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Review

Heat Treatment: Effect on the Quality and Shelf Life of Minimally Processed Vegetables

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Abstract

Fresh-cut vegetables are perishable products, that are prone to rapid physiological and microbiological degradation, leading to a deterioration in appearance, a decline in organoleptic and nutritional properties, and increased losses. Heat treatment applied before or after minimal processing can mitigate these changes, but protocols vary widely in temperature, duration and medium (hot water, hot air, steam), depending on the type of vegetable. This review compiles and organizes studies on the quality and shelf life stability of heat-treated fresh-cut vegetables. A description of the genetic, metabolic, and physiological changes—based on numerous studies—provides an insight into the mechanism by which fresh-cut vegetables respond to thermal shock. Studies combining heat treatment with other physical or chemical methods are also reviewed. In most studies, hot water was used as the heat transfer medium, and the most commonly used parameters for post-cutting treatment were temperatures ranging from 45 to 60 °C and durations of 1 to 3 min. Pre-cutting treatment generally required a higher temperature or a longer treating time. However, while heat treatment improves the stability of fresh-cut vegetables, it does not always eliminate food-borne pathogens. This indicates that inactivating wound-induced enzymes and improving microbiological safety are separate challenges in the treatment of fresh-cut vegetables. Currently, there are no uniform standards regarding the temperature and duration for specific groups of vegetables or even individual species.

Keywords: fresh-cut vegetables; postharvest heat treatment; combined treatments; heat stress; shelf life; sensory quality

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1. Introduction

Toward the end of the 20th century, the demand for minimally processed fruits and vegetables increased sharply, driven by the growing popularity of fast-food restaurants and consumers' increasing interest in ready-to-eat products. Like whole vegetables and fruit, minimally processed products remain metabolically active and undergo biochemical and physiological changes. However, even minor processing steps, such as peeling, trimming, slicing, shredding, and chopping, damage living tissue and accelerate respiration, ethylene production, and enzyme activity. This leads to rapid wilting, discoloration, aging, and rotting [1–3].

The browning of the cut surface is the main problem with many species after minimal processing. The activation of polyphenol oxidase (PPO) and peroxidase (POD) causes the oxidation of polyphenols, which leads to the formation of alpha-quinone and subsequently to the creation of melanins (dark/brown pigments) in damaged tissue [4]. According to Yuan et al. [5], plant cell membranes are a key structural factor influencing the enzymatic

browning of fresh-cut plant products. Most phenolic compounds are stored in vacuoles; when vegetables are cut, the loss of cellular compartmentalization allows direct contact between the enzymes (PPO and POD) and the phenols, leading to oxidation [4]. After minimal processing, there is a sudden surge in phenylalanine ammonia-lyase (PAL) activity, a key enzyme in the primary phenolic pathway. This leads to the increased synthesis and accumulation of a new phenolic compound and thus to increased oxidation and the formation of brown pigments [4,6].

Cutting accelerates the loss of firmness, which results from damage to the cells, particularly the middle layer of the cell wall [7]. This is mainly due to an increase in ethylene production and the activation of hydrolases such as pectin polygalacturonase (PG), pectin methylesterase (PME), glucanase, and galactosidase. These enzymes accelerate the hydrolysis of pectin substances in the cell wall, causing tissue softening [1,8,9].

Contamination with human pathogens poses a particular threat, which explains why research has focused on improving the safety of fresh-cut vegetables. Cutting promotes the growth of various microorganisms by releasing nutrients, including sugars and amino acids [10].

Optimal storage conditions include low temperature (0–5 °C) and high relative humidity (close to 100%). However, during transport, the temperature is usually around 10 °C and the humidity is lower than optimal [11]. Retail display conditions also often involve higher-than-recommended temperatures and lower humidity levels.

Heat treatment (HT) has been studied for years in the context of the postharvest storage of fruits and vegetables [12,13]. This involves the application of heat under controlled conditions to achieve a desired effect such as extending shelf life and facilitating the management of horticultural products during storage and trade. Heat treatment induces heat shock (HS) in plant tissue. This is a physiological response to relatively high temperatures that triggers the plant's natural defense mechanisms. HT is an environmentally friendly approach that can be applied by immersion in hot water (HWT) or exposure to hot vapor (HVT) or hot dry air (HAT). Water is the preferred medium because it transfers heat more than air [14–16]. HWT is already a well-known technology used for intact vegetables and fruit, such as tomatoes, peppers, sweet corn, melon, mango, and citrus fruit [17].

The aim of this review is to summarize progress in determining the impact of HT on the quality and shelf life of fresh-cut vegetables. As an environmentally safe method, HT can help reduce quantitative and qualitative losses and extend storability and the marketing period. This review discusses the mechanism of HS in plant tissues and its effect on the storage life of fresh-cut vegetables. A significant contribution of this review is the comparison of groups of fresh-cut vegetables, the distinction between pre- and post-cutting treatments, and the synthesis of results regarding quality and microbial contamination. The review also presents the responses of sliced vegetables to HT in combination with other technologies. Studies synthesizing the influence of HT on quality and microbial outcomes across different groups of vegetables are presented in a descriptive and tabular form.

2. Literature Search Strategy and Selection Criteria

This narrative review is based on the literature identified through searches of Scopus and PubMed. The searches combined terms related to the product (fresh-cut and minimally processed vegetables) with terms related to the treatment methods (heat treatment, hot water treatment, hot air treatment, steam treatment). In addition, the same product–treatment logic was applied to the names of individual vegetables to include records indexed under terms referring to specific species that would not appear in a general search.

The strategy was exploratory and iterative in nature: it was refined as thematic categories that emerged during the selection process—protocol parameters, physiological

responses, and quality outcomes for specific vegetable groups. The searches were conducted between January and 1 August 2026, during which the first and final versions of the manuscript were prepared. Records were considered eligible if they appeared in the literature no earlier than 2000 and if they were peer-reviewed original research articles or conference papers addressing the application of heat treatment to fresh-cut or minimally processed vegetables, including studies combining heat treatment with other physical or chemical methods. Records were excluded if they dealt exclusively with fruit crops rather than vegetables or if their data were too general to be assigned to a specific vegetable group, heat-treatment protocol, or quality outcome. Screening and full-text review yielded 109 references for inclusion in the reference list.

Additional searches were conducted during manuscript preparation to verify specific mechanisms of response to heat shock—for example, the role of signaling molecules, transcriptomic data, and metabolomic activity. These searches were intended to supplement the sections of the review devoted to mechanisms rather than to expand the core list of sources and were not considered a separate strand of systematic searching. The final reference list contained 155 entries.

Because the review was narrative rather than systematic, no formal risk-of-bias assessment or meta-analysis was performed; the aim was to synthesize and organize the available evidence by vegetable group and protocol type, not to provide a quantitative pooled estimate.

3. Defense Response in Plant Tissue Triggered by Heat Stress

Heat treatment stimulates the defense responses of plant tissue to abiotic stress by altering gene transcription, which is associated with changes in the expression of RNA molecules synthesized from the DNA template [18].

Under certain conditions—depending on the temperature and duration of the treatment—these defense mechanisms also mitigate the negative effects of stress caused by the minimal processing of vegetables. For both fresh-cut and whole vegetables, the first response to thermal stress is the release of signaling molecules, including: calcium ions (Ca^{2+}), reactive oxygen species (ROS), nitric oxide (NO), hydrogen sulfide (H_2S), and abscisic acid (ABA) [19,20]. These molecules interact with one another to trigger reactions designed to protect plant cells from the damage caused by high temperatures. Ca^{2+} ions begin to flow from cell walls and internal organelles into the cytosol, where a wave is generated that affects neighboring cells, thereby converting external stimuli into signals that plants can interpret internally. Transcription factors are activated and decode Ca^{2+} complexes. This enables the recognition of gene sequences and changes in their expression, which in turn leads to metabolic changes in plant tissues [21]. ROS are generated during heat stress by respiratory burst oxidase homologs B (RbohB) and D (RbohD). These signaling molecules trigger the plant's defense mechanisms by activating calmodulin 3 (CaM3). In turn, the CaM3 signaling cascade leads to the stimulation of heat shock factors and gene transcription in the cell nucleus [18]. Signal transducers activated by gases (NO, H_2S) modify target proteins (via S-nitrosylation) to increase the expression of antioxidant enzymes and improve the cells' tolerance to high temperatures [22].

Phytohormones, such as ABA and ethylene, mediate the interaction between damage responses (resulting from the processing of fresh-cut plants) and adaptation to heat stress by regulating downstream pathways that delay tissue senescence [23].

Heat stress induces the activation of a wide range of heat transcription factors (HTFs), which bind to heat shock genes and regulate their expression [20]. The main families of HTFs involved in plant stress responses are: NAC (NAM, ATA1/2, CUC2), ethylene response factors (ERFs) and zinc finger proteins (C3H) [24,25]. According to Zhao et al. [26], NAC

factors are the core regulators responsible for initiating the synthesis of heat shock proteins (HSPs). Ethylene response factors (ERFs) play a broad role in secondary metabolism, the regulation of ethylene production and other biological processes. Eight of these factors are involved in the thermal stress response of Chinese cabbage. Zinc finger proteins (C3H) are specific transcription factors involved in stress adaptation of fresh-cut vegetables, particularly in the case of fresh-cut potatoes. They contribute to the regulation of metabolism and influence quality changes [20,27]. HSPs are crucial for plant responses to heat stress [20]. Treatment temperature appears to be critical in suppressing normal protein synthesis while inducing the creation of HSPs [28–32]. They have the ability to stimulate the activity of antioxidant enzymes (superoxide dismutase—SOD, catalase—CAT) and to strengthen the cells' defense mechanisms against oxidative stress by promoting the accumulation of antioxidant compounds [33]. Increased antioxidant activity protects plant tissues from oxidative damage, which in turn prevents browning, softening, vitamin loss, and aging [34].

Transcriptomic data revealed that changes in gene expression led to alterations in metabolic activity at various levels and, consequently, to the maintenance of better quality in fresh-cut plant material. Heat treatment inhibits the synthesis of initial enzymes (PAL, 4-Coumarate:CoA ligase—4CL, Cinnamate 4-hydroxylase—C4H) responsible for stimulating the synthesis of phenolic compounds and reduces the activity of PPO and POD enzymes [35]. Another mechanism that protects against oxidative stress and cellular damage is the induction of ROS-scavenging enzymes, namely SOD, CAT, ascorbate peroxidase (APX), glutathione S-transferase (GST), monodehydroascorbate reductase (MDHAR), dehydroascorbate reductase (DHAR), and glutathione reductase (GR). Glutathione (GSH) plays a key role in the detoxification of ROS, including hydrogen peroxide (H_2O_2). When thermal stress is applied and ROS oxidize GSH to its oxidized form (GSSG), nicotinamide adenine dinucleotide phosphate (NADPH) facilitates the reduction of GSSG back to GSH, thereby increasing stress resistance [4,36]. According to Liu et al. [37], the upregulation in the expression of genes involved in metabolism of tyrosine, phenylalanine, isoflavone, and phenylpropanoids play a significant role in preventing the senescence of fresh-cut plant material after heat treatment by maintaining color, sensory and nutritional quality during cold storage. The development of a defense mechanism increases the demand for energy supplied by adenosine triphosphate (ATP), which is essential for the synthesis of protective compounds [38]. However, this results in increased respiratory activity in fresh-cut vegetables during the first few days after heat treatment, which can be considered a natural way for the plant tissue to adjust to stress.

Yuan et al. [5] argue that changes in metabolic pathways, including carbon metabolism and the biosynthesis of secondary metabolites, are crucial for understanding the physiological changes that occur in heat-treated plant material.

Nevertheless, it is crucial to note that physiological defense responses to thermal treatments differ across species and even cultivars of fresh-cut vegetables. Chapter 7 attempts to describe the response of minimally processed vegetables to heat treatment within specific vegetable groups.

4. Effect of Heat Treatment on the Quality of Fresh-Cut Vegetables

The development of physiological damage after wounding results from the altered expression of numerous genes and changes in the accumulation of lipid and phenolic metabolites, indicating an integrated interaction between the transcriptome and the metabolome in plant tissues [5,38].

In response to thermal stress, fresh-cut plant tissue undergoes also various molecular changes in gene expression [5], causing shifts in protein synthesis that lead to the replacement of wound-healing enzymes with HSPs [28,31,39–41]. Metabolic pathways then

change, resulting in slowing of the oxidation of phenolic compounds, which is primarily due to PPO denaturation and a reduction in PAL activity in cells damaged by cutting [42].

HT has proven to be an effective method for counteracting the enzymatic process of the cut surface. HS inhibits the cutting-induced increase in PAL activity which affects the phenylpropanoid pathway, resulting in a reduction in the availability of precursors necessary for the synthesis of brown pigments and lignin [4].

Heating can also suppress PPO activity, reduce phenol content and malondialdehyde (MDA) levels, and increase SOD, and CAT activity, as well as antioxidant capacity, which played a key role in inhibiting the synthesis of brown pigments (melanins) [43].

Heat treatment decreases ethylene production, which contributes to the delay of yellowing and softening of intact and fresh-cut green vegetables during storage [38]. Suppressing the activity of enzymes involved in chlorophyll catabolism, such as chlorophyllase and magnesium dechelatase, protects from rapid yellowing [44]. Low ethylene levels prevent the activation of PG enzymes, thereby protecting from quick softening [45]. When fresh-cut vegetables are additionally treated with calcium during HWT, the diffusion of Ca into the tissue is accelerated, which further strengthens the cell walls (pectin matrix) and helps preserve crispness [8].

Heat treatment can increase resistance to chilling injury (CI) by a manner similar to that of intact products. Reducing the activity of PAL and PPO enzymes helps mitigate the effects of CI by limiting electrolyte loss and MDA accumulation [46]. Increasing the content of soluble sugars thereby improves the energy efficiency of the cell wall by preventing a decline in ATP and adenosine diphosphate (ADP), which inhibits the increase in ROS levels and helps protect the cell wall structure [47]. Activation of the arginine metabolism limits the development of CI by increasing the biosynthesis of polyamines (PA), as well as the production of proline and nitric oxide (NO). Polyamines exhibit antioxidant activity by scavenging ROS, proline plays a significant role in osmotic regulation between the cytoplasm and the vacuole, and NO, acting as a powerful antioxidant, regulates lipid metabolism in cell membranes and cell walls [46].

Changes in molecular and biochemical pathways that occur in plant tissues after HT may increase the content of health-promoting components in these products. Some authors claim that HT increases the antioxidant capacity of plant material by promoting the synthesis of carotenoids, ascorbic acid, and phenols [48–51].

However, different vegetable species modify their metabolism in different ways in response to HS. Other factors, such as growing location, soil type, production practices, ripeness at harvest time and storage conditions, also play important roles in these metabolic processes [14,32].

5. Combine Heat Treatment with Other Preservation Techniques

Combining heat treatment with other preservation methods makes it possible to develop new technologies aimed at further extending the shelf life of fresh-cut vegetables. Hot water, as a core strategy enriched with anti-browning agents such as organic acids, has the potential to enhance its effect in inhibiting browning, softening, vitamin degradation, and aging. Heating a solution of ascorbic acid increases the levels of antioxidant enzymes, such as SOD and CAT, and activates the glutathione–ascorbic acid cycle, resulting in a reduction in ROS and MDA content. The oxidative damage to lipids, proteins, and nucleic acids is reduced, thereby preventing tissue degradation [42]. Ascorbic acid helps inhibit PPO activity and prevents the formation of brown pigments [52].

Heating a calcium solution increases the diffusion of Ca^{2+} ions and enhances the solubility of calcium salts in tissues. Reduced PG activity and the binding of Ca^{2+} ions to free carboxyl groups strengthen the cell wall and protect sliced melons from softening [52,53].

Calcium chloride, applied in hot water, had a positive effect on the firmness of cauliflower florets, increasing cell rigidity [54]. The addition of calcium ions to the hot water bath for fresh-cut romaine lettuce treatment contributed to a reduction in PAL activity and improved the stabilization of cell membranes, which inhibited wound-induced enzyme activity, preventing browning of the cut surface [55].

Many authors have found that combined treatments are more effective at controlling foodborne pathogens and naturally occurring microorganisms than HWT alone. Mild heat treatment combined with UV light and acidified sodium hypochlorite (ACS) enhances the reduction in *E. coli* O157:H7 on the surface of spinach and cilantro leaves. It follows that hot water helps reduce the pathogen's ability to adhere to the surface of vegetables [56]. Heating an ascorbic acid solution [57] increases the internal damage to bacterial cells, causing protein denaturation in the plant microbiome. According to Wang et al. [42], the incidence of cross-contamination is reduced by subjecting plant material to ultrasound treatment combined with mild heated ascorbic acid treatment. It has a lethal effect on pathogens, damaging their cell membranes and disrupting intracellular processes, such as DNA replication and energy metabolism. The application of heated hypochlorous acid solution inactivated the biofilms formed by *E. coli* bacteria on fresh-cut lettuce. In addition, the permeability of the bacterial cell membrane increased, which facilitated the decontamination of *E. coli* bacteria within the biofilm [58]. Low concentrations of electrolyzed water, in combination with HT, led to the inactivation of *E. coli* and *Salmonella Typhimurium* through morphological changes in the structure of bacterial cells and damage to cell membranes [59]. Treating whole cantaloupe melons with a hydrogen peroxide solution at a temperature of 70 °C disinfects their surface and significantly reduces the risk of pathogenic bacteria, mold, and yeast being transferred from the rind to the flesh during cutting [60].

Numerous studies indicate that combining different preservation methods has a "combined effect" on the quality of fresh-cut vegetables. The combination of hot air with 1-methylcyclopropene (1-MCP), which prevents excessive ethylene production, effectively reduces softening during short-term storage. According to Nie et al. [61], this combined treatment also reduces CI during the storage of washed purple sweet potatoes in a cold storage facility. The increased resistance to degradation processes resulted from the maintenance of ROS homeostasis, which was due to the altered expression of the relevant genes and elevated levels of antioxidant enzymes (CAT, SOD, ascorbate peroxidase, and GR). Heat treatment has improved the effectiveness of edible coatings (alginate, chitosan and NatureSeal) by reducing respiration rates, minimizing weight loss, delaying discoloration and the loss of flavor and aroma, as well as enhancing gloss and firmness and protecting against the growth of microorganisms [62–64].

The use of controlled-atmosphere storage or modified-atmosphere packaging after HWT effectively delays browning and spoilage by inhibiting metabolic processes under conditions of lower O_2 concentration [40,65]. According to Toivonen et al. [66], an O_2 concentration of 3.1–4.2% is recommended for broccoli storage, whereas 15.0–15.6% is too high and may cause the development of undesirable odors.

6. Limitations on Heat Treatment in the Minimally Processed Vegetable Sector

The response of plant material depends on the treatment, temperature, and exposure duration. Excessively high temperatures or prolonged operation can lead to thermal damage [32,46]. Disruptions in cell membrane function cause the leakage of ions, metabolic byproducts, and intracellular water, resulting in electrolyte loss (36). For example, peeled garlic cloves responded positively to soaking in water at 55 °C, whereas at 60 °C, they were damaged [67]. The HWT of rocket leaves at 50 °C for 20–40 s limited chlorophyll degradation

without causing thermal damage to the tissues. However, when the treatment duration was longer or the temperature was higher, the leaves quickly turned yellow and showed signs of tissue maceration [11]. Similarly, heating the asparagus spears with hot water (HWT) for more than 8 min at 48 °C caused the tissue to soften, leading to secondary damage, such as microbial infection and a decrease in chlorophyll and asparagine content [68].

Excessive heat during the treatment of broccoli florets can cause an olive or even brown tint due to the formation of pheophytin. This occurs when Mg^{2+} ions in chlorophyll are replaced by H^+ ions due to a drop in pH caused by the release of plant acids during heating. An unpleasant odor also develops as a result of cell damage and the onset of fermentation processes. This is caused by accelerated ATP depletion and protein degradation, but particularly by the release of sulfur from amino acids [38].

Although the HT of beans at 52 °C had a positive effect on the appearance of the pods, it did not stop the growth of foodborne bacteria such as *Listeria*, *E. coli*, and *Bacillus* [69]. HT may exacerbate oxidative processes as a result of excessive ROS accumulation [30]. Although ROS act as signaling molecules in response to abiotic stress, once a certain threshold is exceeded, they begin to have a toxic effect on plant tissues [70]. Their strong oxidative properties, which are associated with a high concentration of superoxide anion ($O_2\bullet^-$) and hydrogen peroxide (H_2O_2), cause metabolic disturbances in crops by altering the conformation and structure of the cell membrane as a result of changes in the membrane's lipid composition [3,10,25,40,71,72].

7. Studies on the Use of HT in Individual Vegetable Groups

7.1. Leafy Greens

Leafy greens constitute the largest group of minimally processed vegetables. In addition to yellowing and rotting, rapid wilting and browning of the cut surface contribute to a loss and shorten shelf life.

Among leafy vegetables, iceberg lettuce is a popular fresh-cut vegetable. Numerous studies indicate that heat treatment at temperatures between 45 and 50 °C improves the shelf life of fresh-cut iceberg lettuce by delaying browning and extending its marketability [73–79], as shown in Table 1. According to Loaiza-Valarde and Saltveit [73], thermal shock, induced by HWT (50 °C for 90 s), reduced PAL enzyme activity, thereby protecting the iceberg lettuce from browning. However, Saltveit [28] claimed that the browning process in lettuce required the de novo synthesis of PAL and the accumulation of newly synthesized phenolic compounds. Abeele et al. [79] showed that heat treatment did not directly inactivate the PAL and POD, but suppressed the wound-induced increase in these enzymes during storage, unlike in untreated samples. This is because the production of heat shock proteins consumes energy and leads to a loss of the ability to synthesize other proteins, such as PAL or POD [77]. A further consequence is the inhibition of new polyphenol synthesis and a reduction in the enzymatic browning of cut lettuce [41,75,79]. However, the treatment was effective when applied no later than 36 h after cutting, with the maximum effect achieved approximately 6 h before cutting. The recommended application time is between 24 h before and 12 h after cutting [73].

The use of heat treatment in combination with other solutions is primarily intended to achieve a combined effect from the methods employed. It is recommended to add calcium compounds, such as calcium lactate, to the water bath, which helps maintain high cell turgor and reduces the shrinkage of lettuce tissue cells, preserving crispness during cold storage. Calcium reacts with pectic acid in the cell wall to form calcium pectinate, thereby stabilizing the cell structure and protecting against the loss of turgor. The activation of texture-related enzymes, such as PME, contributes to calcium retention by plant tissues [80]. The use of various disinfectants in combination with HWT increased reduction in microorganisms,

including foodborne pathogens, by destroying the biofilm and the internal structure of microorganisms [58,81,82].

As with iceberg lettuce, thermal shock delayed and reduced the increase in PAL activity in fresh-cut romaine lettuce and oak leaf lettuce [39,83]. According to Campos-Vargas [39], heat shock causes interrelated changes in plant physiology, increasing their resistance to other stressors, including cutting.

Immersing endive slices in a water bath at 45–46 °C effectively prevents the accumulation of PAL1 mRNA by inducing HSP90 synthesis. As a result, the sliced endive does not develop a red color and effectively reduces the microbial load [77,84].

The heat treatment of rocket leaves may reduce their sensitivity to ethylene by altering mechanisms such as ethylene detection, signal transduction, and the transcription of genes associated with plant senescence. Immersing rocket leaves in water at 50 °C for 20–40 s delayed the yellowing process during cold storage. However, it is recommended that the maximum treatment time not exceed 30 s, as prolonged heating causes damage to the plant tissue [11].

HWT at 37–43 °C for 3.5 min protected spinach leaves against the excessive leakage of dissolved substances and, to some extent, against chlorophyll loss. Heat stress causes a short-term increase in H_2O_2 production in the mitochondria, which, according to Gomez [85] and Glowacz [86] acts as a signal prompting the plant to develop its defense mechanisms and should not cause oxidative damage. According to Glowacz et al. [86], heat treatment at 45 °C for 60 s has a positive effect on the concentration of carotenoids and amino acids in spinach leaves, and this is the maximum temperature that can be used for spinach, as more intense heating causes tissue damage. In a previous report, Glowacz et al. [87] concluded that HWT had limited commercial potential in terms of spinach leaf quality after harvest.

Minimally processed green onions, i.e., fresh-cut pseudostems, responded to HWT by inhibiting the elongation of internal leaves ("telescoping") [88,89]. Performing two consecutive HWTs and applying an edible alginate coating produced a combined effect, resulting in greater firmness and less spoilage during storage compared to untreated green onion samples [62].

Fresh-cut Chinese cabbage responded positively to brief immersion in water at 53–55 °C [90]. A sequential treatment involving rinsing with plasma-activated water followed by HT improved the microbiological quality of sliced and salted Chinese cabbage [91]. However, in the case of sliced white cabbage, steam treatment performed prior to inoculation with *Listeria* spp. delays spoilage but promotes the growth of *L. monocytogenes* during refrigerated storage [92].

Table 1. (**a**) The effects of heat treatment on the quality and shelf life of minimally processed leafy vegetable: iceberg lettuce (*—pre-cut treatment; **—post-cut treatment). (**b**) The effects of heat treatment on the quality and shelf life of minimally processed leafy vegetables: romaine lettuce, red oak leaf lettuce, endive, rocket, spinach, green onion, Chinese cabbage, white cabbage (**—post-cut treatment).

(**a**)

Heat Treatment	Storage Temperature	Effects	References
** HWT: 50 °C–90 s	10 °C	- delayed browning	[73]
** HWT: 47 °C–120 s	5 °C	- delayed browning	[74]
** HWT: 50 °C–90 s	4 °C	- delayed browning - inhibited PAL activity and - phenol accumulation	[75]

Table 1. *Cont.*

(**a**)

Heat Treatment	Storage Temperature	Effects	References
** HWT: 45 °C–120 s	4 °C	- inhibited PAL and POD activity - inhibited microbial growth	[77]
** HWT: 45 °C–180 s	4 °C	- prevented pinking	[78]
** HWT: 50 °C–60 s	7 °C	- suppressed the wound-induced increase in PAL and POD activity - delayed browning	[79]
* HWT: 50 °C–60 s	4 °C	- delayed browning - reduced the initial microorganism population	[76]
** HWT: 50 °C–60 s, combined with calcium lactate solution	4 °C	- prevented crispness loss	[80]
** HWT: 50 °C–60 s combined with hydrogen peroxide	4 °C	- delayed browning - delayed senescence	[81]
** HWT: 50 °C–5 min combined with acidic hypochlorous	10 °C	- destroyed *E. coli* biofilm - reduced *E. coli* load	[58]
** HWT: 50 °C–60 s combined with sodium hypochlorite	4 °C	- reduced pathogen population	[82]

(**b**)

Species	Heat Treatment	Storage Temperature	Effects	References
Romaine lettuce	** HWT: 45 °C–120 s 50 °C–120 s	10 °C 5–7 °C	- inhibited PAL activity - delayed browning	[39,83]
	** HWT: 50 °C–120 s	5 °C	- preserved texture and color - inhibited microbial growth - preserved vitamin C and antioxidant activity	[93]
	** HWT: 45 °C–90 s; 50 °C–60 s combined with Ca treatment	5 °C	- inhibited PAL activity - maintained better color	[55]
Red oak leaf lettuce	** HWT: 45 °C–120 s	4 °C	- inhibited PAL activity - delayed browning - inhibited microbial growth	[41]
Endive	** HWT: 46 °C–120 s	10 °C	- prevented red discoloration	[84]
	** HWT: 45 °C–120 s	not stored	- inhibited PAL and PPO activity	[77]
Rocket-*Eruca sativa* M.	** HWT: 50 °C–30 s	8 °C	- delayed yellowing - extended shelf life	[11]

Table 1. *Cont.*

(**b**)

Species	Heat Treatment	Storage Temperature	Effects	References
Spinach	** HWT: 40 °C–210 s	23 °C	- delayed senescence - reduced chlorophyll degradation - decreased solute leakage - prevented vitamin C degradation	[85]
	** HWT: 40 °C–60 s combined with lactic acid	0 °C	- preserved nutritional quality	[86]
	** HWT: 40 °C–5 min combined with lactic acid and hydrogen peroxide	4 °C	- reduced *E. coli* O157:H7, inoculated before HT	[94]
Green onion	** HWT: 55 °C–120 s	5 °C	- controlled internal leaf growth - delayed discoloration	[88,89]
	** HWT: 50 °C–20 s	4 °C	- inhibited microbial growth	[7]
	** HWT: 55 °C–120 s combined with CA	5 °C	- extended shelf life	[88,89]
	** HWT: 55 °C–60 s combined with an edible alginate coating	4 °C	- prevented rotting - preserved firmness	[62]
	** HWT: 50 °C–60 s combined with sodium hypochlorite	not stored	- reduced *E.coli* O157:H7, inoculated before HT	[56]
Chinese cabbage	** HWT: 53–55 °C–3 s	0 °C; 5 °C	- delayed discoloration - preserved sensory properties	[90]
White cabbage	** HVT: 50 °C–3 min	5 °C	- preserved sensory properties - extended shelf life - promoted growth of *L. monocytogenes*, inoculated after HT	[92]

7.2. Root Vegetables

In the root vegetable group, most research on the HT of minimally processed products has focused on carrots. Although carrots can be eaten after cooking, they have a lower glycemic index and are richer in nutrients when is eaten as a fresh vegetable.

Subjecting whole roots to HWT at an extremely high temperature (100 °C for 45 s) immediately before slicing did not cause damage to the flesh but reduced the bacterial count and helped maintain high sensory quality during storage. A decrease in the activity of PAL and POD enzymes and in total polyphenol content in the plant material was also found. The positive effect of pre-cutting HWT was further enhanced by additional UV-C irradiation of the whole roots or by packaging fresh-cut carrots in microperforated film [95–98]. The beneficial effect shown in Table 2. For HT after cutting, a lower temperature in the range of 50–60 °C is recommended. The addition of organic acids (AA and CA) to the water bath contributed more than HWT alone in reducing PAL and POD activities and inhibiting lignin synthesis on the cut surface of carrot disks [57]. Heating calcium lactate or calcium chloride solutions accelerates the rate of Ca^{+2} diffusion into the plant tissue. PME is activated, and

calcium ions are bound by the carboxylate moiety, which results in the firming of plant tissue [99].

In a study on sliced radishes, the use of HWT at 50 °C followed by immersion in CA or AA solution enhanced the retention of color on the cut surface of slices. Lowering the pH inhibited PPO activity and reduced the formation of o-quinones (responsible for oxidative browning) [48,100].

The use of HWT alone, or with the solution of organic compounds, effectively inhibited the browning of cut lotus roots by deactivating enzymes present on the cut surface and inducing stress-protective proteins. The growth of mesophilic microorganisms was also inhibited during low-temperature storage [101].

Table 2. The effects of heat treatment on the quality and shelf life of minimally processed root vegetable (*—pre-cut treatment; **—post-cut treatment).

Species	Heat Treatment	Storage Temperature	Effects	References
Carrot	* HWT: 100 °C–45 s	5 °C	- inhibited microbial growth - improved bioactive quality - preserved sensory properties	[95,97,98]
	* HWT: 100 °C–45 s combined with UV-C irradiation	5 °C	- improved storage ability - increased phenolic content - increased carotenoid content - inhibited POD activity	[96]
	** HWT: 50 °C–60 s combined with calcium lactate solution	4 °C	- inhibited softening - inhibited lignin synthesis	[99]
	** HWT: 60 °C–60 s combined with sodium chloride, citric acid, and lime juice solutions	4 °C	- delayed softening - delayed discoloration - inhibited microbial growth - extended shelf life	[102]
	** HWT: 50 °C–5 min combined with ascorbic acid solution	4 °C	- inhibited PAL and POD activity - inhibited lignin synthesis - inhibited microbial growth	[57]
	** HWT: 45 °C–2 min combined with acidic electrolyzed water	°C	- reduced aerobic bacteria, molds and yeasts	[103]
	** HWT: 50 °C–5 min combined with ultra sound and ascorbic acid	4 °C	- activated SOD and CAT - inactivated *E. coli* and *S. typhimurium*, inoculated before HT	[42]
Radish	** HWT: 50 °C–60–90 s combined with earlier immersion in CA solution	5 °C	- delayed browning	[100]
	** HWT: 50 °C–90 s combined with earlier immersion in AA solution	5 °C	- increased total phenolic - increased flavonoid content - increased antioxidant capacity	[48]

Table 2. *Cont.*

Species	Heat Treatment	Storage Temperature	Effects	References
Lotus	** HWT: 55 °C–45 s	4 °C	- delayed browning - inhibited microbial growth - preserved sensory properties	[101]
	** HWT: 55 °C–45 s combined with ascorbic acid and chamomile extract solution; storage at 100% of CO_2	5 °C	- extended shelf life - inhibited microbial growth	[104]
Burdock	** HWT: 55 °C–45 s combined with NaCl solution	4 °C	- delayed browning - delayed senescence	[105]

7.3. Bulb Vegetables

Bulb vegetables are important sources of vitamins, minerals, essential oils, and other health-promoting substances. They are essential for seasoning dishes and have versatile culinary uses. The application of technology that improves the shelf life of fresh bulb vegetables prepared for direct consumption, without compromising their health properties, is essential for better production and consumer supply.

In the case of leeks, cut pseudostems are becoming an increasingly popular form of sale. The cleaned, white part, without roots or a green rosette is suitable for use in its entirety in meal preparation. When whole plants were subjected to HWT at 50–57.5 °C immediately before cutting, the elongation of the inner leaves (telescopic effect) in the pseudostems was inhibited during low-temperature storage. This indicates that cell division in the meristem had been inhibited. On the other hand, HWT reduced the dry matter, soluble solids, soluble phenol, and thiosulfinate contents and the antioxidant capacity in leek tissue [106,107]. The effects of HT across bulb species are presented in Table 3.

HWT preserved antioxidant properties of fresh-cut onion [108] and inhibited cell division in peeled garlic cloves, delaying the emergence of sprouting and rooting during storage [67,109].

Table 3. The effects of heat treatment on the quality and shelf life of minimally processed bulb vegetables (*—pre-cut treatment; **—post-cut treatment).

Species	Heat Treatment	Storage Temperature	Effects	References
Leek	* HWT: 52.5 °C–(25–35) min; 55 °C–(17.5–20) min; 57.5 °C–(10–15) min	4 °C	- inhibited the elongation of inner leaves	[106]
Onion	** HWT: (50–60) °C–60 s; 50 °C–60 s	4 °C	- increased total phenolic content - delayed discoloration - protected antioxidant capacity	[108]
Garlic	** HWT: 55 °C–10 min	10 °C	- inhibited sprout and root growth	[67]
	** HWT: 55 °C–(7.5–10) min	room temperature	- inhibited sprout and root growth	[109]

7.4. Stem Vegetables

Stem vegetables, which are rich in dietary fiber, aid in digestion and promote a feeling of fullness. They are often used as versatile ingredients in soups, salads, and other dishes.

When preparing celery for sale, the roots and leaf blades are trimmed, leaving only the fleshy leaf stalks (petioles). The HWT of fresh-cut celery petioles should be carried out within a few minutes of cutting to effectively inhibit PAL activity and reduce the synthesis and accumulation of phenols, including chlorogenic acid. Higher PAL levels in vascular tissue compared to the cortex and epidermis explain the more intense browning of the vascular bundles in the damaged segments. Saleh et al. [110] found that celery stalks (20 cm long) responded particularly well to treatment at 45 °C, after which neither browning of the cut surface nor any signs of yellowing were observed during storage. In addition, microbial growth was inhibited, and the celery showed no signs of rotting. Table 4 provides an overview of the effects of HT on various species of stem vegetables.

White asparagus is sensitive to chilling injury and when stored at temperatures below 2.5 °C, it may suffer damage such as loss of glossiness, limpness, or the appearance of dark spots. Immersing spears in water at 45–50 °C increased their resistance to low temperatures during cold storage. Ion loss and cell membrane damage were reduced, and negative geotropic curvature (bending) of the shoots was prevented. However, according to Saltveit [111], the treatment parameters should be adjusted to the diameter of the spears, as thinner ones require a shorter exposure time than thicker ones. HT had a beneficial effect on white asparagus, as it inhibited anthocyanin synthesis, preventing the purple discoloration of spears tips. This is the result of a decrease in PAL activity, since anthocyanins are synthesized as part of the general phenylpropanoid pathway [112,113]. The use of HWT in combination with MAP improved the shelf life for both peeled and unpeeled spears [68,113].

HWT at 55–60 °C is highly effective at reducing aerobic mesophilic bacteria and maintaining good appearance during storage of calçots [114].

Table 4. The effects of heat treatment on the quality and shelf life of minimally processed stem vegetables (**—post-cut treatment).

Species	Heat Treatment	Storage Temperature	Effects	References
Celery	** HWT: 50 °C–90 s	10 °C	- inhibited PAL activity - delayed browning - extended shelf life	[115]
	** HWT: 50 °C–90 s ** HAT: 48 °C–1 h	0 °C	- delayed browning - retained ascorbic acid content	[116,117]
	** HWT: 45 °C–60 s	0 °C	- delayed discoloration - inhibited microbial growth - preserved sensory properties	[110]
Asparagus	** HWT: 55 °C–3 or 2 min	2.5 °C; 25 °C	- delayed purple discoloration of the spear tips - preserved sensory properties	[112]
	** HWT: 45 °C–4 min 50 °C–2.9 min	2.5 °C	- reduced ion leakage - prevented CI - prevented negative geotropic curvature (bending) in spears	[111]

Table 4. *Cont.*

Species	Heat Treatment	Storage Temperature	Effects	References
Asparagus	** HWT: 55 °C–3 or 2 min combined with MAP	3 °C	- delayed discoloration - suppressed respiration intensity - delayed softening - inhibited microbial growth	[113]
	** HWT: 48 °C–2–4 min combine with MAP packaging	4 °C	- extended shelf life	[68]
Calçots	** HWT: 55 °C–60 s	4 °C	- inhibited microbial growth	[114]

7.5. Flower Vegetables

The main flower vegetables are broccoli and cauliflower. They are popular all over the world and are important sources of vitamins and minerals in the human diet.

After harvest, broccoli is prone to rapid yellowing, and according to numerous researchers, applying HWT at 45–50 °C slows down the breakdown of chlorophyll and, consequently, the loss of its green color [52,69,118,119], what summarizes the Table 5. According to Duarte-Sierra [38] and Lemoine et al. [44], heat treatment (50–55 °C) decreases ethylene production, which contributes to delaying the increase in the activity of enzymes such as chlorophyllase and magnesium dechelatase, which are involved in chlorophyll catabolism. In general, the stress caused by heat shock leads to sustained higher levels of protein and sugar, which indicates lower energy expenditure and a delay in the senescence process. The reduction in water loss is due to better coverage of the florets' surface with softened or melted cuticular waxes, which creates a stronger barrier that protects the tissue from water loss. The glucosinolates content in heat-treated broccoli florets increases, which may help improve their resistance to infection and spoilage during storage [38]. However, according to Stringer et al. [69], HT does not prevent the formation of an unpleasant odor or limit the subsequent growth of microorganisms that cause vegetable spoilage. *E. coli* and *Salmonella* spp. bacteria can be completely eliminated only after the broccoli has been exposed to higher temperatures (55–60 °C); however, this causes the tissue to soften and leads to the appearance of scald marks on the broccoli florets [118]. Nevertheless, HWT may enhance the effectiveness of other treatments used to improve the shelf life of broccoli florets. These include edible chitosan coatings [119]; ultrasonic treatment; immersion in a CA solution [120]; and immersion in a sodium chlorate solution [121].

Fresh broccoli stalks are often underestimated in terms of raw consumption, even though they are no less valuable than the florets as a source of vitamins and minerals. HWT technology improves the shelf life of stem segments by reducing browning and inhibiting the growth of microorganisms. The addition of ascorbic acid to the water bath resulted in an increase in vitamin C content and antioxidant activity. In contrast, the addition of trehalose led to increased microbial growth due to greater leakage of cell sap from fresh-cut broccoli stalks [52].

HWT enhanced the effect of the $CaCl_2$ solution on cauliflower florets, allowing them to maintain better firmness during cold storage. This combined treatment inhibited the degradation of ascorbic acid and glucosinolates and counteracted the increase in PG and lipoxygenase activity [54].

Table 5. The effects of heat treatment on the quality and shelf life of minimally processed flower vegetables (**—post-cut treatment).

Species	Heat Treatment	Storage Temperature	Effects	References
Broccoli	** HWT: 52 °C–90 s	10 °C	- improved initial color - delayed browning - controlled spoilage	[69]
	** HWT: 50 °C–180 s	4 °C	- delayed yellowing - did not sufficiently control the growth of *E. coli* and *Salmonella* spp.	[118]
	** HWT: 50 °C–90 s	5 °C	- reduced weight loss - delayed browning of florets and stems - delayed floret yellowing	[119]
	** HWT: 55 °C–60 s	5 °C	- delayed browning - inhibited microbial growth - extended shelf life	[52]
	** HAT: 41 °C–3 h	4 °C	- enhanced phytochemical content - preserved sensory properties	[38]
	** HAT: 48 °C–3 h	0 °C	- delayed yellowing and chlorophyll degradation - lowered electrolyte leakage - inhibited the decrease in total sugar and soluble protein contents	[44]
	** HWT: 50 °C–90 s combined with edible coating (chitosan + acetic acid + 1% glycerol)	5 °C	- reduced yeast, molds and coliforms counts	[63]
	** HWT: 50 °C–180 s combined with ultrasonic treatment and CA dipping	5 °C	- delayed yellowing - inhibited microbial growth - prevented chlorophyll degradation - prevented ascorbic acid degradation - preserved sensory properties - extended the shelf life	[120]
	** HWT: 45 °C–60 s combined with dipping in sodium chlorite solution	4 °C	- inhibited microbial growth - preserved the antioxidant capacity	[121]
	** HAT: 48 °C–3 h. combined with UVC	20 °C	- delayed yellowing - delayed senescence - preserved sensory properties	[122]
Cauliflower	** HAT: 48 °C–180 min combined with packaging in PE bags	4 °C	- reduced color changes - extended shelf life	[123]
	** HWT: 40 °C–10 min combined with $CaCl_2$ solution	4 °C	- delayed senescence - extended shelf life	[54]

7.6. Fruit Vegetables

For some vegetable species, the edible part of the plant is the fruit. Similar to typical fruits, melons and watermelons have a sweet taste and are used in desserts. Other vegetables,

such as tomatoes, bell peppers, and zucchini, have a savory or neutral taste, making them better suited for savory dishes than for desserts. These vegetables are generally low in calories but rich in fiber, phytochemicals, and vitamins and are consumed in large quantities around the world. Minimal processing expands the range of products available on the market and leads to increased consumption.

Subjecting bell peppers to HWT at 55–60 °C before slicing has a positive effect on the shelf life of fresh-cut bell peppers during cold storage [124]. When applying post-cutting treatment, a lower temperature in the range of 45–55 °C is recommended [125,126]. Rodoni et al. [125] observed different reactions to post-cutting HWT depending on the ripeness stage (green and red) at harvest. Green pepper responded positively to treatment at 45–50 °C but red peppers only to treatment at 45 °C. Significant differences were also observed in the response to HWT between the two pepper varieties, which were harvested at full maturity. Freshly sliced red peppers responded positively to HWT at 55 °C, while freshly sliced cream-colored peppers responded positively to HWT at 50–53 °C [126]. The treated red pepper sticks maintained better firmness, which indicated a lower activity of enzymes that break down the cell wall. In cream-colored peppers subjected to HWT, a delay in the browning process was observed, evidencing the inactivation of the enzymes responsible for color change (PAL and PPO) [125]. Adding calcium ascorbate or calcium chloride to hot water helps maintain a better texture in the cut pepper pieces and reduces the number of aerobic bacteria [127,128].

HT induces physiological and biochemical changes that increase stress tolerance and improve the resistance to adverse changes in freshly sliced tomato [129]. Both pre- and post-slicing HAT improve the shelf life of tomatoes stored in a controlled atmosphere [128,129]. According to Zhang et al. [130], heat treatment improved the resistance to the CI of fresh-cut tomatoes by increasing the concentrations of arginine and its derivatives (proline and putrescine). Furthermore, treated fresh-cut tomato exhibited increased activity of the antioxidant enzymes SOD, CAT, and APX, which also prevent damage and inhibit the senescence process.

The main factor limiting the shelf life of freshly sliced eggplants is browning. HWT has proven to be an effective method for reducing PPO activity and limiting discoloration of cut surface [131]. Subjecting eggplant slices to HWT after immersing them in an AA solution, increased the inactivation of PPO and POD enzymes and reduced browning to a greater extent than after AA treatment alone [132]. Heat treatment also helps to extend the shelf life of sliced eggplant stored in MAP [133].

Heating whole cantaloupe or Galia melons in water at 75–76 °C reduced the number of microorganisms on the surface of intact fruit and resulted in lower microbial counts on fresh-cut pieces during cold storage [64,134]. Melon rinds are quite thick, and high temperatures do not penetrate deeply into the flesh and do not cause structural or biochemical changes [134,135]. The purpose of this treatment is to disinfect the fruit before cutting it, to prevent contaminants from transferring from the surface to the flesh during cutting. Ukuku et al. [60,136] even recommended exposing the whole fruit to hot water at 97 °C or hot steam immediately before cutting, in order to reduce the population of natural microflora and inoculated *Salmonella* bacteria. According Lamicanra et al. [137] and Supapvanich et al. [138] the pre-cutting immersion in water at lower temperature (50–60 °C) also reduces the microbial load and delays the softening process of freshly diced melon during storage. However, maintaining the cold chain during storage, distribution, and retail sale is essential for preserving the quality of sliced melons [135]. Numerous studies on sliced melons focus on the combined use of heat treatment with other methods, such as a low dose of radiation [139], the addition of calcium lactate or calcium chloride to the HW bath [140,141], and using a polyethylene film that maintains a modified atmo-

sphere during storage [142]. Also, subjecting fresh-cut Galia melons to two consecutive treatments, namely HWT and immersion in a peracetic, led to an increase in polyamine levels, particularly putrescine, which acted as a free radical scavenger and helped maintain the integrity of the cell membrane of the melon tissue [53].

HWT at 48–55 °C also significantly increased the activity of antioxidant enzymes (SOD, CAT), reduced oxidative stress and helped preserve the quality of fresh-cut cucumbers [143]. Table 6 presents the effects of heat treatment, performed before and after cutting, on fruit vegetables.

Table 6. The effects of heat treatment on the quality and shelf life of minimally processed fruit vegetables (*—pre-cut treatment; **—post-cut treatment).

Species	Heat Treatment	Storage Temperature	Effects	References
Bell peppers	* HWT (55, 60) °C–180 s	4 °C	- preserved firmness and aroma losses - reduced leakage of juice - extended shelf life	[124]
	** HWT: 45–50 °C–180 s	4 °C	- delayed soft rot - delayed shriveling and softening - decreased weight loss - prevented electrolyte leakage - extended shelf life	[125]
	** HWT: 55 °C–12 s	3 °C; 5 °C; 8 °C	- inhibited softening - extended shelf life	[126]
	** HWT:53 °C–180 s; 50 °C–300 s	3 °C; 5 °C; 8 °C	- delayed browning - inhibited softening - extended shelf life	[126]
	** HWT: 50 °C–120 s combined with $CaCl_2$ and calcium ascorbate solutions	5 °C	- inhibited microbial growth - extended shelf life	[127]
	** HWT: 60 °C–60 s combined with acidic electrolyzed water + ultrasound	4 °C	- inhibited microbial growth	[144]
Tomato	** HAT: 35 °C–6 h combined with control atmosphere storage	2 °C	- limited ethylene production - limited fungal infections - maintained high taste ratings - extended shelf life	[128]
	* HWT: 55 °C–300 s combined with control atmosphere storage	5 °C	- limited ethylene production - prevented firmness loss - extended shelf life	[145]
Eggplants	* HWT: 45 °C–30 min	2 °C	- delayed browning - extended shelf life	[131]
	HWT: 50 °C–60 s combined with ascorbic acid solution	4 °C; 5 °C	- delayed browning - inhibited PPO and POD activities - increased the phenolic content - extended shelf life	[132,133]

Table 6. *Cont.*

Species	Heat Treatment	Storage Temperature	Effects	References
Cantaloupe melon	* HWT: 97 °C–60 s	5 °C	- diminished the transfer of pathogenic bacteria to the interior tissue during cutting	[60]
	* HVT–180 s	5–10 °C	- reduced total bacteria population (*E coli* O157:H7, *Salmonella* and *Listeria monocytogenes*), inoculated before HT	[146]
	* HWT: 50 °C–60 min	10 °C	- reduced the transpiration intensity - inhibited bacterial growth - preserved sensory properties	[137]
	* HWT: 76 °C–180 s	4 °C	- inhibited microbial growth	[134]
	* HWT: 76.1 °C–180 s	4 °C	- inhibited microbial growth - reduced population *Salmonella enterica*, inoculated before HT	[64]
	* HVT–180 s	5 °C	- inhibited microbial growth - improved appearance and acceptability of cut pieces	136
	* HWT: 76 °C–180 s combined with irradiation after cutting	4 °C	- inhibited microbial growth - extended shelf life	[139]
	* HWT: 70 °C–1 min combined with H_2O_2	5 °C	- disinfected the surface of whole fruits	[60]
Galia melon	* HWRB: 75 °C–20 s	5 °C; 8 °C; 17 °C	- inhibited microbial growth	[135]
	** HWT: 60 °C–90 or 120 s combined with immersion in a peracetic acid solution	5 °C	- lowered the metabolic activity - inhibited microbial growth - increased the polyamine content	[53]
Muskmelon	* HWT: 50 °C–60 min	4 °C	- delayed softening - maintained a high total phenolic content - maintained a high antioxidant capacity	[138]
Melon	** HWT: 60 °C–60 s combined with 0.5% CA solution	5 °C	- maintained better firmness - inhibited microbial growth	[140]
	* HWT: 50 °C–30 min combined with active packaging	6 °C	- increased the beta-carotene content - inhibited decay development - reduced decay development	[142]
Cucumber	** HAT: 48–49 °C–10 min	5 °C	- inhibited microbial growth - lowered nutrient degradation - prevented firmness - extended shelf life	[143]

7.7. Tuber Vegetables

Tuber vegetables form distinctive underground storage organs that accumulate starch and other nutrients. The most popular of these is the potato, which is classified as a horticulture crop in some countries and as an agriculture crop in others. Botanically, the edible part of sweet potatoes is the root, but commercially, they are often referred to as a tuberous root vegetable.

Similarly to numerous other species, the main problem with fresh-cut potatoes is that their surface browns quickly after being cut [27]. Mild HT reduces browning by decreasing PPO activity, lowering phenolic compound content, increasing antioxidant capacity, reducing MDA levels, and altering the metabolism of free amino acids. Heat stress increases the expression of the serine protease inhibitor (SPI) gene, leading to a decrease in free amino acid content, including free tyrosine, which is considered the primary substrate necessary for enzymatic browning induced by polyphenol oxidase in fresh-cut potatoes [43]. Tsouvaltzis et al. [147] reported that to reduce browning, whole tubers should be heat-treated, then stored at 20 °C for one day, and only then subjected to minimal processing. However, the studies found no correlation between browning and polyphenol content or PPO activity. Heating organic acid solutions enhances the effectiveness of these acids in preventing browning [148,149]. Tsouvaltzis and Brecht [150] hypothesized that citric acid may bind to phenolic substrates or to the PPO enzyme, or that other compounds are formed that prevent the formation of dark pigments. Subjecting the tubers to high-temperature catalytic treatment using infrared radiation enhanced the delay of browning in sliced potatoes during storage [151]. Combining hot air treatment with 1-methylcyclopropene (1-MCP) effectively reduces cold damage during the storage of washed purple sweet potato roots by increasing the levels of antioxidant enzymes that maintain of ROS homeostasis, thereby improving resistance to degradation processes [61].

The HWT of sunchoke, performed before or after cutting, significantly reduced discoloration by decreasing the respiration rate, PAL activity, and total accumulation of phenolic compounds [152]. Similarly, the HAT of yams reduced browning by decreasing phenolic metabolism and the activity of PPO and POD enzymes [4]. HWT also improved the resistance of sliced taro to browning [34]. As shown in Table 7, heat-treated vegetables demonstrate a beneficial effect during storage.

Table 7. The effects of heat treatment on the quality and shelf life of minimally processed tuber vegetables (*—pre-cut treatment; **—post-cut treatment).

Species	Heat Treatment	Storage Temperature	Effects	References
Potato	* HAT: 30 °C–24 h	10 °C	- delayed browning - delayed off-odor	[148]
	* HWT: 55 °C–10 min	5 °C	- delay browning - inhibited phenolic synthesis	[147]
	* catalytic infrared heating: 55 °C–10 min	20 °C	- delayed browning	[151]
	** HWT: 55 °C–60 s combined with AA solution	5 °C	- delayed browning - preserved sensory properties	[149]
Sweet potato	** HAT: 45 °C–3 h combined with 1-MCP	4 °C	- reduced CI	[61]

Table 7. *Cont.*

Species	Heat Treatment	Storage Temperature	Effects	References
Sunchoke	* HWT: 50 °C–20–25 min	5 °C	- delayed red discoloration - extended the shelf life	[152]
	** HWT: 50 °C–6–8 min 55 °C–3–4 min	5 °C	- delayed red discoloration - extended the shelf life	[152]
Yam	** HAT: 35 °C–7 d	4 °C	- delayed browning - limited ethylene production - enhanced flavonoid content	[4]
Taro	** HWT: 55 °C–1 min	4 °C	- delayed browning - enhanced shelf life	[153,154]

7.8. Pod and Grain Vegetables

Pod vegetables include species whose seeds are enclosed in a double-walled, edible or inedible pod. Those with edible pods, such as green beans, are harvested when they are fully grown but still firm and crisp. Sweet corn is botanically classified as a grain but since it is eaten in the "milk stage" when the kernels have a high sugar and a tender texture, it can be considered a starchy vegetable.

Subjecting green beans to HWT after harvest enhanced their initial color and proved effective in preventing spoilage caused by yeast and mold; however, it did not delay the onset of off-odors or reduce the total microbial count. HWT also did not prevent the growth of *Listeria monocytogenes*, *Escherichia coli*, or *Bacillus cereus* inoculated onto bean pods after HT [69]. The influence of HT on pod and grain vegetables is shown in Table 8. Snap bean pods treated with HW showed increased resistance to low-temperature damage during storage due to a higher soluble sugar content, the inhibition of enzymes that break down cell walls, and the reduced oxidation of phenolic compounds [47].

Sweet corn is a highly perishable vegetable, and the HWT of peeled cobs extended their shelf life by maintaining high levels of antioxidants and inducing the synthesis and accumulation of lignin, which promotes the thickening of cell walls and the preservation of tissue integrity. The high content of soluble sugars indicates that HT promotes the conversion of starch and other polysaccharides into low-molecular-weight soluble carbohydrates [155].

Table 8. The effects of heat treatment on the quality and shelf life of minimally processed pod vegetables and sweet corn (**—post-cut treatment).

Species	Heat Treatment	Storage Temperature	Effects	References
Green beans	** HWT: 52 °C–90 s	10 °C	- enhanced initial color - delayed browning - inhibited yeast and mold growth - not prevented growth of *bacteria* inoculated after HT: *L. monocytogenes*, *E coli* and *B. cereus*	[69]
Snap beans	** HWT: 35 °C–10 min	4 °C	- inhibited CI - increased sucrose accumulation - prevented cell wall degradation - inhibited PPO activity	[47]
Sweet corn	** HWT: 50 °C–300 s	20 °C	- reduced weight loss - extended the shelf life	[155]

8. Industrial Applications and Future Prospects in Scientific Research on the Heat Treatment of Fresh-Cut Vegetables

Despite the use of many proven technologies, the fresh-cut vegetable industry is still seeking new solutions that will help extend shelf life and replace chemical preservation. However, for fresh-cut vegetables intended to remain crisp and fresh-like, the challenge is to achieve an appropriate reduction in microorganisms and enzyme activity while minimizing nutrient losses, discoloration, and softening.

The use of heat treatment is still in its early stages and it requires effort to implement this method on a large scale in the fresh-cut sector.

Research to date indicates that heat treatment may help extend the shelf life and even improve the nutritional value of fresh-cut vegetables. However, the scientific community should continue its work on optimizing precise temperature–time parameters and adapting them to specific species, individual varieties, and even local vegetable-growing conditions.

Food safety regarding fresh-cut vegetables should be a key concern in both research and industrial practice. Therefore, special attention should be paid to gaining a thorough understanding of the defense mechanisms (both physical and biochemical) that protect against the excessive proliferation of microorganisms, especially foodborne pathogens.

Mild heat treatment (45–60 °C) alone does not guarantee microbiological safety, but as part of a hurdle strategy, it can significantly help limit growth of microorganisms, including pathogens; however, it must be validated for each product group or even for individual species. The use of extremely high temperatures (above 70 °C) to treat whole melons significantly contributed to surface disinfection and the reduction of microbial contamination of melons after cutting.

Future studies should continue to examine how heat treatment triggers the development of defense mechanisms, particularly the regulation of the polyphenol pathway and the activity of PPO and POD enzymes. Changes in the ultrastructure of the cell wall in response to heat treatment also require further clarification. The significance and mechanisms of action of the factors that determine cell wall stiffness are crucial to understanding a cell's ability to adapt to thermal stress. It is necessary to clarify how heat treatment affects the levels of health-promoting substances in fresh-cut vegetables. This should help establish precise temperature thresholds that prevent the destruction of heat-sensitive substances (especially vitamins and other antioxidants).

A sensory evaluation that takes into account appearance, texture, taste, and aroma indicates the level of interest and acceptance among buyers and consumers. Therefore, analytical methods should also be developed, using available tools such as an electronic nose or near-infrared spectroscopy (NIR), to assess external and internal quality and chlorophyll fluorescence measurements for monitoring the response of vegetables to heat stress. This should help predict shelf life and, consequently, improve inventory management in the supply chain.

The knowledge gained in the areas of gene transcription, enzymatic activity, and biochemical changes should be used to breed and select varieties adapted to the requirements of minimal processing—that is, cultivars with increased tolerance to cutting-related stress, high antioxidant activity and a positive response to heat treatment-induced stress.

Economic and environmental considerations—namely, reducing treatment costs as well carbon footprint through the implementation of energy-efficient heating systems and water recycling—are also the key factors taken into account by manufacturers.

In summary, heat treatment represents a promising physical alternative to chemical methods for improve stability of fresh-cut vegetables, but the optimization of process parameters for each vegetable species remains a key challenge for its industrial implementation.

9. Conclusions

HT technology for minimally processed vegetables has not yet found widespread practical application. Each fresh-cut vegetable has different properties, resulting in different reactions to thermal shock. The results of previous studies indicate that it is difficult to develop universal recommendations for fresh-cut vegetables and that species-specific recommendations are more feasible. This technology needs systematic experimental optimization and validation because effective treatment requires the use of appropriate HT parameters, including temperature and duration.

Since there are no approved general recommendations, only the commonly tested temperature range of 45–60 °C for 1–3 min is provided. However, before practical implementation, these parameters reported in individual studies must be verified under storage conditions (including with regard to packaging, storage temperature, gas composition, etc.). Pre-cutting treatment typically required a higher temperature or a longer treatment time. Different effects of heat were observed across the various vegetable groups, but the most common effect was the inhibition of browning at the cut surface. In many cases, heat treatment reduced the overall population of microorganisms; however, foodborne pathogens proved difficult to control, and this poses a separate challenge for science and industry.

The use of combined technology—HT combined with other preservation methods—typically provides better protection against loss of visual quality and more effectively extends the shelf life of minimally processed vegetables than HT alone. Heat treatment can enhance the effectiveness of measures to prevent browning and softening, as well as strengthen the action of agents that combat foodborne pathogens and naturally occurring microorganisms.

Some species, such as lettuce and melons, have been the subject of extensive research; however, for certain vegetables, including kale and watermelons, the available information is limited, indicating a need to investigate their response to heat treatment. The growing demand for minimally processed fruits and vegetables highlights the need for further research aimed at improving their nutritional, sensory, and microbiological quality, as well as extending their shelf life.

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Abbreviations

The following abbreviations are used in this manuscript:

HT	heat treatment
HS	heat shock or heat stress
HWT	hot water treatment
HAT	hot air treatment
HVT	hot vapor treatment
HSP	heat shock protein

PAL	phenylalanine ammonia lyase
POD	peroxidase
PPO	polyphenol oxidase
SOD	superoxide dismutase
CAT	catalase
PME	pectin methyl esterase
GR	glutathione reductase
CI	chilling injury
CA	citric acid
AA	ascorbic acid
SC	sodium chloride
PE	polyethylene
MAP	modified-atmosphere packaging
d	day
h	hour
min	minute
s	second

References

1. Hu, W.; Jiang, Y. Quality attributes and control of fresh-cut produce. *Stewart Postharvest Rev.* **2007**, *3*, 1–9. [CrossRef]
2. Francis, G.A.; Gallone, A.; Nychas, G.J.; Sofos, J.N.; Colleli, G.; Amodio, M.L.; Spano, G. Factors affecting quality and safety of fresh-cut produce. *Crit. Rev. Food Sci. Nutr.* **2012**, *52*, 595–610. [CrossRef]
3. Iturralde-Garcia, R.D.; Cinco-Moroyoqui, F.J.; Martínez-Cruz, O.; Ruiz-Cruz, S.; Wong-Corral, F.J.; Borboa-Flores, J.; Cornejo-Ramírez, Y.J.; Bernal-Mercado, A.T.; Del-Toro-Sánche, C.L. Emerging technologies for prolonging fresh-cut fruits' quality and safety during storage. *Horticulturae* **2022**, *8*, 731. [CrossRef]
4. Pang, X.; Lin, Z.; Wang, M.; Liang, H.; Zhao, Y.; Li, Y.; Yan, B.J.; He, Y.; Wu, X.; Wang, Q.; et al. Mechanisms underlying the effect of high-temperature curing treatments on the browning response of fresh-cut yams. *Food Chem.* **2025**, *476*, 143317. [CrossRef]
5. Yuan, X.; Zhan, Z.; Lin, W.; Zhang, C.; Wang, B. The membrane may be a key factor influencing browning: A mini review on browning mechanisms of fresh-cut fruit and vegetables from a multi-omics perspective. *Front. Nutr.* **2025**, *12*, 1534594. [CrossRef]
6. Hu, W.; Guan, Y.; Feng, K. Biosynthesis of phenolic compounds and antioxidant activity in fresh-cut fruits and vegetables. *Front. Microbiol.* **2022**, *13*, 906069. [CrossRef]
7. Kim, H.J.; Feng, H.; Toshkov, S.A.; Fan, X. Effect of sequential treatment of warm dip and low-dose gamma irradiation on the quality of fresh-cut green onion. *J. Food Sci.* **2005**, *70*, M179–M185. [CrossRef]
8. Silveira, A.C.; Aguayo, E.; Chisari, M.; Artes, F. Calcium salts and heat treatment for quality retention of fresh-cut 'Galia' melon. *Postharvest Biol. Technol.* **2011**, *62*, 77–84. [CrossRef]
9. Ma, L.; Zhang, M.; Bhandari, B.; Gao, Z. Recent developments in novel shelf life extension technologies of fresh-cut fruits and vegetables. *Trends Food Sci. Technol.* **2017**, *64*, 23–28. [CrossRef]
10. Faisal, M.; Arshad, N.; Wang, H.; Li, C.; Ma, J.; Kong, X.; Luo, H.; Yu, L. Recent advances in technologies for preserving fresh-cut fruits and vegetables. *Foods* **2025**, *14*, 2769. [CrossRef]
11. Koukounaras, A.; Siomos, A.S.; Sfakiotakis, E. Impact of heat treatment on ethylene production and yellowing of modified atmosphere packaged rocket leaves. *Postharvest Biol. Technol.* **2009**, *54*, 172–176. [CrossRef]
12. Artes-Hernandes, F.; Martinez-hernandez, G.B.; Aguayo, E.; Gomez, P.A.; Artes, F. Fresh-cut fruit and vegetables: Emerging Eco-friendly techniques for sanitation and preserving safety. In *Chapter 2 Book: Postharvest Handling*; Academic Press: Cambridge, MA, USA, 2017. [CrossRef]
13. Gomes, B.A.F.; Aleksandre, A.C.S.; de Andrade, G.A.V.; Zanzini, A.P.; de Barros, H.E.A.; Silva, L.M.S.F.; Costa, P.A.; Boas, E.V.D.B.V. Recent advances in processing and preservation of minimally processed fruit and vegetables: A review—Part 2: Physical methods and global market outlook. *Food Chem. Adv.* **2023**, *2*, 100304. [CrossRef]
14. Fallik, E. Prestorage hot water treatments (immersion, rinsing and brushing). *Postharvest Biol. Technol.* **2004**, *32*, 125–134. [CrossRef]
15. Sivakumar, D.; Fallik, E. Influence of heat treatments on quality retention of fresh-cut produce. *Food Rev. Int.* **2013**, *29*, 294–320. [CrossRef]
16. Kadam, S.K.; Ahirrao, P.P.; Relekar, P.P.; Khalangre, A.B.; Nigade, S.D. Hot water treatment for fruits and vegetables: A review. *Trends Biosci.* **2020**, *13*, 773–781.
17. Fallik, E.; Alkalai-Tuvia, S.; Chalupowicz, D. Hot water rinsing and brushing of fresh produce as an alternative to chemical treatment after harvest—The story behind the technology. *Agronomy* **2021**, *11*, 1653. [CrossRef]

18. Kang, Y.; Lee, K.; Hoshikawa, K.; Kang, M.; Jang, S. Molecular bases of heat shock responses in vegetable crops with focusing on heat shock factors and heat shock proteins. *Front. Plant Sci.* **2022**, *13*, 837152. [CrossRef]
19. Kan, Y.; Mu, X.R.; Gao, J.; Lin, H.X.; Lin, Y. The molecular basis of heat stress responses in plant. *Mol. Plant* **2023**, *16*, 1612–1634. [CrossRef]
20. Tan, Y.; Cao, Y.; Mou, F.; Liu, B.; Wu, H.; Zou, S.; Ai, L.; Sui, S. Transcriptome profiling of two *Camellia japonica* cultivars with different heat tolerance reveals heat stress response mechanisms. *Plants* **2024**, *13*, 3089. [CrossRef]
21. You, W.; Zhang, J.; Ru, X.; Xu, F.; Wu, Z.; Jin, P.; Zheng, Y.; Cao, S. Exogenous $CaCl_2$ delays flesh softening by inhibiting the degradation of cell wall in fresh-cut cantaloupe. *Postharvest Biol. Technol.* **2024**, *213*, 112934. [CrossRef]
22. Corpas, F.J.; Taboada, J.; Palma, J.M. Integration of NO and H_2S signaling in higher plants. *Plant Commun.* **2026**, *7*, 101664. [CrossRef]
23. Müller, M. Foes or friends: ABA and ethylene interaction under abiotic stress. *Plants* **2021**, *10*, 448. [CrossRef]
24. Nuruzzaman, M.; Sharoni, A.M.; Kikuchi, S. Roles of NAC transcription factors in the regulation biotic and abiotic stress responses in plants. *Front. Microbiol.* **2013**, *4*, 248. [CrossRef]
25. Chen, Y.; Xia, P. NAC transcription factors as biological macromolecules responded to abiotic stress: A comprehensive review. *Int. J. Biol. Macromol.* **2025**, *308*, 142400. [CrossRef]
26. Zhao, M.; Liu, Z.; Xue, P.; Zhang, X.; Wan, X. Genomic characterization of the NAC transcription factors in carnation and function analysis of DcNAC41 involved in thermotolerance. *Plant Physiol. Biochem.* **2025**, *219*, 109390. [CrossRef]
27. Wang, B.; Yan, T.; Shi, J.; Sun, Y.; Wang, Q.; Li, Q. The stability of cell structure and antioxidant enzymes are essential for fresh-cut potato browning. *Food Res. Int.* **2023**, *164*, 112449. [CrossRef]
28. Saltveit, M.E. Wound induced changes in phenolic metabolism and tissue browning are altered by heat shock. *Postharvest Biol. Technol.* **2000**, *21*, 61–69. [CrossRef]
29. Artes, F.G.; Allende, A. Processing lines and alternative preservation techniques to prolong the shelf-life of minimally fresh processed leafy vegetables. *Eur. J. Hortic. Sci.* **2005**, *70*, 231–245. [CrossRef]
30. Lurie, S.; Pedreschi, R. Fundamental aspects of postharvest heat treatment. *Hortic. Res.* **2014**, *1*, 14030. [CrossRef]
31. Hagele, F.; Baur, S.; Menegat, A.; Gerhards, R.; Carle, R.; Schweiggert, R.M. Chlorophyll fluorescence imaging for monitoring the effect of minimal processing and warm water treatments on physiological properties and quality attributes of fresh-cut salads. *Food Bioprocess Technol.* **2016**, *9*, 650–663. [CrossRef]
32. Jayasundara, J.M.D.N.; Sawbhagya, L.H.N.; Kumarihami, H.M.P.C.; Kramchote, S.; Fallik, E. A comprehensive review of hot water treatments of fruits and vegetables for postharvest quality management. *J. Postharvest Technol.* **2025**, *13*, 1–36. [CrossRef]
33. Aghdam, M.S.; Sevillano, L.; Flores, F.B.; Bodbodak, S. Heat shock proteins as biochemical markers for postharvest chilling stress in fruits and vegetables. *Sci. Hortic.* **2013**, *160*, 54–64. [CrossRef]
34. Wang, B.; Wang, G.; Yuan, X.; Jiang, Y.; Zhu, Y.; Wang, Y.; Yang, P. Metabolomics and transcriptomic profiles reveal membrane lipid metabolism being an important factor of sliced taro browning. *Postharvest Biol. Technol.* **2024**, *214*, 113000. [CrossRef]
35. Li, Z.; Li, B.; Li, M.; Fu, X.; Zhao, X.; Min, D.; Li, F.; Li, X.; Zhang, X. Hot air pretreatment alleviates browning of fresh-cut pitaya fruit by regulating phenylpropanoid pathway and ascorbate-glutathione cycle. *Postharvest Biol. Technol.* **2022**, *190*, 111954. [CrossRef]
36. Kantakhoo, J.; Imahori, Y. Antioxidative responses to pre-storage hot water treatment of red sweet pepper (*Capsicum annuum* L.) fruit during cold storage. *Foods* **2021**, *10*, 3031. [CrossRef]
37. Liu, J.; Huang, J.; Yu, K.; Chang, X.; Li, Y.; Chen, X.; Peng, S.; Zhou, L.; Liu, W. Metabolomic and transcriptomic profiles reveal the mechanism of browning inhibition of *Pueraria lobata* by heat treatment. *Food Chem.* **2025**, *495*, 146442. [CrossRef]
38. Duarte-Sierra, A.; Forney, C.F.; Michaud, D.; Angers, P.; Arul, J. Influence of hermetic heat treatment on quality and phytochemical compounds of broccoli florets during storage. *Postharvest Biol. Technol.* **2017**, *128*, 44–53. [CrossRef]
39. Campos-Vargas, R.; Nonogaki, H.; Suslow, T.; Saltveit, M.E. Heat shock treatments delay the increase in wound-induced phenylalanine ammonia-lyase activity by altering its expression, not its induction in Romaine lettuce (*Lactuca sativa*) tissue. *Physiol. Plant.* **2005**, *123*, 82–91. [CrossRef]
40. He, Q.; Luo, Y. Enzymatic browning and its control in fresh-cut produce. *Stewart Postharvest Rev.* **2007**, *3*, 1–7. [CrossRef]
41. Wulfkuehler, S.; Stark, S.; Dietz, J.; Schmidt, H.; Weiss, A.; Carle, R. Effect of water jet cutting and moderate heat treatment on quality of fresh-cut red oak leaf lettuce (*Lactuca sativa* L. var. *crispa*). *Food Bioprocess Technol.* **2014**, *7*, 3478–3492. [CrossRef]
42. Wang, J.; Zhou, N.; Ma, S.; Yang, X.; Xing, J. Preservation of minimally processed carrots using the combination of ultrasound and mild heat ascorbic acid. *Ultrason. Sonochem.* **2024**, *111*, 107086. [CrossRef]
43. Xu, X.; Liu, P.; Dong, T.; Zhang, S.; Wang, Q. Short-term warming inhibits polyphenol oxidase activity and influenced free amino acid accumulation and de novo synthesis of tyrosine in fresh-cut potato. *Postharvest Biol. Technol.* **2022**, *186*, 111830. [CrossRef]
44. Lemoine, M.L.; Civello, P.; Chaves, A.; Martinez, G. Hot air treatment delays senescence and maintains quality of fresh-cut broccoli florets during refrigerated storage. *LWT—Food Sci. Technol.* **2009**, *42*, 1076–1081. [CrossRef]

45. Qi, Z.; Chen, M.; Zhao, Y.; Li, L.; Zhu, C.; Sun, Y.; Dang, Q.; Zhao, Z.; Shi1, Y.; Chen, K. Postharvest heat treatment delays fruit ripening and softening by S-nitrosylation of PpACO1 in peach. *Food Qual. Saf.* **2025**, *9*, fyaf023. [CrossRef]
46. Aghdam, M.S.; Bodbodal, S. Postharvest heat treatment for mitigation of chilling injury in fruits and vegetables. *Food Bioprocess Technol.* **2014**, *7*, 37–53. [CrossRef]
47. Lv, N.; Zhang, H.; Zhou, H.; Wang, C.; Guo, C.; Wang, L. Hot water mobilizes the metabolism of energy, soluble sugar, cell wall, and phenolics to cope with chilling injury in postharvest snap beans. *J. Sci. Food Agric.* **2024**, *104*, 8263–8274. [CrossRef]
48. Goyeneche, R.; Scala, K.D.; Goni, M.G.; Vega-Galvez, A.; Quispe-Fuentes, I.; Roura, S.I. Application of ascorbic acid and mild shock to improve shelf life and ensure microbial safety of sliced radish (*Raphanus sativus* L.). *J. Food Process. Preserv.* **2015**, *39*, 3022–3031. [CrossRef]
49. Loayza, F.E.; Brecht, J.K.; Simonne, A.H.; Plotto, A.; Baldwin, E.A.; Bai, J.; Lon-Kan, E. A brief hot water treatment alleviates chilling injury symptoms in fresh tomatoes. *J. Sci. Food Agric.* **2020**, *10*, 54–64. [CrossRef]
50. Loayza, F.E.; Brecht, J.K.; Simonne, A.H.; Plotto, A.; Baldwin, E.A.; Bai, J.; Lon-Kan, E. Enhancement of the antioxidant capacity of ripe tomatoes by the application of a hot water treatment at the mature-green stage. *Postharvest Biol. Technol.* **2020**, *161*, 111054. [CrossRef]
51. Ramos, A.; Arboleda, L.; Ramos, S.; Mejia, E. Effect of heat treatment on the antioxidant capacity of fruits and vegetables—A review study. *ESPOCH Congr. Ecuador. J. S.T.E.A.M.* **2024**, *3*, 87–102. [CrossRef]
52. Garcia-Lorca, N.; Salas-Millan, J.; Aguayo, E. Up-cycling broccoli stalks into fresh-cut sticks: Postharvest strategies for quality and shelf-life enhancement. *Foods* **2025**, *14*, 2476. [CrossRef]
53. Silveira, A.C.; Aguayo, E.; Escalona, V.H.; Artes, F. Hot water treatment and peracetic acid to maintain fresh-cut Galia melon quality. *Innov. Food Sci. Emerg. Technol.* **2011**, *12*, 569–576. [CrossRef]
54. Mu, B.; Xue, J.; Zhang, S.; Li, Z. Effects of use of different temperature and calcium chloride treatments during storage on the quality of fresh-cut "Xuebai" cauliflowers. *Foods* **2022**, *11*, 442. [CrossRef]
55. Roura, S.I.; Pereyra, L.; del Valle, C.E. Phenylalanine ammonia lyase activity in fresh cut lettuce subjected to the combined action of heat mild shocks and chemical additives. *LWT—Food Sci. Technol.* **2008**, *41*, 919–924. [CrossRef]
56. Durak, M.Z.; Churey, J.J.; Worobo, R.W. Efficacy of UV acidified sodium hypochlorite, and mild heat for decontamination of surface and infiltrated *Escherichia coli* O157:H7 on green onions and baby spinach. *J. Food Prot.* **2012**, *75*, 1198–1206. [CrossRef]
57. Ma, S.; Zhou, N.; Fu, Y.; Wang, J. Combined ascorbic acid and mild heat treatment to improve the quality of fresh-cut carrots. *Foods* **2024**, *13*, 1904. [CrossRef]
58. Zhang, Y.; Huang, H.H.; Ma, L.Z.; Masuda, Y.; Honjoh, K.; Miyamoto, T. Inactivation of mixed *Escherichia coli* O157:H7 biofilms on lettuce by bacteriophage in combination with slightly acidic hypochlorous water (SAHW) and mild heat treatment. *Food Microbiol.* **2022**, *104*, 104010. [CrossRef]
59. Liu, Q.; Jin, X.; Feng, X.; Yang, H.; Fu, C. Inactivation kinetics of *Escherichia coli* O157:H7 and *Salmonella typhimurium* on organic carrot (*Daucus carota* L.) treated with low concentration electrolyzed water combined with short-term treatment. *Food Control* **2019**, *106*, 106702. [CrossRef]
60. Ukuku, D.O.; Pilizota, V.; Sapers, G.M. Effect of hot water and hydrogen peroxide treatments on survival of *Salmonella* and microbial quality of whole and fresh-cut cantaloupe. *J. Food Prot.* **2004**, *67*, 432–437. [CrossRef]
61. Nie, X.; Zhao, Y.; Li, Y.; Lv, M. 1-Methylcyclopropylene and heat treatment alleviate chilling injury in purple sweet potato by regulating ROS homeostasis. *Sci. Hortic.* **2024**, *324*, 112605. [CrossRef]
62. Medina-Jaramillo, C.; Usgame-Fagua, K.; Franco-Gonzales, N.; Lopez-Cordoba, A. Single and combined effect of mild heat treatment and alginate coatings on quality preservation of minimally processed bunching green onions. *Foods* **2022**, *11*, 641. [CrossRef]
63. Moreira, M.; Ponce, A.; Ansorena, R.; Roura, S.I. Effectiveness of edible coatings combined with mild heat shocks on microbial spoilage and sensory quality of fresh cut broccoli (*Brassica oleracea* L). *J. Food Sci.* **2011**, *76*, 367–374. [CrossRef]
64. Alicea, C.; Annous, B.A.; Mendez, D.P.; Burke, A.; Orellana, L.E. Evaluation of hot water, gaseous chlorine dioxide, and chlorine treatment with combination with in edible coating for enhancing safety, quality, and shelf life of fresh-cut cantaloupes. *J. Food Prot.* **2018**, *81*, 534–541. [CrossRef]
65. Widjaja, F.; Steensma, P.; Annala, L.; Klami, A.; Kangasjarvi, S.; Lehtonen, M.; Mikkonen, K.S. Non-targeted LC-MS metabolomics reveal shifts from wound induced enzymatic browning to lignification during extended storage of fresh-cut lettuce in modified atmosphere packaging. *Curr. Res. Food Sci.* **2025**, *10*, 100959. [CrossRef]
66. Toivonen, P.M.A.; DeEll, J.R. Chlorophyll fluorescence, fermentation product accumulation, and quality of stored broccoli in modified atmosphere packages and subsequent air storage. *Postharvest Biol. Technol.* **2001**, *23*, 61–69. [CrossRef]
67. Cantwell, M.I.; Kang, J.; Hong, G. Heat treatment control sprouting and rooting of garlic cloves. *Postharvest Biol. Technol.* **2003**, *30*, 57–65. [CrossRef]
68. Yoon, H.S.; Choi, I.L.; Heo, J.H.; Kim, J.Y.; Han, S.J.; Kang, H.M. Influence of hot water immersion and MAP pre-treatments on sterilization and asparagus spear qualities during cold storage. *Hortic. Sci. Technol.* **2018**, *36*, 756–765. [CrossRef]

69. Stringer, S.C.; Plowman, J.; Peck, M.W. The microbiological quality of hot water-washed broccoli florets and cut green beans. *J. Appl. Microbiol.* **2007**, *102*, 41–50. [CrossRef]
70. Cao, Z.; Wang, E.; Xu, X.; Tong, C.; Zhao, X.; Song, X.; Wang, J.; Wang, H.; Xia, X.; Zhao, Y. Beat the heat: Signaling pathway-mediated strategies for plant thermotolerance. *Forests* **2023**, *14*, 2026. [CrossRef]
71. Liu, X.; Xiao, K.; Zhang, A.; Zhu, W.; Zhang, H.; Tan, F.; Huang, Q.; Wu, X.; Zha, D. Metabolomic analysis, combined with enzymatic and transcriptome assays, to reveal the browning resistance mechanism of fresh-cut eggplant. *Foods* **2022**, *11*, 1174. [CrossRef]
72. Wu, Z.; Tu, M.; Yang, X.; Xu, J.; Yu, Z. Effect of cutting on the reactive oxygen species accumulation and energy change in postharvest melon fruit during storage. *Sci. Hortic.* **2019**, *257*, 108752. [CrossRef]
73. Loaiza-Velarde, J.G.; Saltveit, M.E. Heat shocks applied either before or after wounding reduce browning of lettuce leaf.issue. *J. Am. Soc. Hortic. Sci.* **2001**, *126*, 227–234. [CrossRef]
74. Fan, X.; Toivinen, P.M.A.; Rajkowski, K.T.; Sokorai, K.J.B. Warm water treatment in combination with modified atmosphere packaging reduces undesirable effects of irradiation on the quality of fresh-cut iceberg lettuce. *J. Agric. Food Chem.* **2003**, *51*, 5. [CrossRef]
75. Murata, M.; Tanaka, E.; Minoura, E.; Homma, S. Quality of cut lettuce treated by heat shock: Prevention of enzymatic browning, repression of phenylalanine ammonia-lyase activity, and improvement on sensory evaluation during storage. *Biosci. Biotechnol. Biochem.* **2004**, *68*, 501–507. [CrossRef]
76. Baur, S.; Klaiber, R.; Wei, H.; Hammes, W.P.; Carle, R. Effect of temperature and chlorination of pre-washing water on shelf-life and physiological properties of ready-to-use iceberg lettuce. *Innov. Food Sci. Emerg. Technol.* **2005**, *6*, 171–182. [CrossRef]
77. Wulkuehler, S.; Kurfiss, L.; Kammerer, D.R.; Weiss, A.; Schmidt, H.; Carle, R. Impact of different washing procedures on quality of fresh-cut iceberg lettuce (*Lactuca sativa* var. *capitata* L.) and endive (*Cichorium endivia* L.). *Eur. Food Res. Technol.* **2013**, *236*, 229–241. [CrossRef]
78. Paillard, M.J.M.; Otma, E.C.; Woltering, E.J. Effect of mild heat-shock treatments on pink discoloration and physiological parameters in fresh-cut iceberg lettuce. *LWT—Food Sci. Technol.* **2017**, *85*, 456–459. [CrossRef]
79. Abeele, C.V.; Raes, K.; Sampers, I. Effect of mild heat treatment on browning-related parameters in fresh-cut iceberg lettuce. *J. Food Biochem.* **2019**, *43*, e12906. [CrossRef]
80. Martin-Diana, A.B.; Rico, D.; Frias, J.; Henehan, G.T.M.; Mulcahy, J.; Barat, J.M.; Barry-Ryan, C. Effect of calcium lactate and heat-shock on texture in fresh-cut lettuce during storage. *J. Food Eng.* **2006**, *77*, 1069–1077. [CrossRef]
81. Lin, C.M.; Moon, S.S.; Doyle, M.P.; McWatters, K.H. Inactivation of *Escherichia coli* O157:H7, *Salmonella enterica Serotype enteritidis*, and *Listeria monocytogenes* on lettuce by hydrogen peroxide and lactic acid and by hydrogen peroxide with mild heat. *J. Food Prot.* **2002**, *65*, 1215–1220. [CrossRef]
82. Kondo, N.; Murata, M.; Isshiki, K. Efficiency of sodium hypochlorite, fumaric acid and mild heat in killing native microflora and *Escherichia coli* O157:H7, *Salmonella typhimurium* DT104, and *Staphylococcus aureus* attached to fresh-cut lettuce. *J. Food Prot.* **2006**, *69*, 2. [CrossRef]
83. Moreira, M.R.; Ponce, A.G.; del Valle, C.E.; Pereyra, L.; Roura, S.I. Mild heat shocks to extend the shelf life of minimally processed lettuce. *J. Appl. Hortic.* **2008**, *10*, 87–92. [CrossRef]
84. Salman, A.; Goupil, P.; Filgueras, H.; Charles, F.; Legoigt, G.; Sallanon, H. Controlled atmosphere and heat shock affect PAL 1 and HSP90 mRNA accumulation in fresh-cut endive (*Cichorium intybus* L.). *Eur. Food Res. Technol.* **2008**, *227*, 721–726. [CrossRef]
85. Gomez, F.; Fernandez, L.; Gergoff, G.; Guiamat, J.J.; Chaves, A.; Bartoli, C.G. Heat shock increases mitochondrial H_2O_2 production and extends postharvest life of spinach leaves. *Postharvest Biol. Technol.* **2008**, *49*, 229–234. [CrossRef]
86. Glowacz, M.; Reade, J.; Monaghan, J.; Mogren, L. Hot water treatment after harvest preserves nutritional quality of spinach during storage. *Acta Hortic.* **2018**, *1209*, 123–128. [CrossRef]
87. Glowacz, M.; Mogren, L.M.; Reade, J.P.H.; Cobb, A.H.; Monaghan, J.M. Can hot water treatment enhance or maintain postharvest quality of spinach leaves? *Postharvest Biol. Technol.* **2013**, *81*, 23–28. [CrossRef]
88. Hong, G.; Peiser, G.; Cantwell, M.I. Use of controlled atmospheres and heat treatment to maintain quality of intact and minimally processed green onions. *Postharvest Biol. Technol.* **2000**, *20*, 53–61. [CrossRef]
89. Cantwell, M.I.; Hong, G.; Suslow, T.V. Heat treatments control extension growth and enhance microbial disinfection of minimally processed green onion. *HortScience* **2001**, *36*, 732–737. [CrossRef]
90. Grzegorzewska, M.; Badelek, E.; Sczech, M.; Kosson, R.; Wrzodak, A.; Kowalska, B.; Colelli, G.; Szwejda-Grzybowska, J.; Maciorowski, R. The effect of hot water treatment on the storage ability improvement of fresh-cut Chinese cabbage. *Sci. Hortic.* **2022**, *291*, 110551. [CrossRef]
91. Choi, E.J.; Park, H.W.; Kim, S.B.; Ryu, S.; Lim, J.; Hong, E.J.; Byeon, Y.S.; Chun, H.H. 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* **2019**, *98*, 501–509. [CrossRef]

92. Ells, T.C.; Hansen, L.T. Growth of *Listeria* spp. in shredded cabbage is enhanced by a mild heat treatment. *J. Food Prot.* **2010**, *73*, 425–433. [CrossRef]
93. Bae, J.M.; Lee, D.U.; Jeong, M.C.; Jeong, H.C. Change of quality characteristics in fresh-cut Romaine lettuce by heat treatment. *Korean J. Food Preserv.* **2016**, *23*, 27–33. [CrossRef]
94. Huang, Y.; Chen, H. Effect of organic acids, hydrogen peroxide and mild heat on inactivation of *Escherichia coli* O157:H7 on baby spinach. *Food Control* **2011**, *22*, 1178–1183. [CrossRef]
95. Alegria, C.; Pinheiro, J.; Goncalves, E.M.; Fernandes, I.; Moldao, M.; Abreu, M. Evaluation of pre-cut heat treatment as an alternative to chlorine in minimally processed shredded carrot. *Innov. Food Sci. Emerg. Technol.* **2010**, *1*, 155–161. [CrossRef]
96. Alegria, C.; Pinheiro, J.; Duthoit, M.; Goncalves, E.M.; Moldao-Martins, M.; Abreu, M. Fresh-cut carrot (cv. Nantes) quality as affected by abiotic stress (heat shock and UV-C irradiation) pre-treatments. *LWT—Food Sci. Technol.* **2012**, *48*, 197–203. [CrossRef]
97. Alegria, C.; Goncalves, E.M.; Moldao-Martins, M.; Abreu, M. Influence of heat-shock pre-treatment on wound-induced phenolic biosynthesis as an alternative strategy towards fresh-cut carrot processing. *Food Sci. Technol. Int.* **2021**, *28*, 421–429. [CrossRef]
98. Alegria, C.; Goncalves, E.M.; Moldao-Martins, M.; Abreu, M. Multi-target alternative approaches to promoting fresh-cut carrots' bioactive and fresh-like quality. *Foods* **2022**, *11*, 2422. [CrossRef]
99. Rico, D.; Martin-Diana, A.B.; Frias, J.M.; Barat, J.M.; Henehan, G.T.M.; Barry-Ryan, C. Improvement in texture using calcium lactate and heat shock treatments for stored ready to eat carrots. *J. Food Eng.* **2007**, *79*, 1196–1206. [CrossRef]
100. Goyeneche, R.; Aguero, M.V.; Roura, S.; Scala, K.D. Application of citric acid and mild shock to minimally processed sliced radish: Color evaluation. *Postharvest Biol. Technol.* **2014**, *93*, 106–113. [CrossRef]
101. Chang, M.S.; Kim, J.G.; Kim, G.H. Quality characteristics of fresh-cut lotus roots according to the temperature of the wash water. *Korean J. Food Preserv.* **2011**, *18*, 288–293. [CrossRef]
102. Nasrin, T.A.A.; Yasmin, L.; Arfin, M.S.; Molla, M.M.; Uddin, M.N. Effect of hot water treatment with organic additives in fresh cut carrot. *J. Agric. Sci. Food Technol.* **2021**, *7*, 1–9. [CrossRef]
103. Koide, S.; Shitanda, D.; Note, M.; Cao, W. Effect of mildly heated, slightly acidic electrolyzed water on the disinfection and physiochemical properties of sliced carrot. *Food Control* **2011**, *22*, 452–456. [CrossRef]
104. Son, J.; Hyun, J.E.; Lee, J.W.; Lee, S.Y.; Moon, B.K. Combined application of anti-browning heat treatment and modified-atmosphere packaging to extend the shelf life of fresh-cut lotus root. *J. Food Sci.* **2015**, *80*, 1178–1187. [CrossRef]
105. Chang, M.S.; An, S.J.; Kim, G.H.; Kim, J.G. Effect of heat treatment and various browning inhibitors on the quality of fresh-cut burdock. *Acta Hortic.* **2018**, *1209*, 431–438. [CrossRef]
106. Tzouvaltzis, P.; Siomos, A.S.; Gerasopoulos, D. Effect of hot water treatment on leaf extension growth, fresh weight loss and color of stored minimally processed leeks. *Postharvest Biol. Technol.* **2006**, *39*, 56–60. [CrossRef]
107. Tzouvaltzis, P.; Gerasopoulos, D.; Siomos, A.S. Effects of base removal and heat treatment on visual and nutritional quality of minimally processed leeks. *Postharvest Biol. Technol.* **2007**, *43*, 158–164. [CrossRef]
108. Siddiq, M.; Roidoung, S.; Sogi, D.S.; Dolan, K.D. Total phenolics, antioxidant properties and quality of fresh-cut onions (*Allium cepa* L.) treated with mild-heat. *Food Chem.* **2013**, *136*, 803–806. [CrossRef]
109. Abd Rahim, A.H.; Osman, A.; Sari, N.; Rahman, A.R. Effect of hot water dips in controlling rooting and sprouting of minimally processed sliced garlic (*Allium sativum* L.) during room temperature storage. *J. Food Agric. Environ.* **2006**, *4*, 2.
110. Saleh, M.A.; Shehata, A.S.A.; Abdelmaksoud, T.G. Effect of different treatment on storage quality of celery petioles. *Future Food J. Food Agric. Soc.* **2023**, *11*, 3. [CrossRef]
111. Saltveit, M.E. Heat-shock treatments increase the chilling tolerance of harvested asparagus spears. *HortScience* **2017**, *52*, 1563–1568. [CrossRef]
112. Siomos, A.S.; Gerasopoulos, D.; Tsouvaltzis, P. Prestorage hot water treatments inhibit postharvest anthocyanin synthesis and retain overall quality of white asparagus spears. *Postharvest Biol. Technol.* **2005**, *38*, 160–168. [CrossRef]
113. Siomos, A.S.; Gerasopoulos, D.; Tsouvaltzis, P.; Koukounaras, A. Effects of heat treatment on atmospheric composition and color of peeled white asparagus in modified atmosphere packaging. *Innov. Food Sci. Emerg. Technol.* **2010**, *11*, 118–122. [CrossRef]
114. Zudaire, L.; Vinas, I.; Ababias, M.; Simo, J.; Aguili-Aguayo, I. Efficacy of chlorine, peroxyacetic acid and mild-heat treatment on the reduction of natural microflora and maintenance of quality of fresh-cut calcots (*Allium cepa* L.). *LWT—Food Sci. Technol.* **2018**, *59*, 339–345. [CrossRef]
115. Loaiza-Velarde, J.G.; Mangrich, M.E.; Campos-Vargas, R.; Saltveit, M.E. Heat shock reduces browning of fresh-cut celery petioles. *Postharvest Biol. Technol.* **2003**, *27*, 3. [CrossRef]
116. Vina, S.Z.; Lopez Osornio, M.M.; Chaves, A.R. Quality changes in fresh-cut celery as affected by heat treatment and storage. *J. Sci. Food Agric.* **2007**, *87*, 1400–1407. [CrossRef]
117. Vina, S.Z.; Chaves, A.R. Effect of heat treatment and refrigerated storage on antioxidant properties of pre-cut celery (*Apium graveolens* L.). *Int. J. Food Sci. Technol.* **2008**, *43*, 44–51. [CrossRef]
118. Renumarn, P.; Srilaong, V.; Uthairatanakij, A.; Kanalayanarat, S.; Jitareerat, P. Effect of hot water treatment on survival of *E. coli* and *Salmonella* spp. and physical properties in fresh-cut broccoli florets. *As. Food Ag-Ind.* **2010**, *3*, 516–525.

119. Ansorena, M.R.; Marcovich, N.E.; Roura, S.I. Impact of edible coatings and mild heat shocks on quality of minimally processed broccoli (*Brassica oleracea* L.) during refrigerated storage. *Postharvest Biol. Technol.* **2011**, *59*, 53–63. [CrossRef]
120. Ansorena, M.R.; Moreira, M.R.; Roura, S.I. Combined effect of ultrasound; mild heat shock and citric acid to retain greenness; nutritional and microbiological quality of minimally processed broccoli (*Brassica oleracea* L.): An optimization study. *Postharvest Biol. Technol.* **2014**, *94*, 1–13. [CrossRef]
121. Renumarn, P.; Srilaong, V.; Uthairatanakij, A.; Kanalayanarat, S.; Jitareerat, P. Influence of hot water treatment combined with sodium chlorite on microbial counts antioxidant quality of fresh-cut broccoli florets. *Acta Hortic.* **2015**, *1088*, 383–388. [CrossRef]
122. Lemoine, M.L.; Civello, P.M.; Chaves, A.R.; Martinez, G.A. Effect of combined treatment with hot air and UV-C on senescence and quality parameters of minimally processed broccoli (*Brassica oleracea* L. var. *Ital.*). *Postharvest Biol. Technol.* **2008**, *48*, 15–21. [CrossRef]
123. Miceli, A.; Vetrano, F.; Romano, C. Effect of hot air treatment on minimally processed cauliflower. *Acta Hortic.* **2013**, *1005*, 309–314. [CrossRef]
124. Sgroppo, S.C.; Pereyra, M.V. Using mild heat treatment to improve the bioactive related compounds on fresh-cut green bell peppers. *Int. J. Food Sci. Technol.* **2009**, *44*, 1793–1801. [CrossRef]
125. Rodoni, L.M.; Hesperue, J.H.; Ortiz, C.M.; Lemoine, M.L.; Concellon, A.; Vicente, A.R. Combined use of mild heat treatment and refrigeration to extend the postharvest life of organic pepper sticks, as affected by fruit maturity stage. *Postharvest Biol. Technol.* **2016**, *17*, 168–176. [CrossRef]
126. Grzegorzewska, M.; Machlanska, A. Post-cutting hot water treatment of pepper fruit: Impact on quality during short-term storage. *Agronomy* **2025**, *15*, 1406. [CrossRef]
127. Das, B.K.; Kim, J.G. Combine effect of heat treatment and washing solutions on the quality and microbial reduction of fresh-cut paprika. *Hortic. Environ. Biotechnol.* **2010**, *51*, 257–261.
128. Kim, J.G. Environmental friendly sanitation to improve quality and microbial safety of fresh-cut vegetables. In *Chapter 11 from Book Biotechnology—Molecular Studies and Novel Applications for Improved Quality of Human Life*; IntechOpen: London, UK, 2012. [CrossRef]
129. Hakim, A.N.; Austin, M.; Batal, D.; Gullo, S.; Khatoon, M. Effect of heat treatment and controlled atmosphere on quality of fresh-cut tomatoes. *Adv. Hortic. Sci.* **2002**, *16*, 88–94.
130. Zhang, X.; Shen, L.; Li, F.; Meng, D.; Sheng, J. Arginase induction by heat treatment contributes to amelioration of chilling injury and activation of antioxidant enzymes in tomato fruit. *Postharvest Biol. Technol.* **2013**, *79*, 1–8. [CrossRef]
131. Ma, Y.; Zhang, L.; Wang, Q. Pre-cut hot water treatment inhibited the browning of fresh-cut eggplants. *Acta Hortic.* **2021**, *1319*, 187–198. [CrossRef]
132. Lemos, M.L.; Gutierez, D.R.; Farias, M.J.; Rodrigez, S.C. Application of antioxidants and hot water treatments to improve shelf life of fresh-cut eggplants (*Solanum melongena* L.) during storage. *Rev. Fac. Nac. Agron. Medellín.* **2023**, *76*, 10381–11039. [CrossRef]
133. Lemos, M.L.; Gutierez, D.R.; Rodrigez, S.C. Influence of modified- atmosphere packaging, antioxidants and mild heat treatment on the shelf life of fresh-cut eggplants (*Solanum melongena*). *Biol. Life Sci. Forum* **2026**, *56*, 21. [CrossRef]
134. Fan, X.; Annous, B.A.; Beaulieu, J.C.; Sites, J.E. Effect of hot water surface pasteurization on whole fruit on shelf life and quality of fresh-cut Cantaloupe. *J. Food Sci.* **2008**, *73*, 9198. [CrossRef]
135. Fallik, E.; Rodow, V.; Horev, B.; Sela, S.; Alkalai-Tuvia, S.; Vinokur, Y. Hot water rinsing and brushing technology for the fresh-cut industry. *Acta Hortic.* **2007**, *746*, 229–236. [CrossRef]
136. Ukuku, D.O.; Geveke, D.J.; Chau, L.; Bigley, A.; Niemira, B.A. Appearance and overall acceptability of fresh-cut cantaloupe pieces from whole melon treated with wet steam process. *LWT—Food Sci. Technol.* **2017**, *82*, 235–242. [CrossRef]
137. Lamicanra, O.; Bett-Garber, L.; Ingram, D.; Watson, M. Use of mild heat pretreatment on quality retention of fresh-cut cantaloupe melon. *J. Food Sci.* **2005**, *70*, 53–57. [CrossRef]
138. Supapvanich, S.; Ngiwpa, J.; Yarprakhon, W. Effect of hot water treatments on quality of fresh-cut muskmelon fruit (*Cucumis melo* L.) 'Honeyworld'. *Acta Hortic.* **2018**, *1209*, 385–390. [CrossRef]
139. Fan, X.; Annous, B.A.; Sokorai, K.J.; Burke, A.; Mattheis, J.P. Combination of hot water surface pasteurization of whole fruit and low dose gamma irradiation of fresh-cut cantaloupe. *J. Food Prot.* **2006**, *69*, 912–919. [CrossRef]
140. Aguayo, E.; Escalona, V.H.; Artes, F. Effect of hot water treatment and various calcium salts on quality of fresh-cut 'Amarillo' melon. *Postharvest Biol. Technol.* **2008**, *47*, 397–406. [CrossRef]
141. Lamicanra, O.; Watson, M.A. Mild heat and calcium treatment effects on fresh-cut cantaloupe melon during storage. *Food Chem.* **2007**, *10*, 1383–1388. [CrossRef]
142. Morgado, C.M.A.; Huguette, S.; Mattiuzo, B.H.; Phrutiya, N.; Charles, F. Heat treatment and active packaging to improve the storage of fresh-cut melons (*Cucumis melo* L). *Fruits* **2016**, *7*, 9–15. [CrossRef]
143. Su, Y.; Wang, Q.; Chen, Y.; Feng, X. Effect of heat-shock treatments on storage of fresh-cut cucumbers. *Trans. Chin. Soc. Agric. Eng.* **2011**, *27*, 381–387. [CrossRef]

144. Luo, K.; Oh, D.H. Synergistic effect of slightly acidic electrolyzed water and ultrasound at mild heat temperature in microbial reduction and shelf-life extension of fresh-cut bell pepper. *J. Microbiol. Biotechnol.* **2015**, *25*, 1502–1509. [CrossRef]
145. Ruiz, H.; Amoros, A.; Escalona, V. Effect of combination of hydrothermal and atmospheric treatment on the quality and shelf life of tomato (*Solanum lycopersicum* L.) minimally processed. *Sci. Hortic.* **2022**, *293*, 5. [CrossRef]
146. Ukuku, D.O.; Geveke, D.; Chau, L.; Niemira, B.A. Microbial safety and overall quality of cantaloupe fresh-cut pieces prepared from whole fruit after wet steam treatment. *Int. J. Food Microbiol.* **2016**, *231*, 86–89. [CrossRef]
147. Tzouvaltzis, P.; Deltsidis, A.; Brecht, J.K. Hot water treatment and pre-processing storage reduce browning development in fresh-cut potato slices. *HortScience* **2011**, *46*, 1282–1286. [CrossRef]
148. Kim, J.G.; Choi, S.T.; Pae, D.H. Effect of heat treatment and dipping solution combination on the quality of peeled potato 'Jopung'. *Hortic. Sci. Technol.* **2009**, *27*, 256–262.
149. Song, H.J.; Kwon, O.Y.; Kang, B.H.; Hur, S.S. Change in quality attributes of fresh-cut potatoes with heat and browning inhibitor treatment during storage. *Korean J. Food Preserv.* **2013**, *20*, 3. [CrossRef]
150. Tsouvaltzis, P.; Brecht, J.K. Inhibition of enzymatic browning of fresh-cut potato by immersion in citric acid is not solely due to Ph reduction of the solution. *J. Food Process. Preserv.* **2017**, *4*, e12829. [CrossRef]
151. Ouyang, N.; Guo, L.; Hong, C.; Zhang, X.; Liu, Y.; Guo, Y.; Wang, Y.; Ma, H. Effects of delayed tuber cutting after catalytic infrared heat treatment on browning of fresh-cut potatoes and its potential mechanisms. *Food Chem.* **2025**, *480*, 143834. [CrossRef]
152. Wang, Q.; Nie, X.; Cantwell, M. Hot water and ethanol treatments can effectively inhibit the discoloration of fresh-cut sunchoke (*Helianthus tuberosus* L.) tubers. *Postharvest Biol. Tchnol.* **2014**, *94*, 49–57. [CrossRef]
153. Chang, M.S.; Park, M.; Kim, G.H.; Kim, J.G. Effect of heat treatment on the quality of fresh-cut taro. *Acta Hortic.* **2013**, *1012*, 939–945. [CrossRef]
154. Chang, M.S.; Kim, G.H. Combined effect of hot water dipping and vacuum packaging for maintaining the postharvest quality of peeled taro. *Hortic. Environ. Biotechnol.* **2015**, *56*, 662–668. [CrossRef]
155. Xu, W.; Guo, T.; Peng, Z.; Li, Y.; Lou, J.; Zhao, F.; Liu, L.; Gao, Y.; Pei, L.; Kacaniova, M.; et al. Ozone, heat shock and microwave differentially promote nutritional quality and antioxidant capacity of sweet corn. *Foods* **2026**, *15*, 911. [CrossRef]

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