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Review

Advances in the Strategic Approaches of Pre- and Post-Harvest Treatment Technologies for Peach Fruits (*Prunus persica*)

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Abstract: Peach (*Prunus persica*) is one of the representative climacteric fruits susceptible to environmental stresses, including microbial contamination. This article analyzed major findings from the literature on pre- and post-harvest technologies for maintaining the quality of peach fruit to figure out the strengths and limitations of each treatment strategy. The key implication from studies of pre-harvest agents directly applied to the fruit surface or supplemented as fertilizer was the application of a mixture regarding substances with diverse working mechanisms to prevent excessive use of the agent. The common objectives of previous research on pre-harvest treatments were not only the improvement in the quality of harvested fruit but also the storability during long-term refrigeration due to the short lifespan of peaches. In the case of post-harvest treatments, the efficacy was considerably affected by various determinant factors (e.g., a cultivar of fruit, the sort of technologies, and storage environments), and thus operating conditions optimized for peach fruit were described in this article. Whereas, although the combined treatment of technologies categorized into principles (physical, chemical, and biological approaches) has been adopted to achieve the synergistic effect, undesirable antagonistic effects (i.e., the inhibition of efficacies expectable from singular treatments) were also reported to highlight the importance for exploring adequate treatment conditions.

Keywords: fruit quality; productivity; fungal infection; long-term fruit storage; fruit ripening; microbial safety; climacteric fruit; stone fruit; combined treatment

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1. Introduction

Peach (*Prunus persica*) is a globally consumed fruit preferred by consumers due to its exotic taste and rich nutritional substances (e.g., minerals, sugars, and amino acids) [1]. Peaches have several antioxidant compounds, including vitamins, phenolic compounds, volatiles, carotenoids, and organic acids [2]. However, as a climacteric fruit, peaches are susceptible to rot and have a short shelf life due to ethylene emission accompanied by a rising respiration rate during storage [3]. Within the *Prunus* genus, peach is a stone fruit that has a thin exocarp or skin with the characteristics of a lignified endocarp and a fleshy mesocarp [4]. Although the production of peaches and nectarines is steadily increasing (Figure 1), the problems in storage and transportation due to their rapid rotting and softening at ambient temperature make their exports difficult [5]. Previous studies regarding the quality of peaches have been conducted with similar objectives to those of other stone fruits (e.g., cherry, plum, and apricot) [6–8]. However, research focused specifically on peaches is needed because peaches age more rapidly and are more vulnerable to disease caused by pathogens than other stone fruits [9].

To enhance the quality and extend the storage period of fruits, both pre-harvest and post-harvest treatment technologies have been consistently developed and applied

from production to storage [10,11]. Pre-harvest treatment is a method performed before harvesting to improve the quality of harvested fruits and/or extend their shelf life during post-harvest storage [12,13]. Post-harvest treatment prevents the deterioration of fruit quality until consumption by consumers [14,15]. Various types of pre- and post-harvest technologies have been reported with differing effects, and even the effects of a particular technology can differ depending on the processing target or environment. Therefore, insights into the design of pre- and post-harvest treatment strategies to secure peach quality and safety can be obtained by the comprehensive analysis of key findings from previous relevant research conducted to determine desirable treatment conditions.

Previous review articles regarding peaches have focused on determinant factors of fruit characteristics and specific pre- or post-harvest technology as follows: pre-harvest conditions linked to the quality of peaches [16], the treatment of salicylic acid to enhance post-harvest storability of peaches [17], the effects of nitrogen application on the internal quality of peaches [18], and the use of oligosaccharides to improve fruit preservation after harvest [19]. However, a comprehensive analysis of the literature on experimental conditions and the results of various pre- and post-harvest treatments optimally designed for peach fruits according to the categorization of the principles of technologies (i.e., physical, chemical, and biological approaches) and the application strategies (i.e., singular or combined treatments) has rarely been reported. This review article suggests a strategic approach for the pre- and post-treatment of peaches based on relevant research with the following topics: (1) the summary of major quality factors selected for evaluating values of treatment technologies; (2) the distinct implications of studies on physical, chemical, and biological treatment technologies; (3) dose-response (i.e., treatment condition-dependent efficacies) of technologies to estimate the optimal operational methods; and (4) the advantages and disadvantages of the combined treatment compared to singular treatments.

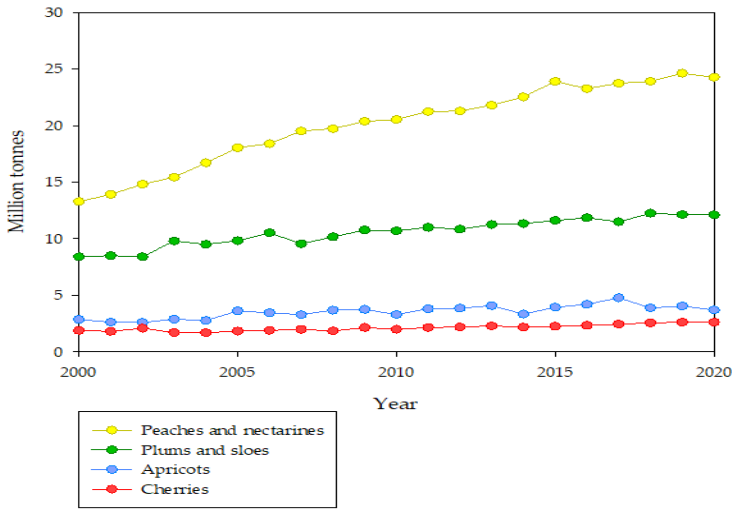

Figure 1. World's production quantities of representative stone fruits (this figure was created by using the data from FAOSTAT [20]).

2. Quality Factors of the Pre- and Post-Harvest Treatment of Peach Fruits

The characteristics of fruit include sensory properties (e.g., texture, taste, aroma, and appearance), chemical constituents, functional values, safety factors (e.g., the concentration of toxigenic substances, and population level of contaminated microorganisms), nutritional value, mechanical properties, and defects caused by the growth or metabolism of pathogens [21]. Major quality factors of peaches investigated from previous research regarding pre- and post-harvest treatments can be categorized as the stability of fruit quality, microbial deterioration, and antioxidant capacity. As shown in Table 1, the quality factors can be estimated from the quantitatively measured values by the indicators related to taste,

color, and nutrients. Examples of the measurable parameters are as follows: firmness, weight loss, volume, total soluble solid (TSS), titratable acidity (TA), ethylene production, vitamin C content, activation of enzymes related to antioxidant ability, antioxidant content, decay incidence, and antimicrobial function. Taste, one of the sensory characteristics, is mainly divided into a sweet and sour flavor that can be indicated by the values of TSS and TA, respectively.

Table 1. Quality factors as the indicator of the effects of pre- and/or post-harvest treatments for peach fruits.

Category	Examples of the Factors
Stability of fruit quality	Weight, volume, length, width or diameter, total soluble solid (TSS), soluble solid content (SSC), titratable acidity (TA), ethylene emission (production), malondialdehyde (MDA) content, firmness, color, vitamin C content, pectin content
Microbial deterioration and damage	Infected wounds, decay, disease incidence, lesion diameter
Antioxidant capacity	Antioxidants content (phenolics, flavonoids), activity of enzymes (catalase (CAT), superoxide dismutase (SOD), ascorbate peroxidase (APX), peroxidase (POD), pectin methyl esterase (PME), phenylalanine ammonia-lyase (PAL), enzymes of ascorbate-glutathione (AsA-GSH) cycle, polyphenol oxidase (PPO), lipoxygenase (LOX))

The stability of fruit quality allows for the maintenance of the product value of peaches from cultivation to harvest followed by storage, and various factors correlated with the changes in physiological characteristics of products have been identified. Quantitative values of morphological characteristics (e.g., volume, length, and width or diameter) can belong to quality factors. One of the major goals of the pre-harvest treatment of fruits is the modulation of metabolisms related to fruit growth and development [22,23]. Whereas, preventing a decrease in weight during fruit storage under refrigerated temperatures due to the loss of water and the response to cold stress is an additional intended function of both pre- and post-harvest treatments [24]. Since an increase in sugar content is closely related to the ripening of peach fruits, TSS can also be an indicator of the product quality of fruit [25]. The measurement of soluble solid content (SSC) is an index of the flavor of peaches to determine the appropriate time for harvest and storage from the perspective of fruit maturation [26]. TA, determined by the titration of internal acid, is a measurement of total acid, which can be used to analyze the growth level and taste of fruits [27]. The ratio of SSC to TA (SSC/TA) is negatively related to the maturity of the fruit and is also used as the representative ripening index [28]. Peach produces ethylene inducing fruit ripening, and the level of ethylene emission or production can be a parameter of maturity [29]. Malondialdehyde (MDA) produced by reactive oxygen species (ROS) is known as an indicator of fruit damage [30]. The color of peach skin and flesh is generally considered a factor in the stability and value of commodities, but is also related to antioxidant capacity because of phytochemicals [31].

The incidence of fungal decay is an important index for shelf life and commercial value because damage to peach fruits is critical from the perspectives of economic loss for producers and retailers. The major fungi reported as the cause of deterioration from peach fruits are brown rot fungi [32], *Rhizopus* rot fungi [33], blue mold [34], and gray mold [35]. Brown rot is commonly caused by fungal species including *Monilinia fructicola, Monilinia laxa,* and *Monilinia fructigena* [36]. *Rhizopus* rot, blue mold disease, and gray mold disease are generally caused by the fungal species of *Rhizopus stolonifer*, *Penicillium expansum*, and *Botrytis cinerea*, respectively [37]. The level of fungal infection has been generally measured by the visual observation of indicators for the severity of fruit diseases (e.g., infected wounds, decay, disease incidence, and lesion diameter).

Antioxidant capacity is the ability to remove ROS, which is a cause of undesirable quality changes in fruits due to weakened stress tolerance and can be evaluated by factors including the contents of phenolics and/or flavonoid compounds [38]. The activity of major enzymes involved in the production or removal of ROS in peach fruits can also

be reported as indicators of the antioxidant capacity as follows: catalase (CAT) [39], superoxide dismutase (SOD) [40], ascorbate peroxidase (APX) [41], peroxidase (POD) [42], pectin methyl esterase (PME) [43], phenylalanine ammonia-lyase (PAL) [44], enzymes that comprise the ascorbate-glutathione (AsA-GSH) cycle [45], polyphenol oxidase (PPO) [46], and lipoxygenase (LOX) [47].

3. Strategic Approach to the Application of Pre-Harvest Treatment Technologies for Peach Fruits

Pre-harvest treatments for general fruits have been used as measures for enhancing the quality and safety of fruits with the treatment of chemical agents (e.g., spraying and spreading, fertilizing) or physical treatments (e.g., bagging fruits, setting a canopy on the fruit tree, and irrigating the field of the orchard) before harvest [16]. Most relevant research using pre-harvest peach fruits reported the application of chemical substances to improve the product quality at harvest and to prevent the deterioration of harvested fruits during storage [48–57]. This indicates that the effects expected from the post-harvest treatment can also be achieved by pre-harvest technologies. Thus, as shown in Table 2, this review mainly analyzed the previous research regarding the evaluation of the efficacies of pre-harvest treatment technologies with the perspectives of not only harvesting but also storage time [58]. Key chemical agents that can be utilized as pre-harvest treatments for peaches by spreading and/or spraying are the following: calcium salts [48–52], acids [53–55], sodium nitroprusside (SNP) [56], and putrescine (PUT) [57]. The use of fertilizer has also been regarded as an effective method to control the quality of peach fruit during cultivation [59,60].

3.1. Spraying and Spreading Chemical Agents to Fruits

3.1.1. Calcium Salts

Spraying salts is a popular pre-treatment for fruits, and salt composed of calcium ions is a representative agent used to treat peaches before harvesting [48,50,52]. Calcium treatment functions in various ways, such as delaying the ageing of fruits by increasing calcium concentrations in the epidermis or slowing hydrolysis by strengthening cell walls to prevent external intrusion [61,62]. Although calcium treatment cannot be an alternative to disinfectants, it increases the resistance of fruit against fungal infection by strengthening cell walls. The composition of calcium salts (e.g., calcium chloride and calcium nitrate) and working concentrations have been reported as important factors that determine effectiveness in the pre-harvest process [48]. The results vary depending on the concentration of the substance, and higher concentrations are generally more effective: in particular, values representing the morphological characteristics (e.g., weight and size) of peaches increase as the content of calcium gradually increases [49,50]. To improve the pre-harvest treatment effects using calcium salts, a combined treatment strategy has generally been adopted to achieve additional or synergistic effects rather than the use of a single compound. Improvement of the stability of fruit quality during the post-harvest storage of peach fruits treated with the agent complex organized with calcium as a basis material (i.e., combining calcium salts with other substances to make the pre-harvest treatment agent: potassium silicate (K_2SiO_3) + Ca^{2+}EDTA, chitosan + calcium chloride ($CaCl_2$), magnesium and titanium + calcium, and potassium sulfate (K_2SO_4) + $CaCl_2$) has been reported. Agents that can improve the stress-modulating capacity of peach fruit can also be combined with calcium salts. Aziz et al. [49] showed the effects of Ca^{2+}EDTA with K_2SiO_3 on the growth and storability of fruit quality from Ca^{2+}EDTA with K_2SiO_3, which support the enzymatic activity encouraging the antioxidant defense mechanism. El-Badawy [50] combined calcium salts with chitosan as the coating material available for the stimulation of plant immune systems supporting fruit growth and protection against microbial attack, and the highest treatment concentration showed the greatest effect. Supplementation of calcium with other activating nutrients (e.g., magnesium and titanium) related to the growth of fruits helps maintain the quality of peaches during storage [51]. Although the combination of various pre-treatment agents is generally expected to show better effects than a singular agent,

agents can have antagonistic effects (i.e., inhibition of the efficacies from agents when used in combination). El-Dengawy et al. [52] reported that the decrease in TSS and anthocyanin with $CaCl_2$ treatment can be complemented by the addition of K_2SO_4; however, this study also showed that combined treatment ($CaCl_2$ + K_2SO_4) resulted in lower firmness than the individual treatment of $CaCl_2$. Therefore, the validation of the presence of undesirable interactions of agents in the pre-treatment complex should be regarded as a prerequisite for the application of combination technology to design appropriate operational conditions.

3.1.2. Acids

Salicylic acid is an organic acid with antimicrobial effects and is regarded as one of the key phenolics naturally present in plants to regulate the growth and stress responses of fruits [63,64]. Erogul and Özsoydan [53] compared the effects of 1 mM and 2 mM salicylic acid solutions spread on peaches at the 23rd and 15th days before harvest on the quality changes during cold storage (2 °C, 8 days), followed by exposure to a simulated environment for shelf life (20 °C, 2 days): the results showed the smallest quality changes (e.g., weight loss, reduction in flesh firmness, and reduction in acidity) with the higher concentration (2 mM) [53].

Oxalic acid, universally present in plants, acts as a natural antioxidant, inducing an increase in membrane integrity and a delay in fruit ripening by controlling enzymes associated with quality changes of peaches [65,66]. Razavi and Hajilou [55] showed dose-dependent enhancement of the antioxidant capacity of the fruit surface treated with oxalic acid (up to 5 mM treatment concentration) 15 days before harvest to elicit an increase in the antioxidant content (phenolics and flavonoids) and the activities of antioxidant enzymes as the key mechanism for the extension of shelf life. Although pre-harvest oxalic acid spraying of peaches with higher concentrations can be expected to improve efficacy, it is necessary to consider the problematic health risk factors in the case of overtreatment due to the potential toxicity of oxalic acid [67].

Gibberellic acid is a diterpenoid carboxylic acid that can function as a plant growth hormone to extend the period of fruit availability by controlling the ability of the fruit to respond to abiotic stress factors and to support plant development during ripening [68]. Pegoraro et al. [54] emphasized the beneficial effects of spraying gibberellic acid on peach fruits at the beginning of pit hardening as a pre-harvest treatment in regard to woolliness (i.e., the prevention of woolliness during long-term post-harvest cold storage) and quality factors (i.e., higher values of fruit size and mass); although a delay in ripening did not occur. Gene expression (mRNA abundance) analysis performed to understand the mechanism of the effects of spraying gibberellic acid also showed the metabolism of beneficial functionalities of cell wall structure, intracellular transport, heat shock proteins associated with the homeostasis of the metabolism of peach ripening, and ethylene biosynthesis [54].

3.1.3. Other Chemical Agents for Pre-Harvest Treatment

Sodium nitroprusside (SNP), as a pre- or post-harvest treatment agent for fruits, has been used as a donor of nitric oxide (NO), which contributes to the enhancement of disease resistance and the suppression of ethylene production for fruit quality control [69]. The modulation of fruit metabolic pathways related to antioxidant and antifungal metabolites by SNP can also result in the maintenance of fruit quality through the suppression of ROS formation and the prevention of pathogenic fungal decay, respectively [70,71]. The research from Saba and Moradi [56] showed the efficacy of pre-harvest spraying of SNP on peach fruits (25 and 50 μmol/L, 14 days before harvest) in regards to chilling tolerance, which results in an improvement of the stability of fruit quality during cold storage, with the suppression of ethylene emission and the activation of antioxidative enzymes being the key mechanisms. However, excessive treatment of SNP can exhibit toxic effects on peach fruits (e.g., increase in weight loss, decrease in firmness, accumulation of reactive nitrogen oxide species, decrease in antioxidant activity, and acceleration of peroxidation), highlighting the importance of investigating adequate treatment concentrations [56].

Putrescine (PUT) is a polyamine involved in the physiological activities of fruits (e.g., growth, softening, senescence, maturation, and regulation of the stress response) [72]. The pre-storage exogenous application of PUT is expected to improve the shelf life and the stability of fruit quality during cold storage by increasing endogenous polyamine levels and inducing the acclimation of fruits [73]. Abbasi et al. [57] revealed the substantial alleviation of chilling injury in peach fruit with desirable effects on quality factors (e.g., weight, firmness, ethylene production, and fruit skin color) during low-temperature storage with the exogenous spray of PUT (1–3 mM) before harvest, but the greatest effect was obtained from the 2 mM PUT treatment; thus, finding the optimal treatment concentration should be regarded as a prerequisite for actual application to fields [57].

3.2. The Use of Fertilizers

Irrational fertilization can cause problems including soil acidification, salinization, compaction, and a lack of fruit moisture. To prevent indiscriminate abuse of fertilizers, the determination of a desirable formulation of ingredients and fertilization period is essential [59,60]. Xiao et al. [59] showed the impact of formulated fertilization (containing urea, organic fertilizer, potassium sulfate, mono ammonium phosphate, and superphosphate) applied to a peach orchard on the physical and chemical characteristics of soil as the increase in the organic matter with the decrease of nitrogen content, highlighting the potential of fertilizers to significantly improve fruit quality. Liang et al. [60] practically demonstrated that the treatment of sprouting fertilizer (i.e., 10–15 days before flowering) and pre-harvest fertilizer (i.e., 15 days before harvest) could increase the quality factors (e.g., weight, firmness, and TSS) of peach fruits.

Table 2. Pre-harvest treatments on peach fruit.

Method	Cultivar	Method and Treatment Conditions	Results and Implications	Reference
Foliar spray of salts six times with 2-week intervals before harvest followed by cold storage after harvest	Scarlett O'Hara	- Calcium concentration of control * Dry weight: 59 mg/100 g - Treatment conditions * Calcium chloride, 4.7–17.9 g/tree * Calcium nitrate, 9.6 g/tree * Calcium glycine chelate, 10.4 g/tree - Storage: 2–4 °C, 3 weeks	- Increase of calcium concentrations in epidermis - Decrease of brown rot infections	[48]
Foliar spray of salts three times with 15-day intervals before harvest followed by cold storage after harvest	Dessert Red	- Control: tap water - Treatment conditions * Combined treatment of Potassium silicate 0.1–0.3% + Ca^{2+}EDTA 0.1–0.3% - Storage: 0 ± 1 °C, 90–95% RH [1], 28 days	- Improvement in the stability of fruit quality * Higher physical characteristics (weight, volume, length, diameter) and lower weight loss * Higher SSC [2] and TA [3] * Decrease of vitamin C contents * Increase of anthocyanin content - Combined treatment with the highest concentrations of each agent showed the highest effects. - Beneficial effects of pre-harvest treatment can be observed at both the harvesting date and during storage	[49]
Foliar spray of salts three times with 2-week intervals before harvest followed by cold storage after harvest	Florida Prince	- Single treatment * Chitosan 0.5–1.0% * Calcium chloride 2–4% - Combined treatment * Chitosan 0.5–1.0% + calcium chloride 2–4% - Storage: 0 ± 2 °C, 90–95% RH [1], 35 days	- Improvement in the stability of fruit quality - Lower weight loss, TSS [4] * Higher firmness and TA [3] - Combined treatment with the highest concentrations of each agent showed the highest effects	[50]
Foliar spray of calcium supplemented with other activating nutrients 10 days after anthesis followed by cold storage after harvest	Sevilla 2	- Composition of spray solution * Calcium 0.1 mM (4 mg/L) + Magnesium 0.103 mM (2.5 mg/L) + Titanium 0.042 mM (2 mg/L) - Treatment condition * Three times, 5 L per tree - Storage: 2 ± 0.5 °C, 90% RH [1], 28 days - Post-storage: 20 °C, 5 days	- Effects on fruits at harvest time * Quality improvement: higher firmness and weight - Effects on fruits during cold storage * Improvement in the stability of fruit quality: lower weight loss, increase of ripening index (TSS [4]/TA [3] ratio) and ethylene production, higher firmness	[51]

Table 2. *Cont.*

Method	Cultivar	Method and Treatment Conditions	Results and Implications	Reference
Foliar spray of salts 6 weeks after blooming followed by cold storage after harvest	Medium Sultani	- Control: tap water - Single treatment * Potassium sulphate (K_2SO_4) 1.5% * Calcium chloride ($CaCl_2$) 2% - Combined treatment * Potassium sulphate (K_2SO_4) 1.5% + Calcium chloride ($CaCl_2$) 2% - Storage: 5 ± 1 °C, 80–85% RH [1], 24 days	- Improvement in the stability of fruit quality * Lower weight loss, TSS [4] /acid value * Higher firmness, lower decay incidence * Higher pectin and vitamin C content - Improvement of nutritional quality * Higher anthocyanin - Combined treatment showed diversity in the increase or the decrease of the effects for the quality factors compared with the effects by singular treatments	[52]
Spreading of the salicylic acid solution 23 and 15 days before harvest followed by cold storage	Cresthaven	- Treatment conditions * Salicylic acid 1–2 mM - Storage: 2 °C, 85–90% RH [1], 8 days - Post-storage: 20 °C, 2 days	- Improvement in the stability of fruit quality * Increase of weight, width, and length of fruit - Improvement of fruit taste factors * Increase of TA [3] (whereas no changes in TSS [4]) * Higher firmness - Improvement of antioxidant activity * Increase of phenol content - Effects on fruits during cold storage * Decrease in color changes of fruit flesh	[53]
Spray of oxalic acid on fruit surface 15 days before harvest followed by cold storage	Anjiry maleki	- Treatment conditions * Oxalic acid 1–5 mmol/L - Storage: 1 °C, 90% RH [1], 28 days - Post-storage: 20 °C, 24 h	- Improvement of antioxidant activity * Increase of phenol and flavonoids contents * Activation of catalase (CAT), peroxidase (POD), and superoxide dismutase (SOD) - Improvement of the stability of the quality * Higher firmness	[55]
Spray of gibberellic acid before harvest (at the beginning or the end of pit hardening) followed by cold storage	Chiripa	- Treatment conditions * Gibberellic acid solution 400 L/ha (gibberellic acid 50 mg/L + surfactant Silwet® 0.05% (*v*/*v*; pH 4.5) at the beginning or the end of the pit hardening stage - Storage: 1 ± 1 °C, 92 ± 5% RH [1], 30 days - Post-storage: 23 ± 3 °C, 75 ± 5% RH [1], 2 days	- No effect to delay the fruit ripening * Ripening without differences in color, firmness of flesh, TSS [4], or ethylene production - Improvement in the stability of fruit quality * Increase of fruit size and mass from the treatment at the beginning of pit hardening stage (whereas, treatment at the end of pit hardening stage did not show differences) - Decrease of the woolliness * The prevention of woolliness from the treatment at the beginning of pit hardening stage (whereas, treatment at the end of pit hardening stage did not show differences)	[54]

Table 2. *Cont.*

Method	Cultivar	Method and Treatment Conditions	Results and Implications	Reference
Spray of sodium nitroprusside (SNP) 14 days before harvest followed by cold storage	GH Hill	- Treatment conditions * SNP 25–100 μmol/L - Storage: 4 °C, 80–90% RH [1], 28 days - Post-storage: 20 °C, 1–4 days	- Improvement in the stability of fruit quality * Lower weight loss * Decrease of ethylene production * Increase of firmness - Alleviation of CI [5] * Decrease of CI [5] index - All beneficial effects were not observed from samples treated with an excess level of SNP (100 μmol/L) * Increase of weight loss, increase of ethylene production, decrease of firmness, increase of CI[5] index, accumulation of ROS [6], decrease of the antioxidant activity, acceleration of peroxidation	[56]
Spray of putrescine (PUT) three times before harvest followed by cold storage	Flordaking	- Treatment conditions * PUT 1–3 mM - Storage: 1 ± 1 °C, 90 ± 2% RH [1], 6 weeks	- Improvement in the stability of fruit quality * Lower weight loss * Increase of firmness * Decrease of ethylene production * Lower SSC [2]/TA [3] ratio - Maintenance of fruit skin color - Alleviation of CI [5] * Decrease of CI [5] index - Treatment condition for the highest effects was not the maximum concentration analyzed in this study (i.e., 2 mM PUT showed a higher effect than 3 mM PUT)	[57]
Application of fertilizer 10–15 days before flowering and 15 days before harvest	Beijing 2	- Soil condition * Annual average precipitation: 895.6 mm * Annual average pressure: 956.4 hpa * Annual average RH [1]: 81% * Average annual sunshine hours: 1032.9 h * Annual average wind speed: 1 m/s - Fertilizer * Urea (N content 46%), organic fertilizer (main ingredient is dried chicken manure), potassium sulfate (K_2O content 50%), monoammonium phosphate (P_2O_5 content 46%, N content 12%), superphosphate (P_2O_5 content 12%)	- Improvement in the stability of fruit quality * Higher weight * Higher firmness and TSS [4]	[60]

[1] RH: relative humidity; [2] SSC: soluble solid content; [3] TA: total (titratable) acidity; [4] TSS: total soluble solid; [5] CI: chilling injury; [6] ROS: reactive oxygen species.

4. Strategic Approach of the Application of Post-Harvest Treatment Technologies for Peach Fruits

4.1. Physical Treatments

Since consumers' concerns about the hazard of residue when using chemical compounds have increased, physical treatment technology emerges as an alternative to protect the quality and safety of fruits [74]. Major examples of physical treatment technologies are as follows: temperature control [75–82], modified atmosphere [83–86], and irradiation [87–93] (Table 3).

4.1.1. Temperature Control

Post-harvest treatment based on the exposure of peach fruits to the temperature change can be categorized as refrigeration (i.e., cooling and/or storage at low temperature) or heating (i.e., thermal processing at high temperature).

Cooling and/or cold storage is one of the simplest methods for extending the shelf life of fruits with minimal quality change through inhibitory effects on not only the enzymatic activities related to the maturation but also microbial infectious metabolism [94–96]. Since fruit rot and microbial growth are mainly caused by the degree and mode of temperature fluctuation, previous research focused on the discovery of determinant factors (e.g., the condition of raw materials, storage temperature and time) for maintaining fruit quality and novel operational methods of temperature control (e.g., hydrocooling). Ceccarelli et al. [75] explored the influence of fruit maturity categorized as I_{AD} (index of maturity defined as a measure of flesh and skin chlorophyll content) and the period of refrigeration on the quality factor and aromatic characteristics of peaches; although chilling injury occurred when fruits were stored for over 4 weeks, the relationship between harvest maturity stages (immature, mature, and ripe) and storage time could be estimated to determine the time required for desirable quality changes during storage (e.g., aroma development, and ripening). In the case of the operational method of cooling, the impact of the decrease in respiration rate and the related decrease in carotenoid content by hydrocooling (i.e., dipping of fruits in H_2O at low temperature; 1 °C for 1 h) on storability was evaluated through research by Caprioli et al. [76], and the results of their comparative analysis confirmed the remarkable efficacy of hydrocooling with various types of gas treatment (1-methylcyclopropene (1-MCP), carbon dioxide, and nitrogen).

To apply thermal post-harvest technologies to peach fruit, hot air and hot water treatments have been adopted as applicable methods operated by air circulation and dipping in solution, respectively. Both hot air and hot water treatments can contribute to not only the improvement of fruit quality (e.g., firmness, ripening, and decay) but also the prevention of chilling injury during cold storage by inhibiting the loss of membrane integrity and the accumulation of ROS [97–99]. However, when tested on the same peach fruit samples, the comparison of hot air and hot water as post-harvest treatment technologies demonstrated that hot water had a higher efficacy than hot air. Huan et al. [77] showed the differences between the heat transfer methods (hot water and hot air) in regard to the efficacy against chilling injury (higher efficiency on the heat transmission of hot water treatment, which is useful for the inhibition of internal browning compared to hot air treatment) and antioxidant activity (enhancement of AsA-GSH metabolisms by hot water treatment, but not by hot air treatment). The effects of hot water treatment were also assessed at room temperature to understand the response of peach fruit during ripening after treatment. Zhang et al. [78] conducted a proteomic analysis of peach fruit treated with hot water (48 °C, 10 min) followed by storage at 25 °C and showed the distinct heat-shock protein expression linked to the resistance to stress responses or self-defense capability and the activation of multiple antioxidant metabolic pathways (e.g., AsA-GSH). The intervention effect of hot water treatment as an effective decontamination technology on peach fruit artificially inoculated with fungi (e.g., *Monilinia* sp.) was also assessed at room temperature [79] and low temperature [80]. Liu et al. [79] revealed the mode of action for hot water treatment against the post-harvest decay caused by brown rot fungi (*M. fructicola*) during the exposure to room temperature by both direct antifungal effects (the dysfunction of mitochondria and

inhibition of spore germination of *M. fructicola*) and the host defense mechanism (induction of chitinase, β-1,3-glucanase, and phenylalanine ammonia lyase enzymes). *M. laxa*, capable of germinating at low temperatures, was also adopted as a target fungus inactivated by hot water treatment (48 °C, 12 min) of peach fruit by Jemric et al. [80], and a decrease in microbial deterioration could also be achieved during cold storage (0 °C, 90% RH, 20 days).

4.1.2. Modified Atmosphere

The methods for the modification of atmosphere during the storage of peaches to extend their shelf life and to improve the fruit quality can be represented as controlled air [82] and hypobaric treatment controlling the atmospheric pressure [84–86].

Supplying controlled air can maintain the intended composition of gas filled in the area for the storage of fruits. Liu et al. [83] showed the effects of sealing peach fruits in a 50 L container with a strictly controlled atmosphere (5% O_2, 10% CO_2, and 85% N_2) during cold storage to alleviate chilling injury and the accumulation of aroma volatiles preferred by consumers.

The hypobaric treatment allows the generation of a low oxygen environment by decreasing atmospheric pressure. Wu et al. [84] suggested the beneficial effect of hypobaric treatment as the regulation of defense-related enzymes governing antioxidant activities (e.g., stimulation of SOD and PPO, and suppression of CAT). Whereas, the major problems in applying modified atmospheric control technology (e.g., high operating costs, the difficulty of maintaining a stable hypobaric environment, and the loss of quality of firmness) are expected to be solved by using short-term hypobaric treatment [85,86]. Zhang et al. [85] placed peaches in the hypobaric tank (0.45 atm for 4 h at 20 °C) before cold storage and enhanced chilling tolerance of fruits by the activation of antioxidant enzymes along with the suppression of membrane oxidation to prevent the accumulation of MDA was shown. Zhan, et al. [86] also emphasized the protective effect of short-term hypobaric treatment against chilling injury during subsequent cold storage and revealed the major working mechanism as the regulation of fruit metabolisms linked to the membrane fatty acids (e.g., activation of fatty acid synthetase (the synthesis of fatty acid) and fatty acid desaturase (the desaturation of fatty acid), but suppression of LOX (the degradation of unsaturated fatty acid)).

4.1.3. Irradiation

Light Irradiation

Light-based antimicrobial photoinactivation has been applied in the food industry for the maintenance of quality, especially for fresh-cut fruits and vegetables that cannot be processed with heat [100]. The irradiation of fruits with light can also affect various physiological metabolic pathways related to growth, development, ripening, softening, stress-response, and disease tolerance [101]. Both visible light and ultraviolet light (UV) are expected to achieve decontamination and to modulate metabolism, but UV treatment has been preferred due to the probability of inducing ripening (e.g., synthesis of ethylene) and the lower decontamination effects of visible light [102]. The post-harvest effects of light irradiation are known to be wavelength-dependent within the area of UV (categorized as UV-A (315–400 nm), UV-B (280–315 nm), and UV-C (100–280 nm)) [103–105]. Previous research regarding the application of UV irradiation to harvested peaches has been reported as a singular treatment of UV-B [88] or UV-C [87], and the combined treatment of UV-B with UV-C [89].

Santin et al. [88] analyzed changes in plant secondary metabolism through non-targeted fruit metabolomics after a low level of UV-B irradiation (2.3134 W/m^2, 60 min, 24 °C), and showed noteworthy metabolomic changes in most phenolics according to the storage time after treatment (e.g., the decrease and accumulation of phenolics after 24 h and 36 h storage, respectively), emphasizing the importance of time after UV-B irradiation as the key determining factor of the efficacy [88]. The transcriptome-based investigation of the effects of UV-C (4 kJ/m^2, 30 min, 10 °C) irradiation on the control of fruit metabolism associated with softening and senescence (cell wall, antioxidant, secondary metabolism,

lipid, and energy) during storage was also conducted by Kan et al. [87] and revealed the upregulation of genes linked to defense systems with the activation of antioxidation enzymes and the downregulation of genes inducing undesirable quality deterioration (e.g., ethylene biosynthesis, oxidative stress, lipid peroxidation, and cell wall decomposition). In the case of combined treatment (UV-B + UV-C), Abdipour et al. [89] demonstrated a relatively lower effect of UV-B than UV-C by the direct comparison of the effects of UV irradiation with different wavelengths on the storability of the same peach samples, but the combined treatment can be considered a strategy to complement the limited effects of UV-B and to increase the overall effects, improving fruit quality parameters (TSS, firmness, total phenolic compounds, TA, vitamin C content, and acidity).

Gamma Irradiation

Gamma ray that has greater energy than X-ray or UV photons has been generally used to destroy covalent bonds in the DNA of microbial contaminants by penetrating target foods [106]. Whereas, Khan et al. [91] observed that irradiating peaches with gamma rays (2.5 and 5 kGy) in an ambient temperature did not induce a significant difference in the quality of fruits. However, excessive exposure of peaches to gamma ray causes fruit softening (>1 kGy). Melo et al. [92] also demonstrated that irradiation-induced immediate softening is associated with cell wall modifications, pectin hydrolysis, and pectin methylesterase activity by evaluating the influence of gamma irradiation (ca. 1 kGy) to peaches on ripening parameters (e.g., changes in color, weight, and contents of antioxidants).

Microwave Irradiation

Microwaves, which transform electromagnetic field energy into thermal energy, have frequencies and wavelengths in the range of 0.3–300 GHz and 0.001–1 m, respectively [107]. Wang et al. [93] observed that the quality change of peach fruits exposed to a microwave and the longest irradiation time exhibited the most effective results (e.g., decrease of internal browning, inhibition of the phenolic accumulation, and improvement of membrane stability) among treatment conditions (45.5 W for 3, 5, and 7 min). This study also suggested that a protective mechanism to internal browning induced by chilling injuries was considered as a non-thermal effect because 45.5 W microwave irradiation could not increase the core temperature of peach fruit [93].

Table 3. Post-harvest treatments of physical technologies on peach fruit.

Method	Cultivar	Treatment Conditions	Results and Implications	Reference
Cold storage	August Flame	- Maturity class of fruit samples * Pre-climacteric (CI; immature): I_{AD} [1] 1.6–1.3 * Onset of climacteric (CM; mature): I_{AD} [1] 1.2–0.8 * Climacteric (CR; ripen): I_{AD} [1] 0.7–0.0 - Storage: 0 °C, 95% RH [2], 4 weeks - Post-storage: 18 °C, 6 days	- Fruit ripening and quality change were affected by the harvest maturity stage according to the period of cold storage * Different pattern of the changes in firmness, SSC [3], TA [4], ethylene emission, and aroma development among samples (CI, CM, CR)	[75]
Hydrocooling followed by cold storage	Spring Belle	- Treatment conditions * Dipping in 1 °C water, 1 h - Storage: 0 °C, 7 days - Post-storage: 20 °C, 50–60% RH [2], 1 day	- Improvement in the stability of fruit quality * Higher firmness and carotenoid content * Lower level of respiration rate and ethylene production - No effect on SSC [3] and skin color	[76]
Hot air or hot water treatment followed by cold storage	Xiahui 5	- Hot air treatment * Air-circulation (38 °C, 3 h) - Hot water treatment * Immersion (48 °C, 10 min) and air-drying (1 h) - Storage: 4 ± 0.5 °C, 85–90% RH [2], 35 days	- Higher efficacy from hot water than hot air treatment * Improvement in the stability of fruit quality: Higher firmness and membrane integrity, lower respiration rate and ethylene production, lower internal browning index * Improvement of antioxidant capacity	[77]
Hot water treatment followed by room temperature storage	Huiyulu	- Treatment conditions * Immersion (48 °C, 10 min) and air-drying (1 h) - Storage: 25 ± 1 °C, 80–90% RH [2], 5 days	- Improvement of antioxidant capacity * Lower ROS [5] content - Improvement of self-capability of the defense * Expression of proteins related to the stress-response and antioxidant metabolism	[78]
Hot water treatment followed by room temperature storage	June Prince	- Treatment conditions * Inoculation before the treatment: *Monilinia fructicola* (10 μL, ca. 4 log spores/mL) * Immersion (40 °C, 5–10 min) and air-drying (25 °C, 10 min) - Storage: 25 °C, 3 days	- Decrease of microbial deterioration and damage * Lower disease incidence and lesion diameter - Induction of the expression of defense-related genes * Chitinase, β-1,3-glucanase, phenylalanine ammonia lyase - No adverse effects on product quality * Firmness, SSC [3], and TA [4]	[79]

Table 3. *Cont.*

Method	Cultivar	Treatment Conditions	Results and Implications	Reference
Hot water treatment followed by cold storage	Roig	- Treatment conditions * Inoculation before the treatment: *Monilinia laxa* (2 µL, 5 log conidia/mL) * Immersion (48 °C, 12 min) - Storage: 0 °C, 90% RH [2], 20 days	- Decrease of microbial deterioration and damage * Lower decay index - Improvement in the stability of fruit quality * Lower TA [4] and SSC [3]/TA [4] ratio	[80]
Controlled air treatment during cold storage	Hujingmilu	- Treatment conditions * 5% O_2 and 10% CO_2, and 85% N_2 - Storage: 0 °C, 90% RH [2], 28 days	- Improvement in the stability of fruit quality * Inhibition of ethylene emission and internal browning * Higher firmness - Higher accumulation of aroma volatiles	[83]
Hypobaric treatment during cold storage	Xiahui-8	- Treatment conditions * 55 ± 5 kPa in a hypobaric chamber - Storage: 4 ± 0.5 °C, 16 days	- Improvement in the stability of fruit quality * Higher firmness * Lower malondialdehyde (MDA) content * Delay of respiration peak * Activation of the antioxidant enzymes (superoxide dismutase (SOD), polyphenol oxidase) * Suppression of catalase (CAT) activity	[84]
Short-term hypobaric treatment followed by cold storage	Yingshuanghong	- Treatment conditions * 0.45 atm (standard atmospheric pressure) for 4 h at 20 °C in a hypobaric tank - Storage: 5 ± 1 °C, 85 ± 5% RH [2], 24 days	- Improvement in the stability of fruit quality * Lower respiration rate * Higher TSS (total soluble sugar) concentration * Delay of climacteric peak * Activation of the antioxidant enzymes (SOD, CAT, peroxidase (POD), ascorbate peroxidase)	[85]
Short-term hypobaric treatment followed by cold storage	Feicheng	- Treatment conditions * 45.6 kPa at 20 °C for 2.5 h in a hypobaric chamber - Storage: 0 ± 0.5 °C, 90 ± 5% RH [2], 35 days	- Improvement in the stability of fruit quality * Lower MDA and electrolyte leakage * Higher membrane fluidity and fatty acid unsaturation - Regulation of the enzymes involved in membrane fatty acid metabolisms * Suppression of lipoxygenase activity * Activation of fatty acid synthetase and fatty acid desaturase	[86]

Table 3. *Cont.*

Method	Cultivar	Treatment Conditions	Results and Implications	Reference
UV-C irradiation followed by cold storage	Xiahui 5	- Treatment conditions * UV-C irradiation: 4 kJ/m^2, 30 min, 10 °C - Storage: 10 °C, 85% RH [2], 9 days	- Improvement in the stability of fruit quality * Higher firmness * Lower ethylene production - Transcriptomic analysis * Upregulation of genes related to pectin content, secondary metabolism, lipid or energy metabolism, and stress resistance * Upregulation of genes related to antioxidant enzymes (SOD, POD) * Upregulation of genes related to signal transduction	[87]
UV-B irradiation followed by room temperature storage	Fairtime	- Treatment conditions * UV-B irradiation: 2.3134 W/m^2, 60 min, 24 °C - Storage: 24 °C, 85% RH [2], 24–36 h	- Improvement in the stability of fruit quality * Higher structural lipid - Improvement of antioxidant capacity * Higher phenolic contents (dihydroflavonols, anthocyanins, and flavones), alkaloid (pteridine)	[88]
UV-C and UV-Birradiation followed by cold storage	-	- Singular treatment * UV-B irradiation: 0.72 kJ/m^2, 20 min, 8 °C * UV-C irradiation: 0.72 kJ/m^2, 20 min, 8 °C - Combined treatment * UV-B + UV-C irradiation: 1.44 kJ/m^2, 20 min, 8 °C - Storage: 4 °C, 80–85% RH [2], 25 days	- Improvement in the stability of fruit quality * Lower weight loss * Higher firmness, vitamin C content, and TA [4] * Lower TSS [6] - Decrease of microbial deterioration and damage * Lower decay rate - Improvement of antioxidant capacity * Higher total phenolics content - Synergistic effects by the combined treatments of UV-B with UV-C	[89]
Gamma irradiation followed by room temperature storage	-	- Treatment conditions * Co-60 gamma ray: 71.4 krad/h * Irradiation: 2.5, 5 kGy - Storage: 25 ± 2 °C, 14 days	- No significant difference between control and irradiated peach samples	[91]

Table 3. *Cont.*

Method	Cultivar	Treatment Conditions	Results and Implications	Reference
Gamma irradiation followed by cold storage	Mid pride	- Treatment conditions * Prior to irradiation: dipping in 100 mg/L active chlorine solution at 3 °C for 10 min * Irradiation: average absorbed dose as 1030 Gy - Storage: 1 °C, 7 days - Post-storage: 23 ± 2 °C, 6 days	- Demonstration of the mechanism for irradiation-induced immediate loss of firmness as pectin hydrolysis, cell wall modifications, and pectin methylesterase activity	[92]
Microwave irradiation followed by cold storage		- Treatment conditions * Power: 45.5 W, 25 °C, 3–7 min - Storage: 5 °C, 30 days - Post-storage: 25 °C, 1 day	- Improvement in the stability of fruit quality * Decrease of internal browning * Inhibition of phenolic accumulation * Increase of membrane stability	[93]

[1] I_{AD}: index of absorbance difference; [2] RH: relative humidity; [3] SSC: soluble solid content; [4] TA: total (titratable) acidity; [5] ROS: reactive oxygen species; [6] TSS: total soluble solid.

4.2. Chemical Treatments

Using chemical agents that can enhance the quality and safety of fruits by controlling fruit maturation (e.g., naturally occurring compounds extracted from growing plants; putrescine, spermidine) and decontamination (e.g., bactericidal and/or fungicidal substances) has been regarded as an efficient post-harvest treatment method. Treatment strategies can be categorized as liquid (solution) and gas (vaporized materials) phases of the chemical agents according to the application methods, as shown in Table 4.

4.2.1. Spraying or Dipping Treatment Methods Using Solutions of Chemical Agents

Treatment solutions containing active chemical agents can be mainly applied to fruits by spraying or dipping. Dipping treatment enables the even exposure of fruits to chemical agents, and thus is likely to be preferable as the post-harvest treatment to fruits rather than spraying treatment.

Spraying Treatment

Citric acid spraying can enhance the stability of fruit quality factors (firmness, TA, and TSS) during room temperature storage, and the considerable reduction of decay incidence is likely due to the potential antifungal capability of citric acid [108].

Glucose oxidase (GOx) is a natural anti-browning and antimicrobial agent that can be used as an alternative to synthetic chemicals [109]. Batool et al. [110] immobilized GOx by using zinc oxide nanoparticles (ZnONPs) to improve not only the stability but also the activity of the enzyme, and GOx/ZnONP bioconjugation spray resulted in the maintenance of the physiological appearance of peach fruits and a decrease in undesirable quality changes of peach fruits (e.g., firmness, and TSS). These effects occurred through the expected mechanisms as follows: (1) antioxidant (i.e., scavenging oxygen) and antimicrobial effects; and (2) formation of H_2O_2 layer to slow fruit metabolism associated with ripening and to protect the fruit from fungal contamination.

Spraying essential oils (EOs) on the surface of fruits has been adopted as the representative decontamination treatment against pathogenic and/or spoilage bacteria and fungi [111–113]. In the case of peaches, research by Elshafie et al. [114] on antifungal effects of the major constituents in Greek oregano (*Origanum vulgare* L. ssp. *hirtum*) EO revealed that thymol and carvacrol showed strong efficacy against fruit pathogenic fungi (*Monilinia* spp.; *M. laxa*, *M. fructigena*, and *M. fructicola*).

Dipping Treatment

EO is one of the most popular antifungal agents and has been generally applied directly to food products by spraying or dipping methods. Dipping peaches in EOs showed antifungal effects against fruit pathogens equivalent to those of commercial fungicide products, highlighting the value of EOs as natural antifungals that are feasible alternatives to synthetic fungicides; however, the species-dependent efficacy from each source of EOs indicates the importance of identifying the spectrum of EOs to be used [115]. However, the peculiar fragrance of EOs and relatively high cost compared with synthetic chemical antifungals used for fruits have been regarded as the major limitations [116,117]. Thus, the combined treatment of EO with other antifungal agents is expected to improve the overall effects on the product quality as a countermeasure for those limitations. Rahimi et al. [118] reported that dipping treatment with a solution of EO and chitosan considerably prevented fungal decay with desirable effects on sensory characteristics as well.

Glycine betaine (GB) can act as an osmotic adjustment substance to enhance the tolerance of fruits against cold stress factors by preventing membrane damage [119]. Shan et al. [120] evaluated the effects of exogenous GB treatment from the perspective of reducing the chilling injury of cold-stored peaches; their findings suggested that the key mechanism is an increase in the contents of endogenous substances involved in protective responses to cold stresses (GB, g-aminobutyric acid (GABA), and proline) through the induction of relevant enzymes (betaine

aldehyde hydrogenase (BADH), glutamate decarboxylase (GAD), D 1 -pyrroline-5-carboxylate synthetase (P5CS), and ornithine d-aminotransferase (OAT)).

Exogenous melatonin treatment extends the shelf life of peach fruits through the activation of antioxidant enzymes capable of enzymatic ROS control during both room temperature [121] and cold storage [122]. Gao et al. [121] reported that dipping peaches in a melatonin solution can maintain fruit quality (e.g., firmness and decay incidence) and decrease weight loss, with the key mechanism being the activation of antioxidant enzymes (SOD, POD, CAT, and APX). Research by Cao et al. [122] also showed an increase in the activity of antioxidant enzymes (POD, SOD, and CAT) in peaches during cold storage, and suggested that antioxidant systems were activated by the upregulated transcription of genes involved in the production of not only those enzymes but also reductants (AsA and GSH), serving as the mode of action of the increased tolerance of peaches against cold stress.

Putrescine, a poly-amine substance widely used as an antiaging compound for fruit skin, can contribute to the control of post-harvest loss of the quality and nutrition of peaches by preventing chilling injuries and the breakdown of biochemical compounds (e.g., phenolic compounds, vitamin C, and organic acids), respectively [123].

Endogenous GABA is involved in the defense system against cold stress and the effects of exogenous GABA treatment as post-harvest interventions of chilling injuries were reported as the result of the accumulation of endogenous GABA with proline linked to stress adaptation to the cold environment. Shang et al. [124] reported those effects on peaches treated with 10 min of dipping in GABA solution; although, the effects were not concentration-dependent (i.e., 5 mM was the most effective treatment concentration rather than the highest treatment concentration in this study (10 mM)).

Salicylic acid is a phenolic compound that plays a role in the regulation of the ripening and growth of fruits. The effects of salicylic acid dipping treatment as the post-harvest intervention against the quality change of peach fruits during cold storage have also been consistently reported, with in-depth examinations indicating that the major mechanisms of these effects are both the activation of vital antioxidant enzymes (SOD, POD, and CAT) and the inhibition of the browning enzyme (PPO) [125,126].

$CaCl_2$ has been reported as one of the most common post-harvest treatment agents that can stabilize cellular membranes and delay senescence by inhibiting enzymes responsible for the deterioration of products [127]. The dipping of peaches in 6% $CaCl_2$ solution for 10 min showed a delay in spoilage and various undesirable quality changes (decrease in firmness, acidity, and reduction of sugar content) accompanied by minimized PME activity to ensure the long-term storage (3 weeks under ambient temperature and 3 days under cold temperature as storage and post-storage conditions, respectively) of fruits in an edible state, which was also validated by the palatability test [128].

The direct validation of antifungal effects has been conducted by using peaches artificially inoculated with pathogenic or spoilage fungi and a case study of the applicability test for peach fruits has been reported with the following agents: yeast saccharides (YS) and benzo-thiadiazole-7-carbothioic acid S-methyl ester (BTH) [129,130]. YS from the cell wall can induce the defense responses of products due to their antifungal activities (activation of chitinase and β-1,3-glucanase, which can degrade chitin and β-1,3-glucan in the cell wall of fungi, respectively) with enhanced phenolic synthesis (higher PAL and POD activities) and these activities were linked to the role of YS as a trigger for increasing endogenous nitric oxide (NO) levels of the product [129]. However, according to research by Yu et al. [129], optimizing the treatment conditions of dipping products in YS based on endogenous NO levels is necessary because those effects are not treatment concentration-dependent: treatment with 0.5 mg/L YS was more effective (higher NO levels and lower decay) than treatment with 0.1 or 1.0 mg/L YS. For BTH treatment, the expected mechanisms of antifungal effects against *P. expansum* in the product are the production of ROS followed by the strengthening of systemic acquired resistance through the activation of host defense enzymes (e.g., PAL, PPO, and POD) [130].

Fruit surface can be coated by dipping in the solution of nanoparticles, which are nontoxic and available for the targeted localization. Calcium nanoparticles combined with ascorbic acid (9 mM/L) suppressed the incidence of chilling injury during the cold storage of peach fruits with a stable preservation of skin color and moisture [131]. Gad and Ibrahim [132] suggested nano-chitosan as a coating agent, which allowed the maintenance of fruit quality (e.g., lower weight loss, a decrease of decay incidence, and higher firmness) of peaches, and showed better effects obtained from a specific treatment condition (400 ppm) than the maximum concentration tested in this study (800 ppm) to highlight the importance on the exploration of the optimal condition. Since chitosan nanoparticles are effective and eco-friendly, the enhancement of marketability and storability of peach fruits is expected [132].

Films and coatings applied to fruits and vegetables with edible agents (e.g., gum) by dipping can protect foods from environmental stress factors (e.g., moisture migration, microbial contamination, light exposure, and oxidation), which can result in product quality changes [133]. Peach-gum coating (i.e., dipping in 1–10% gum solution) was suggested as a novel strategy for the prevention of ageing, which can result in the softening of the products, and the mechanism of this effect was revealed by transcriptomic analysis to be the downregulation of genes related to the deterioration of product quality (e.g., ethylene synthesis and cell wall degradation) [134].

Sequential Dipping and Spraying Treatments

The combined treatment of dipping followed by the spraying of antifungal agents can be adopted as the post-harvest sanitation strategy with durable fruit decontamination ability. The effects of the dipping treatment of near-neutral (pH = 6.3–6.5) electrolyzed oxidizing water (NEO water), which inactivates brown rot fungi (*M. fructicola*) to mitigate the potential infection on the surface of peaches (i.e., reducing the incidence and severity of brown rot), was improved by the combined treatment of daily spraying of NEO water after NEO dip [32]. The use of electrolyzed water as the post-harvest antifungal treatment has been regarded as practical and has commercial traits due to its economic feasibility (e.g., low cost of raw materials and the maintenance of electrolyzed water generators) [135].

4.2.2. Gas Treatment of Vaporized Chemical Agents

Volatile organic compounds (VOCs) produced by microorganisms have been used for post-harvest pathogen control and Zhou et al. [136] showed that the fumigation of benzothiazole as a VOC (from *Bacillus subtilis*), which is known as an antifungal agent against *M. fructicola*, can be used not only for the decontamination of pathogenic fungi but also for the activation of antioxidant enzymes.

Fumigation of NO can prevent the quality change of peaches during storage through the reduction of ethylene production and/or the improvement of antioxidant capacity supported by higher activities of antioxidant enzymes (e.g., CAT and SOD) [137–139]. NO can also reduce the activity of LOX and 1-aminocyclopropane-1-carboxylic acid (ACC) oxidase through nitrosation to inhibit membrane lipid peroxidation and the ethylene biosynthesis pathway, respectively [138]. Since controversial results regarding the effects of NO fumigation on product quality factors (e.g., color, TA, or TSS) were also observed, optimization of treatment conditions based on various quality factors is also required [137,138]. In the case of changes in the lipid composition associated with ion leakage and membrane integrity, the most desirable effects were achieved by treatment with an intermediate concentration (10 μL/L), whereas opposite effects according to the excessive exposure of peaches to fumigated NO were observed at the highest concentration (15 μL/L), highlighting the importance of determining the optimum conditions [139]. Mechanisms for the beneficial effects of NO treatment during ripening were also revealed by proteomic analysis as follows: (1) induction of antioxidant enzymes (SOD, enzymes of the AsA-GSH cycle); (2) decrease in ethylene production by the production of complex 1-aminocyclopropane-1-carboxylic acid oxidase (ACO–NO–ACC) supported by the upregulation of S-adenosylmethionine syn-

thetase (SAMS) to promote the generation of the precursor of ACC (S-adenosylmethionine (SAM)); (3) the reduction of ATP supply generated by substrate oxidation by the application of alternative pathways for energy production (TCA cycle and glycolysis) through the regulation of cytochrome c oxidase synthesis with electron transport and oxygen consumption; (4) suppression of the degradation of the cell wall by upregulation of proteins associated with both the loss of Ca^{2+} ions and the structural components of the cell wall; and (5) the induction of defense capacity by upregulating the heat-shock protein 70 (HSP70) [140].

Peach fruits can be exposed to volatile EOs in a gas state as the post-harvest treatment for the control of fungi responsible for the deterioration of products (e.g., *B. cinerea* and *Alternaria alternata*) [141,142]. However, the requirement of high EO concentrations to achieve the suppression of brown rot and *Rhizopus* rot limits their application in the food industry from the perspective of marketability due to relatively higher cost of EOs as natural agents compared that of conventional gaseous fumigants as synthetic chemical agents; furthermore, EOs have potential phototoxicity [141]. Thus, the encapsulation of EOs and the combined treatment with another decontamination technology can be adopted as the countermeasure for those limitations of EO fumigation treatment [142]. Cyclodextrin-based (CD-based) microencapsulation could protect EOs from environmental factors that decrease their stability (e.g., temperature, light, and oxygen) and the simultaneous treatment with 1-MCP could contribute to the maintenance of fruit quality (e.g., firmness, acidity, and decay incidence) through its inhibitory effects against ethylene releases.

1-MCP is an ethylene-antagonizing compound controlling endogenous and exogenous ethylene to prevent the senescence of fruits, and the ephemeral microcirculation of gaseous post-harvest agents during the storage of peach fruits showed effective preservative efficacies. Du et al. [143] sequentially treated peach fruits fumigated with 1-MCP with ozone during cold storage (8 ppm O_3 at 0 °C for 45 days) and reported the effects on storability (reduction of the decay rate, reduction of MDA content, the maintenance of fruit quality (firmness, SSC, TA, and color)).

Table 4. Post-harvest treatments of chemical technologies on peach fruits.

Method	Cultivar	Method and Treatment Conditions	Results and Implications	Reference
Spraying citric acid followed by room temperature storage	Hujingmilu	- Treatment conditions * Even spraying with 1.5 L (10 g/L) citric acid - Storage: 20 ± 0.5 °C, 85 ± 1% RH [1], 14 days	- Improvement in the stability of fruit quality * Lower TSS [2] and decay incidence * Increase of TA [3] * Higher firmness	[108]
Spraying glucose oxidase immobilized on ZnO nanoparticles (GOx/ZnONPs) followed by room temperature storage	-	- Treatment conditions * Catalytic activity of GOx/ZnONPs: 23.3 ± 2.08 U/mL - Storage: 25 ± 1 °C, 15 days	- Improvement in the stability of fruit quality * Lower weight loss * Higher firmness, lower TSS [2] - Higher DPPH free radical scavenging activity	[110]
Spraying the essential oil (EO) compounds emulsion followed by room temperature storage	Springcrest	- Treatment conditions * Carvacrol and thymol emulsion: 150, 500 ppm - Storage: 16–24 °C (room temperature), moist chamber, 5 days	- Antifungal effects * Effective against *Monilinia laxa*, *Monilinia fructigena*, and *Monilinia fructicola*	[114]
Dipping in EO solution followed by cold or room temperature storage	Chimarrita	- Treatment conditions * Dipping time: 10 min * Essential oil: 0.15, 0.20% extracts from *Eucalyptus globulus*, *Cinnamomum camphora*, and *Cymbopogum citratus* * Fungicide: Orthocide 2.4 g/L - Storage * Cold condition: 20 days * Room temperature: 10 days	- Antifungal effects * Effectiveness equivalent to fungicide (orthocide) *C. camphora* and *C. citratus* against *Colletotrichum gloeosporioides* : *C. citratus* against *M. fructicola*	[115]
Dipping in EO and/or chitosan followed by cold storage	Zaferani	- Treatment conditions * Dipping time: 15 min * Single treatment : 0.5% chitosan : 200 mg/L thymol * Combined treatment : 0.5% Chitosan + 200 mg/L thymol - Storage: 6 °C, 80% RH [1], 30 days	- Improvement in the stability of fruit quality * Lower weight loss * Higher firmness * Lower TSS [2] and decay incidence - Improvement of nutritional quality * Higher anthocyanin and carotenoid - Sensory properties * Preferable sensory characteristics	[118]

Table 4. *Cont.*

Method	Cultivar	Method and Treatment Conditions	Results and Implications	Reference
Dipping in glycine betaine (GB) solution followed by cold storage	YuhuRa No.2	- Treatment conditions * Dipping time: 10 min * 10 mM exogenous GB - Storage: 0 °C, 5 weeks	- Alleviation of CI [4] * Lower CI [4] index * Higher level of endogenous GB, γ-aminobutyric acid (GABA), and proline contents * Activation of enzymes related to the response to cold stress: betaine aldehyde hydrogenase (BADH), glutamate decarboxylase (GAD), D1-pyrroline-5-carboxylate Synthetase (P5CS), and ornithine d-aminotransferase (OAT) - Improvement in the stability of fruit quality * Lower firmness, higher extractable juice - Higher energy status * Higher energy charge, ATP, and ADP contents	[120]
Dipping in melatonin solution followed by room temperature storage	Shahong, Qinmi	- Treatment conditions * Dipping time: 10 min * 0.1 mM/L melatonin - Storage: 25–28 °C, 60–70% RH [1], 7 days	- Improvement in the stability of fruit quality * Lower weight loss * Higher firmness, lower decay incidence * Lower malondialdehyde (MDA), decreased activity of lipoxygenase (LOX) * Activation of the antioxidant enzymes: superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), ascorbate peroxidase (APX)	[121]
Dipping in melatonin followed by cold storage	Hujing	- Treatment conditions * Dipping time: 120 min * 100 μM melatonin - Storage: 4 °C, 80% RH [1], 28 days	- Alleviation of CI [4] * Lower CI [4] index * Improvement in the stability of fruit quality * Lower MDA content * Activation of antioxidant enzymes (CAT, SOD, APX) * Upregulation of the genes associated with the modulation of reductants (ascorbate acid (AsA), glutathione (GSH)), which can directly detoxify ROS [5]	[122]
Dipping in putrescine (PUT) solution followed by room temperature storage	Monley	- Treatment conditions * Dipping time: 2 min * 0.4, 0.8, 1.2, 1.6 mM PUT (1 L) - Storage: 0 ± 0.5 °C, 90 ± 5% RH [1], 40 days	- Improvement in the stability of fruit quality * Lower weight loss * Lower decay incidence * Higher firmness, higher fruit density * Prevention of the degradation of phenolic compounds, vitamin C, and organic acid	[123]

Table 4. *Cont.*

Method	Cultivar	Method and Treatment Conditions	Results and Implications	Reference
Dipping in GABA solution followed by cold storage	Baifeng	- Treatment conditions * Dipping time: 10 min * 1, 5, 10 mM GABA - Storage: 1 °C, 85–95% RH [1], 35 days - Post-storage: 20 °C, 3 days	- Alleviation of CI [4] * Lower CI [4] index - Increase in the activities of enzymes related to the accumulation of endogenous GABA and proline: glutamate decarboxylase (GAD), Δ1-pyrroline-5-carboxylate synthetase (P5CS), and ornithine δ-aminotransferase (OAT) - Overall effects were not concentration-dependent: 5 mM GABA showed the highest effects (compared with 1 mM and 10 mM GABA)	[124]
Dipping in salicylic acid solution followed by cold storage	Anjiry maleky	- Treatment conditions * Dipping: 0.5, 1, 1.5 mM, 10 min - Storage: 1 °C, 80–90% RH [1], 28 days	- Improvement in the stability of fruit quality * Lower weight loss * Lower pH and TSS [2] * Higher firmness and TA - Improvement of nutritional quality * Higher contents of total phenol and flavonoid	[126]
Dipping in salicylic acid solution followed by cold storage	Flordaking	- Treatment conditions - Dipping: 0.5, 1, 1.5, 2.0 mM, 5 min - Storage: 0 °C, 90% RH [1], 5 weeks	- Improvement in the stability of fruit quality * Lower weight loss * Higher firmness, lower pH, lower decay incidence * Activation of antioxidant enzymes (CAT, SOD, POD) - Decrease in the activity of fruit browning enzyme: polyphenol oxidase (PPO) - Higher radical scavenging activity	[125]
Dipping in $CaCl_2$ solution followed by ambient temperature storage after cold storage	Earli Grande	- Treatment conditions - Dipping: 4, 6% $CaCl_2$, 10 min * Storage: 0–2 °C, 85–90% RH [1], 21 days - Post-storage: 28–30 °C, 65–70% RH [1], 72 h	- Improvement in the stability of fruit quality * Lower spoilage incidence, higher firmness, higher acidity, higher reducing sugar, minimum pectin methyl esterase (PME) activity * Higher palatability rating	[128]

Table 4. *Cont.*

Method	Cultivar	Method and Treatment Conditions	Results and Implications	Reference
Dipping in yeast saccharide solution followed by room temperature storage	Baifeng	- Treatment conditions * Dipping: 0.1, 0.5, 1.0 mg/L (in 10 L), 20 °C, 5 min * Drying: 3 h - Inoculation * *Penicillium expansum* - Storage: 20 °C, 95% RH [1], 6 days	- Improvement in the stability of fruit quality * Lower decay incidence and lesion diameter - Induction of defense responses of products against fungal infection based on the increase of endogenous nitric oxide (NO) levels * Activation of the antifungal enzymes (chitinase, β-1,3-glucanase) * Enhancement of phenolic synthesis by higher activities of phenylalanine ammonia-lyase (PAL) and POD	[129]
Dipping in benzo-thiadiazole-7-carbothioic acid S-methyl ester (BTH) solution followed by room temperature storage	Jiubao	- Treatment conditions * Dipping: 200 mg/L BTH solution, 5 min - Inoculation * *P. expansum* (after 60 h of dipping treatment) - Storage: 22 °C, 85–95% RH [1], 16 days	- Improvement in the stability of fruit quality * Lower weight loss * Lower disease incidence rate - Induction of defense responses of product against fungal infection * Enhancement of the activities of PAL, PPO, and POD * Increase of total phenolic compounds and H_2O_2	[130]
Soaking in calcium nanoparticles with ascorbic acid followed by cold storage	Florida Prince	- Treatment conditions * Soaking: 9 mM calcium nanoparticles with ascorbic acid, 15 min, 4 °C - Storage: 4 ± 1 °C, 95 ± 1% RH [1], 30 days	- Improvement in the stability of fruit quality * Lower CI [4] index, SSC [6]/TA [3] ratio, ethylene production, and respiration rate * Higher firmness * Lower MDA content	[131]
Dipping in nano-chitosan followed by cold storage	Florida Prince	- Treatment conditions * Dipping: 200, 400, 800 ppm nano-chitosan - Storage: 0 ± 1 °C, 90–95% RH [1], 3 weeks - Post-storage: 20 ± 2 °C, 70–75% RH [1], 3 days	- Improvement in the stability of fruit quality * Lower weight loss * Higher firmness * Lower decay incidence	[132]
Dipping in gum followed by refrigerated storage	Jinxiu	- Treatment conditions * Dipping: 1, 5, 10% peach gum solution, 10 min - Storage: 8 °C, 25 days	- Improvement in the stability of fruit quality * Lower weight loss * Lower ethylene production * Higher firmness * Reduction of sorbitol breakdown - Transcriptomic analysis * Downregulation of genes governing ethylene synthesis, softening, ageing, and stress responses	[134]

Table 4. *Cont.*

Method	Cultivar	Method and Treatment Conditions	Results and Implications	Reference
Dipping and daily spraying of electrolyzed oxidizing water followed by room temperature storage	-	- Inoculation * *M. fructicola* - Treatment conditions * Near-neutral electrolyzed oxidizing water (pH 6.5–6.7; oxidation/reduction potential 800–900 mV; 250 ppm total residual chlorine species) * Dipping: 10 min * Spraying: 6 mL, daily - Storage: 25 °C, 90% RH [1], 20 days	- Antifungal effects * Effective against *M. fructigena* : Lower incidence of infection and diseases severity	[32]
Fumigation of volatile organic compounds from *Bacillus subtilis* followed by room temperature storage	Zhaohui	- Treatment conditions * Addition of 200 µL of CF-3 24h FB on filter paper sheet - Storage: 25 °C, 4 days	- Improvement in the stability of fruit quality * Decrease of enzyme (cellulase, pectinase) activities which destroy the plant tissues * Activation of antioxidant enzymes (POD, PPO, CAT, SOD) to decrease MDA content and cell membrane permeability by the protection from product damage by oxidants	[136]
Fumigation of NO gas followed by cold storage	Feicheng	- Treatment conditions * 5, 10, 15 (µL/L), 3 h - Storage: 5 °C, 40 days	- Improvement in the stability of fruit quality * Higher firmness, lower ion leakage, lower rot index - Changes of lipid composition * Decrease of unsaturated C-18 fatty acid (18:3) associated with ion leakage and the integrity of the membrane	[139]
Fumigation of NO gas followed by cold or room temperature storage	Feicheng	- Treatment conditions * 5, 10, 15 (µL/L), 3 h - Storage (Cold): 5 °C, 40 days - Storage (Room temperature) : 25 °C, 7 days	- Improvement in the stability of fruit quality * Higher firmness, lower TSS [2] - Lower ethylene production - Lower activity of LOX and 1-aminocyclopropane-1-carboxylic acid (ACC) oxidase	[138]
Fumigation of NO gas followed by room temperature storage	Rojo Rito	- Treatment conditions * 5 µL/L, 7 min - Storage: 20 °C, 14 days	- Improvement in the stability of fruit quality * Lower respiratory rate and ethylene production * Higher activities of the antioxidant enzymes (CAT, SOD) - No effects to TSS [2], TA [3], and color	[137]

Table 4. *Cont.*

Method	Cultivar	Method and Treatment Conditions	Results and Implications	Reference
Fumigation of NO gas followed by room temperature storage	Xiahui no.5	- Treatment conditions * 10 μL/L, 3 h - Storage: 20–25 °C, 80–90% RH [1], 5 days	- Mode of action for the effects of NO gas fumigation was revealed by the proteomic analysis	[140]
Fumigation of EO followed by room temperature storage	Early grand	- Treatment conditions * Peppermint and sweet basil EOs, 1–4 mL/box - Storage: 27 °C, 22 days	- Suppression of brown rot and *Rhizopus* rot diseases - Phytotoxicity of fruits with the treatment of a high concentration of EO (4 mL/box)	[141]
Exposure to volatile EO (microencapsulated) and/or 1-methylcyclopropene (1-MCP) followed by cold storage	Yanhong	- Singular and combined treatment * *Syringa* EO microencapsulation (SEOM): attachment of 1.5 g powder sealed in non-woven bag (5 cm × 5 cm) with holes to the headspace inside fruit packages * *1-MCP: 1 μL/L, 20 h - Storage: 1 ± 0.5 °C, 90% RH [1], 35 days	- Improvement in the stability of fruit quality: Delaying fruit ripening, decrease of ethylene production, higher firmness - Synergistic effects by the combined treatments of SEOM with 1-MCP	[142]
Fumigation of 1-MCP followed by cold storage with the flow microcirculation of ozone (O_3)	Jinqiuhong	- Singular treatment * 1-MCP: Fumigating, 5 μL/L, 24 h * Storage: 0 °C, 45 days - Combined treatment * 1-MCP: Fumigating, 5 μL/L, 24 h * Storage with O_3 flow microcirculation : O_3 0.08 ppm, 0 °C, 45 days - Post-storage: 20 ± 0.1 °C, 95% RH [1], 10 days	- Improvement in the stability of fruit quality * Decrease of MDA content and ethylene emission * Higher firmness, SSC [6], and TA [3] * Color retention - Decrease of microbial deterioration and damage * Reduction of decay rate, increase of PPO resistance	[143]

[1] RH: relative humidity; [2] TSS: total soluble solid; [3] TA: total (titratable) acidity; [4] CI: chilling injury; [5] ROS: reactive oxygen species; [6] SSC: soluble solid content.

4.3. Biological Treatments

Fungal diseases in peach fruits are usually caused by latent infection via wounds during handling in fields, processing, and storage [144,145]. Antagonists are microorganisms that control pathogens by colonization on fruit surfaces or flesh exposed by the wound (i.e., competitive exclusion) and resource competition for nutrients [146]. Moreover, previous research regarding the inoculation of antagonists on peaches also showed an increase in the activities of antioxidant enzymes (e.g., APX, CAT, PAL, POD, and SOD) as an indirect effect of post-harvest treatments [147,148]. Since the antagonists used on fruits have been validated as safe for consumption, there is no concern about the residue, which is not the case for the chemical treatment technologies using toxic fungicides [149]. Major examples of antagonists reported as applicable for peach fruits are as follows: *Pichia caribbica* [147], *B. subtilis* [148], *Cryptococcus laurentii* [150], and *Aureobasidium pullulans* [151]. The function of antagonism can be diverse according to the determinant factors including region, cultivar, and environment (Table 5).

Rapid growth on peaches can be a key characteristic of antagonists from the perspective of colonization competition. Xu et al. [147] revealed the competitive growth of a fast-growing antagonist (*P. caribbica*) against a fungal pathogen (*R. stolonifera)*, which can also grow rapidly in the flesh of peaches by penetration of the wound, and showed the effects of biocontrol capability by decreasing the level of fungal decay (lower disease incidence and lesion diameter) during room temperature storage.

The identification of post-harvest pathogens isolated from stone fruits and the subsequent characterization of their ability to cause decay in fresh fruit can indicate the microbial strain that should be targeted for control [152,153]. Zhang et al. [148] isolated peach-decaying fungal strains (*Alternaria tenuis* and *B. cinerea*, which showed 100% and 92.33% disease incidence for fresh peach fruits, respectively) and revealed competitive inhibition as the antagonistic mechanism of *B. subtilis* by co-culture with those pathogens on peach wounds under room temperature storage. This study also showed that ca. 7 log CFU/mL antagonist suspension achieved the highest inhibitory effects against pathogenic fungal growth compared to other concentrations (from 5 to 9 log CFU/mL), suggesting the importance of the specific concentration optimized for each type of antagonist.

Since the changes in physicochemical and/or organoleptic characteristics (e.g., odor, flavor, and color) from the results of the use of synthetic fungicides on fruits have been regarded as one of the major obstacles for the commercialization of chemical post-harvest treatment technologies, antagonists can be an alternative that does not result in quality changes after treatment [146,154]. Zhang et al. [150] showed the broad spectrum of treatment concentration-dependent inhibitory effects of *C. laurentii* (6–9 log CFU/mL) against fungal decay, such as gray mold (*B. cinerea*), blue mold (*P. expansum*), and *Rhizopus* rot (*R. stolonifer*) during room temperature storage (at 25 °C up to 5 days) without changes in other undesirable quality parameters.

Although most co-culture growth experiments of antagonist pathogens have been conducted at room temperature within a few days due to the limited growth range of the antagonist and short shelf life of peach fruits [147,148,150], antagonists active at low temperatures are also needed for the preservation of fruits during long-term storage under refrigeration conditions. *A. pullulans* is a well-known cold-tolerant antagonist that can be used to control fungi decaying the fruit during cold storage [155–158]. Zhang et al. [151] demonstrated the antifungal effects of *A. pullulans* PL 5 treatment of peach fruit in regards to the reduction of *M. laxa* incidence and the diameter of decay and showed that the mechanisms were both direct (competition during the co-culture of antagonist pathogens) and indirect (activation of enzymes governing the host defense (chitinase and β-1,3-glucanase)).

Table 5. Post-harvest treatments of biological technologies on peach fruits.

Method	Cultivar	Treatment Conditions	Results and Implications	Reference
Inoculation of antagonist on peach followed by room temperature storage	Dajiubao	- Treatment conditions * Antagonist: *Pichia carbic* (spot-inoculation, 30 μL, 6–9 log cells/mL) * Target fungi: *Rhizopus stolonifer* (spot-inoculation, 30 μL, ca. 4 log spore/mL) - Storage: 20 °C, 95% RH [1], 4 days	- Improvement of antioxidant activity * Activation of peroxidase (POD), catalase (CAT), and phenylalanine ammonia-lyase (PAL) - Decrease of microbial deterioration and damage * Decrease of disease incidence and lesion diameter	[147]
Inoculation of antagonist on peach followed by room temperature storage	Baifeng	- Treatment conditions * Antagonist: *Bacillus subtilis* JK-14 (spot-inoculation, 30 μL, 5–9 log CFU/mL) * Target fungi: *Alternaria tenuis* (spot-inoculation, 15 μL each, 6 log CFU/mL, *Botrytis cinerea* (spot-inoculation, 15 μL each, log CFU/mL) - Storage: 20 °C, 85% RH [1], 5 days	- Improvement of antioxidant activity * Activation of superoxide dismutase (SOD), POD, CAT, and ascorbate peroxidase (APX) - Decrease of microbial deterioration and damage * Decrease of disease incidence and lesion diameter	[148]
Inoculation of antagonist on peach followed by room temperature storage	Baihua	- Treatment conditions * Antagonist: *Cryptococcus laurentii* (spot-inoculation, 30 μL, 6–9 log CFU/mL) * Target fungi: *B. cinerea* (spot-inoculation, 15 μL, 5 log spore/mL), *Penicillium expansum* (spot-inoculation, 15 μL, ca. 4 log spore/mL), *R. stolonifer* (spot-inoculation, 15 μL, ca. 4 log spore/mL) - Storage: 25 °C for 4 days (*B. cinerea, P. expansum*), 25 °C for 5 days (*R. stolonifer*)	- Decrease of microbial deterioration and damage * Decrease of disease incidence - No effects on other quality parameters * Firmness, ascorbate content, TA [2]	[150]
Inoculation of antagonist on peach followed by cold storage	Redhaven	- Treatment conditions * Antagonist: *Aureobasidium pullulans* PL5 (dipping inoculation, 8 log cell/mL, 1 min) * Target fungi: *Monilinia laxa* (spray inoculation, 1 mL, 4 log conidia/mL) - Storage: 1 °C, 95% RH [1], 28 days	- Decrease of microbial deterioration and damage * Decrease of disease incidence, lesion diameter - Improvement of pathogenesis-related proteins linked to the host defense * Activation of chitinase and β-1,3-glucanase	[151]

[1] RH: relative humidity; [2] TA: total (titratable) acidity.

4.4. Combined Treatments

Many previous studies conducted to enhance the quality of peach fruits combined multiple post-harvest technologies categorized as physical (e.g., heating and irradiation), chemical (e.g., dipping in treatment solution and spraying or fumigating solution), and biological (e.g., co-culture of antagonistic organisms) treatments. The major aim of the combination of technologies is to achieve a greater effect than the sum of individual technologies (i.e., synergistic effect) and/or to complement the limitation of each technology with perspectives on the intervention mechanism of quality changes in peaches. The findings of studies on the development of the combination method of technologies and the establishment of optimal treatment conditions highlight novel effects that were unexpected based on the results of the application of individual technologies for peach fruit post-harvest treatments. Since the combination of technologies results in antagonistic effects (i.e., a lower effect than the sum of individual technologies or the inhibition of the intended effects by the interaction among the combined technologies), the exploration of adequate treatment concentrations is also needed to avoid inefficiency. Table 6 summarizes the findings of the previous research focused on combined treatment methods applied for the post-harvest quality and safety control of peach fruits.

4.4.1. Combination of Physical and Chemical Treatment

Since there are concerns about the toxicity and environmental pollution derived from the excessive use of chemical post-harvest agents, the combination of physical treatment technologies has been attempted to reduce the treatment concentration of agents [159,160]. In the case of peach fruits, salicylic acid treatment combined with ultrasonication or thermal pre-treatment are representative examples [161,162]. Ultrasound treatment for fresh fruits and vegetables has been used to clean surfaces and to inactivate microbial contaminants with the disruption of cells; however, direct antimicrobial efficacy is likely to be insufficient to achieve a reduction in fungal decay, and thus the combination with other decontamination technology is generally needed [163]. Yang et al. [161] combined salicylic acid (dipping in solution (0.05 mM)) and ultrasonication at 20 °C for 10 min followed by room temperature storage (20 °C, 6 days) of peach fruits infected with blue mold (*P. expansum*); all treatments (both singular and combined) did not affect the quality factors (weight loss, firmness, TSS, and vitamin C content), but the beneficial effects from the singular salicylic acid treatment (activation of enzymes governing antioxidant and host defense mechanisms and decrease of the fungal decay) were synergistically improved by the combined treatment with ultrasonication; although, individual ultrasound treatment did not influence those effects. The sequential approach of thermal pre-treatment before the application of chemical agents has also been adopted as a combined treatment strategy for post-harvest preservative processing [164]. According to the research by Cao et al. [162], exposure to heat (hot air at 38 °C, 12 h) prior to salicylic acid treatment (dipping in salicylic acid 1 mM at 20 °C for 5 min) is expected to induce the expression of heat-shock proteins related to fruit tolerance, and thus showed desirable effects on internal browning as an indicator of cold stress response capability, antioxidant activities, and polyamine levels during long-term cold storage (0 °C, 35 days).

Radical irradiation has been widely used for the extension of the shelf life of vegetables and fruits due to its cold nature and strong decontamination effects [165]. Edible coating with polysaccharides can preserve the quality parameters of fruits by inhibiting fungal growth on the coated surface [166–168]. As reported by Hussain et al. [169], gamma irradiation (1.2 kGy) of peach fruits coated with carboxymethyl cellulose (1%) can improve the effects on the inhibition of fungal infection, the prevention of quality changes (firmness, TSS, and TA), and the delay of ripening or senescence during cold storage.

4.4.2. Combination of Physical and Biological Treatment

Although it is difficult to predict the effect of commonly used fungicide products through only physical or biological treatment, the support of antifungal biocontrol agents

in combination with physical treatments (e.g., heat treatment) has achieved desirable pathogen control efficacies for fruits [170,171]. Biocontrol agents are generally ineffective against the micro-organisms infecting fruits prior to the application of those agents, and thus the complementation of the antifungal efficacy by support from physical treatment is needed. Microwave treatment enables the rapid heating of food products to efficiently inactivate the microbial cause of decay of fruits and vegetables [172,173]. Zhang et al. [170] suggested the biocontrol strategy of the inoculation of an antagonist (*C. laurentii*) into infected peach fruit (*R. stolonifera*) after microwave heating (2450 MHz, 2 min) for fungal inactivation, and the persistent protective effects of the antagonist were also validated by the decrease in infected wounds on fruits without quality changes (firmness, TA, and TSS). Zhang et al. [171] also showed that the exposure of peach fruit to heated air (37 °C, 48 h) before the application of the antagonist (*C. laurentii*) also ensured its active competitive effects against fungal contaminants causing the decay of peaches (decrease in the ratio of infected wounds by 22.5% and 5% for the infectious disease caused by *P. expansum* and *R. stolonifer*, respectively) without remarkable differences in physicochemical characteristics of fruits (TSS, TA, and vitamin C content).

4.4.3. Combination of Chemical and Biological Treatment

Since biological control using antagonists is generally not as effective as the direct application of disinfectants from the perspective of immediate killing effects, antagonists for peaches have been combined with organic or inorganic additives (e.g., antifungal effects and/or plant growth regulators) to complement the limited effects of antagonists [37,174].

Zhang et al. [174] used antagonist suspensions (*Rhodotorula glutinis*; 8 log cells/mL) amended with salicylic acid (100 µg/mL) for 30 s of dipping treatment before artificial inoculation with gray mold (*Botrytis cinerea*) on peaches, and showed that limited effects of individual treatment with salicylic acid or an antagonist (*R. glutinis*) in reducing the lesion diameter could be significantly improved by the combined treatment without impairing the quality of wounded fruits (TSS, TA, ascorbic acid content, and firmness) [174].

The antagonist *Bacillus* spp. can protect the fruit surface by producing extracellular polysaccharides (e.g., glycocalyx) in biofilm as a physical barrier against the colonization of fungal pathogens, and this biofilm-forming ability can be supported by Eos. Arrebola et al. [37] designed combined treatment technologies between post-harvest spraying of an antagonist on peach fruits followed by packaging with the delivery system of EOs (e.g., thymol and lemongrass oil) and showed a broad spectrum of the disease control, including gray mold (*B. cinerea*), blue mold (*P. expansum*), and *Rhizopus* rot (*R. stolonifer*). This combined treatment technology can also reduce the burden of the application concentration of EO, which is known to have a potential phytotoxic effect causing the browning of fruits and an unpleasant odor [37,113].

Table 6. Post-harvest treatments of combined technologies (physical, chemical, and biological technologies) on peach fruits.

Method	Cultivar	Treatment Conditions	Results and Implications	Reference
Dipping in salicylic acid solution with ultrasound treatment followed by room temperature storage	Baifeng	- Inoculation * *Penicillium expansum* (spot-inoculation, 15 μL, 5 log spores/mL) - Singular treatment * Dipping: salicylic acid 0.05 mM, 20 °C, 10 min * Ultrasonication (40 kHz, 350 W): 20 °C, 10 min - Combined treatment * Dipping in salicylic acid (0.05 mM) + ultrasonication (40 kHz, 350 W) at 20 °C for 10 min - Storage: 20 °C, 95% RH [1], 6 days	- Improvement of antioxidant activity * Activation of phenylalanine ammonia-lyase (PAL), polyphenol oxidase (PPO), and peroxidase (POD) - Activation of the production of pathogenesis-related proteins linked to the host defense * Activation of chitinase and β-1,3-glucanase - Decrease of microbial deterioration and damage * Decrease of lesion diameter and disease incidence - Synergistic effects by the combined treatments of salicylic acid with ultrasonication	[161]
Dipping in salicylic acid solution after hot air treatment followed by the cold storage	Baifeng	- Singular treatment * HA: 38 °C, 12 h * Dipping: salicylic acid 1 mM, 20 °C, 5 min - Combined treatment * Dipping in salicylic acid 1 mM at 20 °C for 5 min after hot air (38 °C, 12 h) treatment - Storage: 0 °C, 90–95% RH [1], 35 days	- Improvement in the stability of fruit quality * Decrease of internal browning - Improvement of antioxidant activity * Activation of superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), and glutathione reductase (GR) * Decreased activity of lipoxygenase (LOX) - Increase of polyamine levels * Higher levels of putrescine, spermidine, and spermine - Synergistic effects by the combined treatments of salicylic acid with hot air	[162]
Gamma irradiation treatment after carboxymethyl cellulose coating followed by cold or room temperature storage	-	- Singular treatment * Carboxymethyl cellulose coating: 0.5–1.0% * Irradiation: γ-ray, 1.2 kGy - Combined treatment - Irradiation (γ-ray, 1.2 kGy) after the carboxymethyl cellulose coating (0.5–1.0%) * Storage (cold): 3 ± 1 °C, RH [1] 80%, 35 days - Storage (room temperature): 25 ± 2 °C, RH [1] 70%, 15 days	- Improvement in the stability of fruit quality * Lower weight loss * Decrease of ascorbic acid, TSS [2], and total sugar * Delay of ripening, senescence, and respiration rate - Improvement of antioxidant activity * Increase of total phenol compounds	[169]

Table 6. *Cont.*

Method	Cultivar	Treatment Conditions	Results and Implications	Reference
Inoculation of antagonist after microwave treatment	Baihua	- Treatment conditions for the experiments of the application of antagonist after the microwave treatment of peach inoculated with pathogen * Target fungi: *Rhizopus stolonifer* (spot-inoculation, 20 μL, 5 log spore/mL) * Microwave treatment: 2450 MHz, 2 min * Antagonist: *Cryptococcus laurentii* (spot-inoculation, 30 μL, 8 log CFU/mL) * Storage: 25 °C, 4 days	- Decrease of microbial deterioration and damage * Decrease of infected wounds - Antifungal effects * Effective against *R. stolonifer* - No effects to other quality parameters * Firmness, TSS [2], TA [3], vitamin C content	[170]
Inoculation of antagonist after hot air treatment	Baihua	- Treatment conditions for the experiments of the application of antagonist after the hot air treatment of peach inoculated with pathogen * Target fungi: *R. stolonifer* (spot-inoculation, 20 μL, 5 log spore/mL), *P. expansum* (spot-inoculation, 20 μL, ca. 4 log spore/mL) * HA: 37 °C, 48 h * Antagonist: *C. laurentii* (spot-inoculation, 30 μL, 8 log CFU/mL) - Storage: 25 °C, 7 days	- Improvement in the stability of fruit quality * Higher firmness - Decrease of microbial deterioration and damage * Decrease of infected wounds - No effects to other quality parameters * Firmness, TSS [2], TA [3], vitamin C content	[171]
Treatment of salicylic acid with antagonist	Jiubao	- Treatment conditions for the experiments of the application of antagonist and salicylic acid treatment before inoculation of pathogen * Antagonist: *Rhodotorula glutinis* (spot-inoculation, 30 μL, 8 log CFU/mL) * SA: 100 μg mL (spot-inoculation, 30 μL) * Target fungi: *B. cinerea* (spot-inoculation, 30 μL, 8 log CFU/mL) - Storage: 20 °C, 95% RH [1], 5 days	- Decrease of microbial deterioration and damage * Decrease of decay incidence, lesion diameter - No effects to other quality parameters * TSS [2], TA [3], ascorbic acid, firmness	[174]

Table 6. *Cont.*

Method	Cultivar	Treatment Conditions	Results and Implications	Reference
Treatment of essential oils (EOs) with antagonist followed by room temperature and cold storage	Transvaal	- Singular treatment * Antagonist: *Bacillus amyloliquefaciens* PPCB004 (spray inoculation, 10–15 min, 8 log CFU/mL) * EO: lemongrass or thyme (75 µL impregnated for each package bag) - Combined treatment * Packaging of peach fruits sprayed with antagonist (*B. amyloliquefaciens* PPCB004; spray inoculation, 10–15 min, 8 log CFU/ mL) in bag impregnated with EO (lemongrass or thyme; 75 µL) - Inoculation of target pathogen after the treatment: *B. cinerea* (spraying for 10–15 min, 6 log spore/mL), *P. expansum* (spraying for 10–15 min, 6 log spore/mL), *R. stolonifer* (spraying for 10–15 min, 6 log spore/mL) - Storage (room temperature): 25 °C, 5 days - Storage (cold): 4 °C, 90% RH [1], 14 days	- Decrease of microbial deterioration and damage * Decrease of the incidence and severity of the diseases	[37]

[1] RH: relative humidity; [2] TSS: total soluble solid; [3] TA: total (titratable) acidity.

5. Conclusions

This review provides comprehensive information based on the findings from studies regarding pre- and post-harvest treatment strategies optimized for peach fruits to extend the durable intake. Since peaches are vulnerable to environmental stresses under room temperature, most relevant studies aim to ensure fruit quality during long-term cold storage. Recent research has mainly focused on the development of new technologies and the design of novel combined treatment, whereas the in-depth study of pre- and post-harvest processes previously reported as applicable for stone fruits to optimize operational conditions for peaches should also be consistently conducted due to the diversity in the efficacies of treatment methods according to various determinant factors (e.g., a cultivar of fruits, processing environments, storage temperature, and time). Major implications from the analysis of the literature can be summarized as follows: (1) the discovery of side-effects from the overuse of treatment agents (chemical and biological technologies) or severe treatment conditions (physical technology) highlights the importance of the determination of the adequate criteria for the limitation of operational conditions; (2) since the result of the combined treatment is generally unexpectable (e.g., synergistic, additive, and antagonistic effects), the establishment of strategies which can harmonize both the efficacy and efficiency should be followed; and (3) pre-harvest treatment technologies generally aim to achieve sustentative effects allowing the improvement in the stability of fruit quality during the long-term cold storage, and thus the combined (sequential) treatment with subsequent post-harvest treatment is expected to enhance overall efficacies. This focused review suggests practical information for the design of advanced pre- and post-harvest treatments for peach fruits based on insights into advantages and disadvantages of currently reported technologies. As a future perspective on the research area in peaches, the quality control system based on the technologies in the Fourth Industrial Revolution era is expected to be integrated into pre- and post-harvest treatment strategies for peach fruit by sensing the fruit quality, strict pre-harvest quality control in smart farms, and web cloud-based precise quality management during the storage and/or distribution. The sensor-based analysis of the changes in the fruit quality factor can be a promising countermeasure for undesirable antagonistic effects derived from the combined treatment of pre- and post-harvest technologies described in this study.

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