh produce, reduced to puree or juice.

et al., 2019), fresh-cut potato (Aihaiti et al., 2023), mushrooms (Gavahian et al., 2020; Zhao et al., 2021), and chili (Sawangrat et al., 2022) (Table 4). Any PAW application significantly reduced the microbial load of fresh-cut produce without affecting quality parameters, showing a widespread potential for utilization.

2.5. Other technologies

The application of other physical preservation methods like UV irradiation, pulsed light, and ionizing radiation on fresh-cut fruits and vegetables aims to extend shelf life, ensure safety, and maintain quality. A selection of the most representative case studies concerning the application of these technologies on minimally processed products is reported to provide a comprehensive overview (Table S1). When implementing these technologies, it is crucial to consider the type of fruit or vegetable to be treated and its sensitivity, the optimization of treatment conditions, and aspects related to regulatory approval, cost-effectiveness, and scalability. Often, these methods are combined between them or with conventional postharvest treatments to achieve an improvement of their beneficial effects and better preservation outcomes.

UV irradiation uses ultraviolet light, typically UV-C (200–280 nm), to inactivate microorganisms by damaging their DNA and RNA. Consequently, its application aims to surface decontamination of fresh-cut fruits and vegetables and reduction of spoilage microorganisms and pathogens. When applied at appropriate intensities, this approach led to shelf life extension without the use of chemicals and minimal impact on sensory qualities (colour, texture, and flavour). However, it shows limited penetration depth, effectiveness only on exposed surfaces, and can damage the produce if overexposed.

Pulsed light application is based to the use of intense, short-duration pulses of UV, visible, or infrared light, to inactivate microorganisms on fresh-cut product surface. The benefits are represented by rapid treatment process and minimal thermal damage to the produce without residues. Limited penetration ability and high initial equipment cost are, conversely, the main disadvantages.

Disinfection effect on fresh produce can be also obtained using ionizing radiation, by means of gamma rays, electron beams, or X-rays application to disrupt the DNA of microorganisms, leading to their inactivation. Unlike other methods, it is capable of deep penetration, but it presents risks of acceptability by consumers due to misconceptions about irradiated foods, and it can potentially lower texture, flavour, and nutritional quality at higher doses.

The use of ultrasounds on fresh-cut products enhances food safety and quality by employing high-frequency sound waves to disrupt microbial cells, reduce spoilage, and extend shelf life without altering the produce's nutritional and sensory properties. Advantages include its effectiveness in maintaining freshness and non-thermal nature, thus preserving the product's natural characteristics. However, disadvantages include the potential high initial cost of ultrasound equipment and the need for precise control to avoid damaging the product's texture.

2.6. *Hurdle technology*

2.6.1. *General aspects*

The hurdle technology is represented by the combined application of several conventional and emerging preservation methods intending to provide a series of factors to achieve microbial safety and quality maintenance of the product (Fig. 2). '*Fit for purpose*' is the basis of this approach, promoting an approach that provides a tailored combination depending on the matrix and the problem to be managed, realizing advantage from the synergy of different agents that are not decisive individually (Mogren et al., 2018). In aiming to accomplish the final objective, which is to produce safe produce with adequate quality standards, "the deliberate and intelligent use of the combination of existing and novel preservation techniques to establish a series of preservative factors (hurdles) that any microorganisms present should not be able to overcome" (Aaliya et al., 2021). The most exploited hurdles in food preservation are high or low temperature, natural or synthetic preservatives, biocontrol microorganisms, and all the above can be combined with emerging mild physical treatments to contain the deleterious effect on product quality while increasing effectiveness by exploiting their synergic effect against undesired microbes (Bigi et al., 2023; Capozzi et al., 2009; De Simone et al., 2021). The individual hurdles may be applied simultaneously or sequentially, depending on the product type and its preservation method. The appropriate combination of hurdles may guarantee microbial safety and quality and the target organoleptic and nutritive parameters of the product (Tsironi, 2021).

2.6.2. *Postharvest application on fresh and minimally processed fruits and vegetables*

Several hurdle approaches can be used in fresh fruit and vegetable processing, and the main objective to be taken into consideration is to satisfy safety standards without compromising food quality and consumer health (Dabas & Khan, 2020). The proper choice of hurdles, their intensity, and their sequence will represent innovation for the future of minimally processed fruits and vegetables (Bigi et al., 2023), to reduce the intensity of the single techniques reaching similar effectiveness without detrimental effect on product freshness and quality. To effectively prolong the shelf-life of fresh horticultural products, mild heat treatments, chemicals, low-temperature storage, irradiation, and proper packaging could be applied. Since these commodities are 'ready-to-eat', the washing and sanitation steps are fundamental for the final food safety standards regarding fresh-cut fruits and vegetables. The hurdle technology objective is to remove pesticide residues, dirt, and foreign objects and reduce microbial load, thus avoiding quality degradation and spoilage (Aaliya et al., 2021; Bigi et al., 2023). This subparagraph briefly describes the main hurdles that included at least one emerging physical treatment and their effects on the quality and safety of fresh-cut fruits and vegetables (Table 5). Mainly, cold plasma and PAW have been utilized as innovative treatments on the hurdle technology approach in the postharvest field, complementing the conventional ones, such as packaging for cherry tomatoes (Bremenkamp et al., 2021), heating for ready-to-use kimchi cabbage (Choi et al., 2019) and grape (Xiang et al., 2020), ultrasound in blueberry (Wang & Wu, 2022). All the cited authors reported the significant effect of the combined treatment on microbial and pathogenic microorganisms load without deleterious effects on quality for the different types of fresh and minimally processed plant-based products studied. The combination often increases the efficiency of each treatment when applied on its own. Combination of low pressure HHP with dipping increased sanitation effect on fresh-cut broccoli combining it with cationic washing (Woo et al., 2019). PEF and ultrasound improve the quality of strawberry juice (Bebek Markovinovic et al., 2023). Finally, the combination of vacuum precooling of minimally processed leafy vegetables with modified atmosphere packaging during storage allowed to delay enzymatic browning (Wanakamol et al., 2022). The combination of emerging physical approaches with microbial biocontrol agents has been little explored in the relevant scientific literature. This field of study could be promising as physical treatment before inoculation could benefit the dominance of the biocontrol agent.

3. Final considerations and conclusions

Many traditional postharvest technologies can negatively impact the quality of fresh produce and/or affect the sustainability of processes. In recent years, there has been a spotlight on emerging innovative physical techniques designed to replace thermal treatments in order to reduce nutrient losses and enhance consumer acceptability. This comprehensive review delves into recent developments in postharvest technologies, focusing on their mode of action and their impact on the quality and safety attributes of both fresh and fresh-cut produce. Extensive analysis has been conducted on various techniques, including vacuum and hydrocooling, microwave heating, pulsed electric field, high hydrostatic pressure, and cold plasma application.

Each technique offers unique advantages and limitations, vacuum cooling, for instance, is relatively simple to implement and highly effective for leafy vegetables, but it can cause dehydration and is less effective for dense produce. Hydrocooling, while inexpensive and efficient for a variety of produce types, can lead to water wastage and the potential for contamination if the water quality is not properly managed. In contrast, microwave heating and PEF are more advanced techniques that offer significant improvements in microbial safety and enzyme inactivation. Microwave heating can quickly reduce microbial load and delay spoilage, but its application requires precise control to avoid

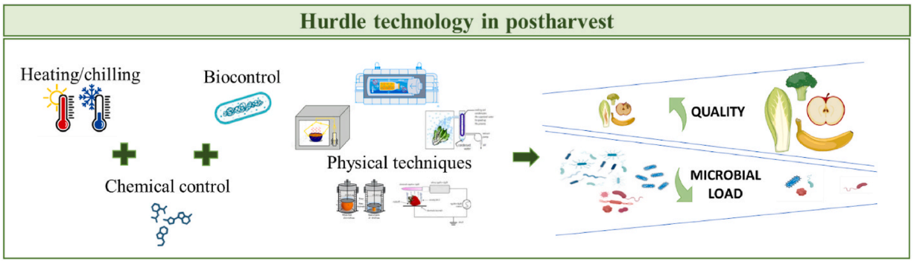

Fig. 2. Hurdle technology approach for fresh and minimally processed horticultural products.

Table 5
The main application of hurdle technology on fresh and minimally processed fruit and vegetables of the last ten years.

Hurdles applied	Experimental condition	Food matrix	Effects	Reference
Plasma-activated water (PAW) + Mild heating (MH)	30,60, and 120 min of plasma activation; heating at 60 ± 1 °C for 5 min	Kimchi cabbage$^{\mathrm{RtU}}$	Treatment with 120-PAW alone resulted in approx. 1/2 log CFU g^{-1} reduction in mesophiles, LAB, yeast and moulds, and coliforms. Subsequent MH treatment reduced the counts to below detection limits, significantly reducing *L. monocytogenes* and *S. aureus* inoculated in cabbage samples.	Choi et al. (2019)
High Hydrostatic Pressure (HHP) + Cationic Surfactant Washing	HHP: 400 MPa for 1, 3, and 5 min and 0.05% benzethonium chloride (BEC) washing	Broccoli$^{\mathrm{FC}}$	Combined treatment with HHP and BEC was more effective in removing *L. monocytogenes* from the product compared to the individual application of the studied technologies. Colour and total glucosinolate content were maintained after the combined treatment, while fresh-cut broccoli firmness slightly decreased.	Woo et al. (2019)
Plasma-activated water (PAW) + Mild heat	Mild heat (50, 52.5, and 55 °C, 30 min)	Grape$^{\mathrm{RtU}}$	The hurdle combination showed synergistic fungicidal activity against *S. cerevisiae* on grapes. Maximum inactivation was 5.85 $\log_{10}$ CFU g^{-1} after the PAW treatment at 55 °C for 30 min. No significant changes were observed in the physico-chemical attributes of treated grapes.	Xiang et al. (2020)
Cold plasma treatment + Equilibrium modified atmosphere packaging (EMAP) + Controlled temperature	Temperature: 10 and 20 °C	Cherry tomatoes$^{\mathrm{RtU}}$	Plasma treatment preserved the sensorial quality also favoring a reduction of microbial load on the product surface. Package presence prevented weight loss and changes in TSS, while a higher bacterial growth was detected. Plasma treatment before packing reduced it.	Bremenkamp et al. (2021)
Ultrasound (US) + In-package atmospheric cold plasma	Free chlorine [FC] at 10 ppm and peracetic acid [PAA] at 80 ppm were combined with low-frequency US (25 kHz) during washing, followed by in-package disinfection using dielectric barrier discharge cold plasma (CP).	Blueberry$^{\mathrm{RtU}}$	The combination of US-FC and US-PAA against *E. coli* O157:H7 and *S. typhimurium* was significantly more effective than the treatments alone. The highest disinfection efficacy of CP was observed at the pulse frequency range of 400–800 Hz. US-FC + CP, US-PAA + CP, US-FC, or US-PAA did not affect the quality of the product. Treatments lowered the reactive oxygen species content, suggesting that in-package cold plasma can activate the blueberry antioxidant system, thereby lowering the losses of quality.	Wang and Wu (2022)
Vacuum Precooling + Modified atmosphere packaging (MAP)	Precooling by decreasing pressure to 0.6 kPa for 5–7 min. MAP in PP packaging.	Leafy vegetables$^{\mathrm{FC}}$	Synergistic effects of the considered technologies can delay enzymatic browning, prolonging the product shelf life up to 9 days.	Wanakamol et al. (2022)
Pulsed Electric Field (PEF) + High-Power Ultrasound (HPU)	PEF 30 kV cm^{-1}, 100 Hz during 1.5, 3, and 4.5 min. HPU 25% amplitude and 50% pulse during 2.5, 5.0, and 7.5 min.	Strawberry juice$^{\mathrm{P}}$	Shorter treatment times allowed better stability of bioactive compounds and antioxidant activity of strawberry juice. Total phenols and hydroxycinnamic acids were the most stable compounds during treatment and storage, while flavonols and condensed tannins were most affected by the duration of the treatments.	Bebek Markovinovic et al. (2023)

The superscript letters in the table indicate the following: *W* = fresh, whole unprocessed product, intended for storage; *RtU* = fresh ready-to-use product, unprocessed, intended for sale; *FC* = fresh-cut product, which has undergone minimal processing; P = processed fresh produce, reduced to puree or juice.

overheating and potential texture damage. PEF, though effective in maintaining the nutritional and sensory attributes of fresh-cut produce, necessitates sophisticated equipment and can be energy-intensive, making it a less viable option for small-scale operations. Cold plasma technology represents a cutting-edge approach that effectively inactivates pathogens on produce surfaces without the use of chemicals or significant heat, thus preserving the produce's fresh-like quality. However, the high cost of plasma generation equipment and the need for specialized knowledge for safe and effective operation can be barriers to widespread adoption. HHP treatment stands out for its ability to uniformly treat produce without altering its physical structure, flavor, or nutritional content. It is highly effective at inactivating pathogens and spoilage organisms. Nevertheless, the initial investment in HHP equipment is substantial, and the technology requires a high level of technical expertise and operational control to ensure consistent results. Ultimately, the choice of technique depends on the specific type of produce, the desired shelf life, and quality attributes, as well as the economic and operational considerations of the processing facility. Traditional methods like vacuum cooling and hydrocooling are more accessible and economically feasible for many producers, whereas novel technologies such as microwave heating, PEF, cold plasma, and HHP offer superior microbial safety and quality retention, justifying their higher costs and complexity for high-value or highly perishable products.

The study highlights the effectiveness of these treatments in reducing microbial load while preserving the fresh-like and quality characteristics of a variety of horticultural products, in a matrix-dependent manner. Additionally, examples illustrating the application of hurdle technology to enhance synergistic effects by combining multiple techniques are provided. The general objective of the review is to sustain a comparative analysis considering that *i)* not all techniques are universally suitable for all products and *ii)* each technology has its limitations, dependent on the type of product and the intensity applied. From this point of view, an adequate comparative evaluation can promote the use of these emerging approaches by promoting sustainability in the management of resources, the consumption of fruit and vegetables, and reducing waste and production losses. However, it is critical to address some limitations and challenges associated with the application of cutting-edge physical techniques. While these technologies show promise, their scalability and economic feasibility remain significant concerns. Moreover, there is a need for further research to understand the long-term effects of these treatments on product quality and safety, as well as their impact on nutritional and sensory attributes over extended storage periods. The variability in the effectiveness of these techniques across different types of produce also describes the need for a tailored approach, adapting treatments to specific commodities, as well as validation and standardization processes. Addressing these issues through interdisciplinary research and collaboration between industry stakeholders, scientists, and policymakers will be crucial for the successful integration of these innovative technologies into conventional postharvest management practices. In particular, the design of tailored solutions for specific products and the development of solutions inspired by the concept of the 'hurdle' approach emerge from this review as strategic paths of interest for future research activities in this field.

Data availability

No data was used for the research described in the article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tifs.2024.104619.

References

Aaliya, B., Valiyapeediyekkal Sunooj, K., Navaf, M., Parambil Akhila, P., Sudheesh, C., Ahmed Mir, S., Sabu, S., Sasidharan, A., Theingi Hlaing, M., & George, J. (2021). Recent trends in bacterial decontamination of food products by hurdle technology: A synergistic approach using thermal and non-thermal processing techniques. *Food Research International, 147*, Article 110514. https://doi.org/10.1016/j.foodres.2021.110514

Abbas Syed, Q. (2017). Pulsed electric field technology in food preservation: A review. *Journal of Nutritional Health & Food Engineering, 6*(6), 168–172. https://doi.org/10.15406/jnhfe.2017.06.00219

Abouelenein, D., Mustafa, A. M., Nzekoue, F. K., Caprioli, G., Angeloni, S., Tappi, S., Castagnini, J. M., Dalla Rosa, M., & Vittori, S. (2023). The impact of plasma activated water treatment on the phenolic profile, vitamins content, antioxidant and enzymatic activities of rocket-salad leaves. *Antioxidants, 12*(1), 28. https://doi.org/10.3390/antiox12010028

Aihaiti, A., Maimaitiyiming, R., Wang, L., & Wang, J. (2023). Processing of fresh-cut potato using plasma-activated water prepared by decreasing discharge frequency. *Foods, 12*(12), 2285. https://doi.org/10.3390/foods12122285

Alabi, K. P., Fadeyibi, A., & Obateru, F. T. (2023). Magnetic field hydrocooling system: Effect of field intensities on the cooling characteristics of three different leavy vegetables. *Innovative Food Science and Emerging Technologies, 86*, Article 103347. https://doi.org/10.1016/j.ifset.2023.103347

Bagheri, H., & Abbaszadeh, S. (2020). Effect of cold plasma on quality retention of fresh-cut produce. *Journal of Food Quality*, 1–8. https://doi.org/10.1155/2020/8866369, 2020.

Barba, F. J., Parniakov, O., Pereira, S. A., Wiktor, A., Grimi, N., Boussetta, N., Saraiva, J. A., Raso, J., Martin-Belloso, O., Witrowa-Rajchert, D., Lebovka, N., & Vorobiev, E. (2015). Current applications and new opportunities for the use of pulsed electric fields in food science and industry. *Food Research International, 77*, 773–798. https://doi.org/10.1016/j.foodres.2015.09.015

Bebek Markovinovic, A., Stulc, V., Putnik, P., Birkic, A., Jambrovic, M., Šaško, D., Ljubicic, J., Pavlic, B., Herceg, Z. B., & Kovacević, D. (2023). Pulsed Electric Field (PEF) and High-Power Ultrasound (HPU) in the hurdle concept for the preservation of antioxidant bioactive compounds of strawberry juice — a chemometric evaluation — Part I. *Foods, 12*, 3172. https://doi.org/10.3390/foods12173172

Bigi, F., Maurizzi, E., Quartieri, A., De Leo, R., Gullo, M., & Pulvirenti, A. (2023). Non-thermal techniques and the "hurdle" approach: How is food technology evolving? *Trends in Food Science and Technology, 132*, 11–39. https://doi.org/10.1016/j.tifs.2022.12.015

Bremenkamp, I., Ramos, A. V., Lu, P., Patange, A., Bourke, P., & Sousa-Gallagher, M. J. (2021). Combined effect of plasma treatment and equilibrium modified atmosphere packaging on safety and quality of cherry tomatoes. *Future Foods, 3*. https://doi.org/10.1016/j.fufo.2021.100011

Bussiahn, R., Brandenburg, R., Gerling, T., Kindel, E., Lange, H., Lembke, N., … Kocher, T. (2010). The hairline plasma: An intermittent negative dc-corona discharge at atmospheric pressure for plasma medical applications. *Applied Physics Letters, 96*(14).

Capozzi, V., Fiocco, D., Amodio, M. L., Gallone, A., & Spano, G. (2009). Bacterial stressors in minimally processed food. *International Journal of Molecular Sciences, 10*(7), 3076–3105. https://doi.org/10.3390/ijms10073076

Castagnini, J. M., Iaccheri, E., Tylewicz, U., Dalla Rosa, M., & Rocculi, P. (2020). Pulsed electric fields effect on mechanical and sorption properties of dried apple tissue. *Innovative Food Science and Emerging Technologies, 65*. https://doi.org/10.1016/j.ifset.2020.102442

Chamorro, J. C., Denoya, G. I., Santamaria, B., Fina, B., Ferreyra, M., Cejas, E., Rodriguez, A., Vaudagna, S. R., & Prevosto, L. (2023). Effects of the plasma-activated water on the quality and preservation of fresh-cut lettuce. *IEEE Transactions on Plasma Science*, 1–11. https://doi.org/10.1109/TPS.2023.3297009

Chen, C., Liu, C., Jiang, A., Guan, Q., Sun, X., Liu, S., Hao, K., & Hu, W. (2019). The effects of cold plasma-activated water treatment on the microbial growth and antioxidant properties of fresh-cut pears. *Food and Bioprocess Technology, 12*(11), 1842–1851. https://doi.org/10.1007/s11947-019-02331-w

Choi, E. J., Park, H. W., Kim, S. B., Ryu, S., Lim, J., Hong, E. J., Byeon, Y. S., & Chun, H. H. (2019). Sequential application of plasma-activated water and mild heating improves microbiological quality of ready-to-use shredded salted kimchi cabbage (*Brassica pekinensis* L.). *Food Control, 98*(December 2018), 501–509. https://doi.org/10.1016/j.foodcont.2018.12.007

Colelli, G., Amodio, M. L., & de Chiara, M. L. V. (2021). Operating conditions for microwave application throughout production process to reduce microbial load of fresh-cut apples. *Acta Horticulturae, 1319*, 223–230. https://doi.org/10.17660/ActaHortic.2021.1319.26

Dabas, K., & Khan, K. A. (2020). Use of hurdle technology in processing of fruits and vegetables. In K. A. Khan, R. Megh, P. E. Goyal, & A. A. Kalne (Eds.), *Processing of fruits and vegetables—from farm to fork* (pp. 113–138). Oakville, ON, Canada: Apple Academic Press.

de Chiara, M. L. V., De Simone, N., Spano, G., Amodio, M. L., & Colelli, G. (2023). Effect of microwave mild heat treatment on postharvest quality of table grapes. *Advances in Horticultural Science, 37*(1), 33–40. https://doi.org/10.36253/ahsc-13908

De Simone, N., Capozzi, V., Amodio, M. L., Colelli, G., Spano, G., & Russo, P. (2021). Microbial-based biocontrol solutions for fruits and vegetables: Recent insight, patents, and innovative trends. *Recent Patents on Food, Nutrition & Agriculture, 12*(1), 3–18. https://doi.org/10.2174/2212798412666210125141117

De Simone, N., Pace, B., Grieco, F., Chimienti, M., Tyibilika, V., Santoro, V., Capozzi, V., Colelli, G., Spano, G., & Russo, P. (2020). *Botrytis cinerea* and table grapes: A review of the main physical, chemical, and bio-based control treatments in post-harvest. *Foods, 9*, 1139, 10.3390/foods9091138.

Denoya, G. I., Polenta, G. A., Apóstolo, N. M., Budde, C. O., Cristianini, M., & Vaudagna, S. R. (2022). High-pressure processing applied for enhancing the antioxidant content of minimally processed peaches. *International Journal of Food Science and Technology, 57*(1), 684–694. https://doi.org/10.1111/ijfs.15448

Denoya, G. I., Polenta, G. A., Apóstolo, N. M., Cejas, E., Fina, B., Chamorro, J. C., Ferreyra, M., Prevosto, L., & Vaudagna, S. R. (2023). Effect of in-package cold plasma treatments on the quality of minimally processed apples. *International Journal of Food Science and Technology, 58*(5), 2465–2475. https://doi.org/10.1111/ijfs.16387

Ding, P., & Mat, R. N. R. (2021). Hydro-cooling as means to retain fresh sweet corn ears quality. *Sains Malaysiana, 50*(12), 3593–3602. https://doi.org/10.17576/jsm-2021-5012-11

Faber, I., Rini, L., Schouteten, J. J., Bom Frøst, M., De Steur, H., & Perez-Cueto, F. J. A. (2024). The mediating role of barriers and trust on the intentions to consume plant-based foods in Europe. *Food Quality and Preference, 114*, Article 105101. https://doi.org/10.1016/J.FOODQUAL.2024.105101

Fan, X., & Wang, W. (2021). Quality of fresh and fresh-cut produce impacted by nonthermal physical technologies intended to enhance microbial safety. *Critical Reviews in Food Science and Nutrition, 62*(2), 362–382. https://doi.org/10.1080/10408398.2020.1816892

Fernández, M. V., Denoya, G. I., Agüero, M. V., Vaudagna, S. R., & Jagus, R. J. (2020). Quality preservation and safety ensurement of a vegetable smoothie by high-pressure processing. *Journal of Food Processing and Preservation, 44*(2), 1–9. https://doi.org/10.1111/jfpp.14326

Ganesan, A. R., Tiwari, U., Ezhilarasi, P. N., & Rajauria, G. (2021). Application of cold plasma on food matrices: A review on current and future prospects. *Journal of Food Processing and Preservation, 45*(1), 1–16. https://doi.org/10.1111/jfpp.15070

Garrido, Y., Tudela, J. A., & Gil, M. I. (2015). Comparison of industrial precooling systems for minimally processed baby spinach. *Postharvest Biology and Technology, 102*, 1–8. https://doi.org/10.1016/j.postharvbio.2014.12.003

Gavahian, M., Sheu, F. H., Tsai, M. J., & Chu, Y. H. (2020). The effects of dielectric barrier discharge plasma gas and plasma-activated water on texture, color, and bacterial characteristics of shiitake mushroom. *Journal of Food Processing and Preservation, 44*(1), 1–9. https://doi.org/10.1111/jfpp.14316

Giancaterino, M., & Jaeger, H. (2023). Impact of pulsed electric fields (PEF) treatment on the peeling ability of tomatoes and kiwifruits. *Frontiers in Food Science and Technology, 3*, 1–12. https://doi.org/10.3389/frfst.2023.1152111

Giannoglou, M., Stergiou, P., Dimitrakellis, P., Gogolides, E., Stoforos, N. G., & Katsaros, G. (2020). Effect of Cold Atmospheric Plasma processing on quality and shelf-life of ready-to-eat rocket leafy salad. *Innovative Food Science and Emerging Technologies, 66*, Article 102502. https://doi.org/10.1016/j.ifset.2020.102502

Gomes, B. A. F., Alexandre, A. C. S., de Andrade, G. A. V., Zanzini, A. P., Barros, H. E. A., dos Santos Ferraz e Silva, L. M., … Vilas Boas, E. V. B. (2023). Recent advances in processing and preservation of minimally processed fruits and vegetables: A review – Part 2: Physical methods and global market outlook. *Food Chemistry Advances, 2*, Article 100304. https://doi.org/10.1016/j.focha.2023.100304

González-Tejedor, G., Garre, A., Egea, J. A., Aznar, A., Artés-Hernández, F., & Fernández, P. S. (2023). Application of High Hydrostatic Pressure in fresh purple smoothie: Microbial inactivation kinetic modelling and qualitative studies. *Food Science and Technology International, 29*(4), 372–382. https://doi.org/10.1177/10820132221095607

Guo, J., Qin, D., Li, W., Wu, F., Li, L., & Liu, X. (2021). Inactivation of *Penicillium italicum* on kumquat via plasma-activated water and its effects on quality attributes. *International Journal of Food Microbiology, 343*, Article 109090. https://doi.org/10.1016/j.ijfoodmicro.2021.109090

Hu, X., Ma, T., Ao, L., Kang, H., Hu, X., Song, Y., & Liao, X. (2020). Effect of high hydrostatic pressure processing on textural properties and microstructural characterization of fresh-cut pumpkin (*Cucurbita pepo*). *Journal of Food Process Engineering, 43*(4). https://doi.org/10.1111/jfpe.13379

Hu, K., Peng, D., Wang, L., Liu, H., Xie, B., & Sun, Z. (2021). Effect of mild high hydrostatic pressure treatments on physiological and physicochemical characteristics and carotenoid biosynthesis in postharvest mango. *Postharvest Biology and Technology, 172*, Article 111381. https://doi.org/10.1016/j.postharvbio.2020.111381

Iaccheri, E., Castagnini, J. M., Dalla Rosa, M., & Rocculi, P. (2021). New insights into the glass transition of dried fruits and vegetables and the effect of pulsed electric field treatment. *Innovative Food Science & Emerging Technologies, 67*, Article 102566. https://doi.org/10.1016/j.ifset.2020.102566

Iaccheri, E., Castagnini, J. M., Tylewicz, U., & Rocculi, P. (2022). Modelling the mechanical properties and sorption behaviour of pulsed electric fields (PEF) treated carrots and potatoes after air drying for food chain management. *Biosystems Engineering, 223*, 53–60. https://doi.org/10.1016/j.biosystemseng.2021.09.011

Karoney, E. M., Molelekoa, T., Bill, M., Siyoum, N., & Korsten, L. (2024). Global research network analysis of fresh produce postharvest technology: Innovative trends for loss reduction. *Postharvest Biology and Technology, 208*, Article 112642. https://doi.org/10.1016/J.POSTHARVBIO.2023.112642

Kongwong, P., Boonyakiat, D., & Poonlarp, P. (2019). Postharvest Biology and Technology Extending the shelf life and qualities of baby cos lettuce using commercial precooling systems. *Postharvest Biology and Technology, 150*, 60–70. https://doi.org/10.1016/j.postharvbio.2018.12.012

Koo, A., Chew, D. X., Ghate, V., & Zhou, W. (2023). Residual polyphenol oxidase and peroxidase activities in high pressure processed bok choy (*Brassica rapa* subsp. *chinensis*) juice did not accelerate nutrient degradation during storage. *Innovative Food Science and Emerging Technologies, 84*, Article 103284. https://doi.org/10.1016/j.ifset.2023.103284

Koutchma, T., Popović, V., Ros-Polski, V., & Popielarz, A. (2016). Effects of ultraviolet light and high-pressure processing on quality and health-related constituents of fresh juice products. *Comprehensive Reviews in Food Science and Food Safety, 15*(5), 844–867. https://doi.org/10.1111/1541-4337.12214

Kundukulangara Pulissery, S., Kallahalli Boregowda, S., Suseela, S., & Jaganath, B. (2021). A comparative study on the textural and nutritional profile of high pressure and minimally processed pineapple. *Journal of Food Science and Technology, 58*(10), 3734–3742. https://doi.org/10.1007/s13197-020-04831-6

Laurita, R., Gozzi, G., Tappi, S., Capelli, F., Bisag, A., Laghi, G., Gherardi, M., Cellini, B., Abouelenein, D., Vittori, S., Colombo, V., Rocculi, P., Dalla Rosa, M., & Vannini, L. (2021). Effect of plasma activated water (PAW) on rocket leaves decontamination and nutritional value. *Innovative Food Science and Emerging Technologies, 73*, Article 102805. https://doi.org/10.1016/j.ifset.2021.102805

Li, M., Li, X., Han, C., Ji, N., Jin, P., & Zheng, Y. (2019). Physiological and Metabolomic Analysis of cold plasma treated fresh-cut strawberries. *Journal of Agricultural and Food Chemistry, 67*(14), 4043–4053. https://doi.org/10.1021/acs.jafc.9b00656

Li, X., Li, M., Ji, N., Jin, P., Zhang, J., Zheng, Y., Zhang, X., & Li, F. (2019). Cold plasma treatment induces phenolic accumulation and enhances antioxidant activity in fresh-cut pitaya (*Hylocereus undatus*) fruit. *Lwt, 115*, Article 108447. https://doi.org/10.1016/j.lwt.2019.108447

Li, J., Shi, J., Huang, X., Wang, T., Zou, X., Li, Z., Zhang, D., Zhang, W., & Xu, Y. (2020). Effects of pulsed electric field pretreatment on frying quality of fresh-cut lotus root slices. *LWT-Food Science & Technology, 132*, Article 109873. https://doi.org/10.1016/j.lwt.2020.109873

Li, Z., Yang, H., Fang, W., Huang, X., Shi, J., & Zou, X. (2023). Effects of variety and pulsed electric field on the quality of fresh-cut apples. *Agriculture, 13*(5), 929. https://doi.org/10.3390/agriculture13050929

Liu, C., Chen, C., Jiang, A., Sun, X., Guan, Q., & Hu, W. (2020). Effects of plasma-activated water on microbial growth and storage quality of fresh-cut apple. *Innovative Food Science and Emerging Technologies, 59*, Article 102256. https://doi.org/10.1016/j.ifset.2019.102256

Liu, D., Wang, F., Xiao, G., Brennan, C., Ying, X., Bu, Z., & Ma, L. (2023). Effects of cold plasma treatment on maintaining the quality of fresh-cut bamboo shoots during shelf-life storage. *Lwt, 185*, Article 115151. https://doi.org/10.1016/j.lwt.2023.115151

López-Gámez, G., Elez-Martínez, P., Martín-Belloso, O., & Soliva-Fortuny, R. (2020a). Enhancing phenolic content in carrots by pulsed electric fields during post-treatment time: Effects on cell viability and quality attributes. *Innovative Food Science and Emerging Technologies, 59*, Article 102252. https://doi.org/10.1016/j.ifset.2019.102252

López-Gámez, G., Elez-Martínez, P., Martín-Belloso, O., & Soliva-Fortuny, R. (2020b). Pulsed electric fields affect endogenous enzyme activities, respiration and biosynthesis of phenolic compounds in carrots. *Postharvest Biology and Technology, 168*, Article 111284. https://doi.org/10.1016/j.postharvbio.2020.111284

López-Gámez, G., Elez-Martínez, P., Martín-Belloso, O., & Soliva-Fortuny, R. (2021). Changes of carotenoid content in carrots after application of pulsed electric field treatments. *LWT-Food Science & Technology, 147*, Article 111408. https://doi.org/10.1016/j.lwt.2021.111408

Mahajan, K., Gupta, S. K., Sharma, S. R., Singh, N. P., & Kanojia, V. (2023). Evaluation of precooling methods for shelf-life enhancement of pear (*Pyrus* spp.) fruits under ambient storage. *Indian Journal of Agricultural Sciences, 93*(1), 116–118. https://doi.org/10.56093/ijas.v93i1.130140

Mahnot, N. K., Siyu, L. P., Wan, Z., Keener, K. M., & Misra, N. N. (2020). In-package cold plasma decontamination of fresh-cut carrots: Microbial and quality aspects. *Journal of Physics D: Applied Physics, 53*(15), Article 154002. https://doi.org/10.1088/1361-6463/ab6cd3

Martínez-Hernández, G. B., Amodio, M. L., de Chiara, M. L. V., Russo, P., & Colelli, G. (2017). Microbial inactivations with hydrolysed lactoferrin and other natural antimicrobials in fresh-cut fennel. *LWT - Food Science and Technology, 84*, 353–358. https://doi.org/10.1016/j.lwt.2017.05.079

Mogren, L., Windstam, S., Boqvist, S., Vågsholm, I., Söderqvist, K., Rosberg, A. K., Lindén, J., Mulaosmanovic, E., Karlsson, M., Uhlig, E., Håkansson, Å., Alsanius, B., & Holden, N. (2018). The hurdle approach – a holistic concept for controlling food safety risks associated with pathogenic bacterial contamination of leafy green vegetables . a review. *Frontiers in Microbiology, 9*, 1–20. https://doi.org/10.3389/fmicb.2018.01965

Niemira, B. A., & Gutsol, A. (2011). Nonthermal plasma as a novel food processing technology. In H. Q. Zhang, G. V. Barbosa-Cánovas, V. M. Bala Balasubramaniam, C. P. Dunne, D. F. Farkas, & J. T. C. Yuan (Eds.), *Non-thermal processing technologies for food* (pp. 271–288). Wiley- Blackwell publishing.

Oliveira, E. De, Sena, A., Silas, P., Grazielle, H., Araujo, S. De, Crystiane, M., Batista, D. A., Nogueira, P., Alonso, S., Fernando, L., Oliveira, G. De, Augusto, M., & Carnelossi, G. (2019). Postharvest quality of cashew apple after hydrocooling and coold room. *Postharvest Biology and Technology, 155*, 65–71. https://doi.org/10.1016/j.postharvbio.2019.05.002

Onyeaka, H., Ghosh, S., Obileke, K., Miri, T., Odeyemi, O. A., Nwaiwu, O., & Tamasiga, P. (2024). Preventing chemical contaminants in food: Challenges and prospects for safe and sustainable food production. *Food Control, 155*, Article 110040. https://doi.org/10.1016/J.FOODCONT.2023.110040

Paciulli, M., Ganino, T., Gabriela, I., Meza, M., Rinaldi, M., Rodolfi, M., Morbarigazzi, M., & Chiavaro, E. (2021). High pressure and thermal processing on the quality of zucchini slices. *European Food Research and Technology, 247*(2), 475–484. https://doi.org/10.1007/s00217-020-03640-7

Paciulli, M., Medina Meza, I. G., Rinaldi, M., Ganino, T., Pugliese, A., Rodolfi, M., Barbanti, D., Morbarigazzi, M., & Chiavaro, E. (2019). Improved physicochemical and structural properties of blueberries by high hydrostatic pressure processing. *Foods, 8*(7), 272. https://doi.org/10.3390/foods8070272

Paciulli, M., Rinaldi, M., Rodolfi, M., Ganino, T., Morbarigazzi, M., & Chiavaro, E. (2019). Effects of high hydrostatic pressure on physico-chemical and structural properties of two pumpkin species. *Food Chemistry, 274*, 281–290. https://doi.org/10.1016/j.foodchem.2018.09.021

Palumbo, M., Attolico, G., Capozzi, V., Cozzolino, R., Corvino, A., de Chiara, M. L. V., Pace, B., Pelosi, S., Ricci, I., Romaniello, R., & Cefola, M. (2022). Emerging postharvest technologies to enhance the shelf-life of fruit and vegetables: An overview. *Foods, 11*(23), 1–29. https://doi.org/10.3390/foods11233925

Pan, Y., & Jun-Hu Cheng, D.-W. S. (2019). Cold plasma-mediated treatments for shelf life extension of fresh produce: A review of recent research developments. *Comprehensive Reviews in Food Science and Food Safety, 18*(5), 1312–1326. https://doi.org/10.1111/1541-4337.12474

Perinban, S., Orsat, V., & Raghavan, V. (2022). Influence of plasma activated water treatment on enzyme activity and quality of fresh-cut apples. *Food Chemistry, 393*, Article 133421. https://doi.org/10.1016/j.foodchem.2022.133421

Raj, P., Boulet, C., Yildiz, S., Sablani, S., Tang, J., Barbosa-c, G. V., Nationale, E., Agronomie, S. D., & Alimentaires, I. (2022). Effect of high hydrostatic pressure on microbial inactivation and quality changes in carrot-orange juice blends at varying pH. *LWT - Food Science and Technology, 159*, Article 113219. https://doi.org/10.1016/j.lwt.2022.113219

Ramos-Parra, P. A., García-Salinas, C., Rodríguez-López, C. E., García, N., García-Rivas, G., Hernández-Brenes, C., & Díaz de la Garza, R. I. (2019). High hydrostatic pressure treatments trigger de novo carotenoid biosynthesis in papaya fruit (*Carica papaya* cv. Maradol). *Food Chemistry, 277*, 362–372. https://doi.org/10.1016/j.foodchem.2018.10.102

Rana, S., Mehta, D., Bansal, V., Shivhare, U. S., & Yadav, S. K. (2020). Atmospheric cold plasma (ACP) treatment improved in-package shelf-life of strawberry fruit. *Journal of Food Science and Technology, 57*(1), 102–112. https://doi.org/10.1007/s13197-019-04035-7

Ribas-Agustí, A., Martín-Belloso, O., Soliva-Fortuny, R., & Elez-Martínez, P. (2019). Enhancing hydroxycinnamic acids and flavan-3-ol contents by pulsed electric fields without affecting quality attributes of apple. *Food Research International, 121*, 433–440. https://doi.org/10.1016/j.foodres.2018.11.057

Rinaldi, M., Dhenge, R., Rodolfi, M., Bertani, G., Bernini, V., Dall'Acqua, S., & Ganino, T. (2023). Understanding the impact of high-pressure treatment on physico-chemical, microstructural, and microbiological aspects of pumpkin cubes. *Foods, 12*(6), 1280. https://doi.org/10.3390/foods12061280

Rux, G., Gelewsky, R., Schlüter, O., & Herppich, W. B. (2020). High hydrostatic pressure treatment effects on selected tissue properties of fresh horticultural products. *Innovative Food Science and Emerging Technologies, 61*, Article 102326. https://doi.org/10.1016/j.ifset.2020.102326

Sawangrat, C., Phimolsiripol, Y., Leksakul, K., Thanapornpoonpong, S. N., Sojithamporn, P., Lavilla, M., Castagnini, J. M., Barba, F. J., & Boonyawan, D. (2022). Application of pinhole plasma jet activated water against *Escherichia coli, Colletotrichum gloeosporioides*, and decontamination of pesticide residues on chili (*Capsicum annuum* L.). *Foods, 11*(18), 2859. https://doi.org/10.3390/foods11182859

Schnabel, U., Andrasch, M., Stachowiak, J., Weit, C., Weihe, T., Schmidt, C., Muranyi, P., Schlüter, O., & Ehlbeck, J. (2019). Sanitation of fresh-cut endive lettuce by plasma processed tap water (PPtW) – up-scaling to industrial level. *Innovative Food Science and Emerging Technologies, 53*, 45–55. https://doi.org/10.1016/j.ifset.2017.11.014

Segura-Ponce, L. A., Reyes, J. E., Troncoso-Contreras, G., & Valenzuela-Tapia, G. (2018). Effect of low-pressure cold plasma (LPCP) on the wettability and the inactivation of *Escherichia coli* and *Listeria innocua* on fresh-cut apple (Granny Smith) skin. *Food and Bioprocess Technology, 11*(5), 1075–1086. https://doi.org/10.1007/s11947-018-2079-4

Silvetti, T., Pedroni, M., Brasca, M., Vassallo, E., Cocetta, G., Ferrante, A., De Noni, I., Piazza, L., & Morandi, S. (2021). Assessment of possible application of an atmospheric pressure plasma jet for shelf life extension of fresh-cut salad. *Foods, 10* (3), 1–13. https://doi.org/10.3390/foods10030513

Sudarsan, A., & Keener, K. (2022). Inactivation of spoilage organisms on baby spinach leaves using high voltage atmospheric cold plasma (HVACP) and assessment of quality. *Innovative Food Science and Emerging Technologies, 79*, Article 103023. https://doi.org/10.1016/j.ifset.2022.103023

Tan, J., & Karwe, M. V. (2021). Inactivation of *Enterobacter aerogenes* on the surfaces of fresh-cut purple lettuce , kale , and baby spinach leaves using plasma activated mist (PAM). *Innovative Food Science and Emerging Technologies, 74*, Article 102868. https://doi.org/10.1016/j.ifset.2021.102868

Tappi, S., Ragni, L., Tylewicz, U., Romani, S., Ramazzina, I., & Rocculi, P. (2019). Browning response of fresh-cut apples of different cultivars to cold gas plasma treatment. *Innovative Food Science and Emerging Technologies, 53*, 56–62. https://doi.org/10.1016/j.ifset.2017.08.005

Tomar, M. S., & Pradhan, R. C. (2023). Effect of hydro and cold room pre-cooling on cooling kinetics and post-harvest quality of amla. *Journal of Scientific & Industrial Research, 82*, 899–905. https://doi.org/10.56042/jsir.v82i08.1315

Tsironi, M. C. (2021). The hurdle effect of osmotic pretreatment and high-pressure cold pasteurisation on the shelf-life extension of fresh-cut tomatoes. Giannakourou and Theofania N., T. *Foods, 10*, 830. https://doi.org/10.3390/foods10040830Academic

Tylewicz, U., Mannozzi, C., Castagnini, J. M., Genovese, J., Romani, S., Rocculi, P., & Dalla Rosa, M. (2022). Application of PEF-and OD-assisted drying for kiwifruit waste valorisation. *Innovative Food Science & Emerging Technologies, 77*, Article 102952.

Usall, J., Ippolito, A., Sisquella, M., & Neri, F. (2016). Physical treatments to control postharvest diseases of fresh fruits and vegetables. *Postharvest Biology and Technology, 122*, 30–40. https://doi.org/10.1016/j.postharvbio.2016.05.002

Vanga, S. K., Wang, J., Jayaram, S., & Raghavan, V. (2021). Effects of pulsed electric fields and ultrasound processing on proteins and enzymes: A review. *Processes, 9*(4), 1–16. https://doi.org/10.3390/pr9040722

Wanakamol, W., Kongwong, P., Chuamuangphan, C., Bundhurat, D., Boonyakiat, D., & Poonlarp, P. (2022). Hurdle approach for control of enzymatic browning and extension of shelf life of fresh-cut leafy vegetables using vacuum precooling and modified atmosphere packaging: Commercial application. *Horticulturae, 8*(8), 745. https://doi.org/10.3390/horticulturae8080745

Wang, C. Y., Huang, H. W., Hsu, C. P., & Yang, B. B. (2016). Recent advances in food processing using high hydrostatic pressure technology. *Critical Reviews in Food Science and Nutrition, 56*(4), 527–540. https://doi.org/10.1080/10408398.2012.745479

Wang, J., & Wu, Z. (2022). Combined use of ultrasound-assisted washing with in-package atmospheric cold plasma processing as a novel non-thermal hurdle technology for ready-to-eat blueberry disinfection. *Ultrasonics Sonochemistry, 84*, Article 105960. https://doi.org/10.1016/j.ultsonch.2022.105960

Wang, J., Zhang, L., Shi, J., Vanga, S. K., & Raghavan, V. (2023). Effect of microwave processing on the nutritional properties and allergenic potential of kiwifruit. *Food Chemistry, 401*, Article 134189. https://doi.org/10.1016/j.foodchem.2022.134189

Woo, H. J., Park, J. B., Kang, J. H., Chun, H. H., & Song, K. B. (2019). Combined treatment of high hydrostatic pressure and cationic surfactant washing to inactivate *Listeria monocytogenes* on fresh-cut broccoli. *Journal of Microbiology and Biotechnology, 29*(8), 1240–1247. https://doi.org/10.4014/JMB.1906.06006

Xiang, Q., Zhang, R., Fan, L., Ma, Y., Wu, D., Li, K., & Bai, Y. (2020). Microbial inactivation and quality of grapes treated by plasma-activated water combined with mild heat. *LWT-Food Science & Technology, 126*(136), Article 109336. https://doi.org/10.1016/j.lwt.2020.109336

Yi, F., Wang, J., Xiang, Y., Yun, Z., Pan, Y., Jiang, Y., & Zhang, Z. (2022). Physiological and quality changes in fresh-cut mango fruit as influenced by cold plasma. *Postharvest Biology and Technology, 194*, Article 112105. https://doi.org/10.1016/j.postharvbio.2022.112105

Younis, M., Ahmed, I. A. M., Ahmed, K. A., Yehia, H. M., Abdelkarim, D. O., Fickak, A., El-Abedein, A. I. Z., Alhamdan, A., & Elfeky, A. (2023). Pulsed electric field as a novel technology for fresh barhi date shelf-life extension: Process optimization using response surface methodology. *Horticulturae, 9*(2), 155. https://doi.org/10.3390/horticulturae9020155

Zhang, T., Zhang, Q., Lei, Y., Yu, X., & Jiang, H. (2023). Plasma activated water on improving the quality of fresh-cut banana slices. *Postharvest Biology and Technology, 201*, Article 112360. https://doi.org/10.1016/j.postharvbio.2023.112360

Zhang, Y., Zhang, W., Wu, W., Farag, M. A., Wang, L., Xiao, S., Gao, H., & Weibo Jiang, C. (2023). Critical assessment of the delivery methods of chemical and natural postharvest preservatives for fruits and vegetables: A review. *Critical Reviews in Food Science and Nutrition*, 1–23. https://doi.org/10.1080/10408398.2023.2289071

Zhang, Y., Zhang, J., Zhang, Y., Hu, H., Luo, S., Zhang, L., Zhou, H., & Li, P. (2021). Effects of in-package atmospheric cold plasma treatment on the qualitative, metabolic and microbial stability of fresh-cut pears. *Journal of the Science of Food and Agriculture, 101*(11), 4473–4480. https://doi.org/10.1002/jsfa.11085

Zhang, C., Zhou, P., Mei, J., & Xie, J. (2023). Effects of different pre-cooling methods on the shelf life and quality of sweet corn (*Zea mays* L.). *Plants, 12*(12), 2370. https://doi.org/10.3390/plants12122370

Zhao, Y., Chen, R., Liu, D., Wang, W., Niu, J., Xia, Y., Qi, Z., Zhao, Z., & Song, Y. (2019). Effect of nonthermal plasma-activated water on quality and antioxidant activity of fresh-cut kiwifruit. *IEEE Transactions on Plasma Science, 47*(11), 4811–4817. https://doi.org/10.1109/TPS.2019.2904298

Zhao, Z., Wang, X., & Ma, T. (2021). Properties of plasma-activated water with different activation time and its effects on the quality of button mushrooms (*Agaricus bisporus*). *Lebensmittel-Wissenschaft und -Technologie, 147*, Article 111633. https://doi.org/10.1016/j.lwt.2021.111633

Zhou, D., Li, T., Cong, K., Suo, A., & Wu, C. (2022). Influence of cold plasma on quality attributes and aroma compounds in fresh-cut cantaloupe during low temperature storage. *LWT-Food Science & Technology, 154*, Article 112893. https://doi.org/10.1016/j.lwt.2021.112893

Zhou, L., Tey, C. Y., Bingol, G., Balaban, M. O., & Cai, S. (2022). Effect of different microwave power levels on inactivation of PPO and PME and also on quality changes of peach puree. *Current Research in Food Science, 5*, 41–48. https://doi.org/10.1016/j.crfs.2021.12.006

Zhou, R., Zhou, R., Mai-Prochnow, A., Zhang, X., Xian, Y., Cullen, P. J., & Ostrikov, K. (2020). Surface plasma discharges for the preservation of fresh-cut apples: Microbial inactivation and quality attributes. *Journal of Physics D: Applied Physics, 53*(17), Article 174003. https://doi.org/10.1088/1361-6463/ab6f8f