Physical, Chemical and Processing Postharvest Technologies in Strawberry

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Abstract

Strawberry (*Fragaria × ananassa*) is a fruit of great acceptance worldwide but has characteristics that make it a highly perishable fruit, with shelf life of about a week, which makes it difficult to transport and store it to consumer places. Throughout the years, post-harvest techniques have been studied to extend their useful life and improve their properties. Strawberry deterioration may be due to various factors such as overripe, fungal involvement, moisture loss, mechanical damage, among others. Among the techniques which have been tried to slow the deterioration of the fruit are the use of modified atmospheres and treatments gases, use of edible coatings and smart packings, application of radiation of various types, use of chemical treatments among many others. In this chapter, we will examine the most relevant treatments applied to the strawberry to extend its useful life and improve its organoleptic quality that have been reported in the literature.

Keywords: modified atmosphere, radiation, quality, physiology, shelf life

1. Introduction

Strawberry (*Fragaria × ananassa*) is considered a non-climacteric fruit [1] that is, it does not continue its maturation process after being cultivated. Coming from the *Rosaceae* family, it is cultivated in various countries around the world and consumed throughout the world due to its taste, smell and color. It is consumed fresh, dry, in preserves and culinary preparations, its transport can be carried out in fresh or in freezing, which can alter its organoleptic characteristics.

Being a non-climacteric fruit, it should be grown at its peak ripeness; however, this makes shorter lifespan compared to climacteric fruits, which can be matured along transportation. The high moisture content of the fruit and the characteristics of its skin make it susceptible to mechanical damage and the proliferation of fungi and other microorganisms that damage the fruit.

For the realization of this chapter, more than 100 scientific articles from different databases were searched using search parameters “strawberry” “postharvest” “shell life”. As can be seen in Figure 1, most studies have focused on the use of treatments with gases and modified atmospheres to extend the useful life of the product while maintaining its quality parameters with about 21.3% of the total of studies.
reviewed (violet zone). Second, the use of physical elicitors such as radiation, ultrasound, changes in pressure among others, to reduce the biological load on the surface of the fruits, activate defense mechanisms of plant tissue or the generation of compounds to maintain the shelf life of fruits, covering just under 15% of those surveyed items (blue zone).

Other technologies in postharvest have been applied in strawberry as thermal treatments, application of edible coatings, use of chemical solutions in fruits or the application of several technologies at the same time to generate synergistic responses in the product.

Each of the technologies studied has its advantages and disadvantages, as well as its application in various scenarios for the transport and storage of the product. The use of each one depends on the amount of fruit to be treated, as well as the cost of application, the need on the part of the producers and the demands on the part of the buyers.

2. Modified atmospheres and gas application

The use of modified atmospheres, controlled atmospheres and application of gases in post-harvest is one of the treatments with greater acceptance in the post-harvest industry [2]. The use of these gases has an impact on the appearance and texture of the fruits; however, the effects on taste and odor are not yet clear and may differ from product to product. In the studies carried out, it has been found that the use of modified atmospheres generates changes in post-harvest parameters such as titratable acidity (TA), total soluble solids (TSS), sugars and organic acids and metabolites derived from fermentative processes.
The use of carbon dioxide as part of a modified atmosphere has shown positive effects in preserving the sensory characteristics of strawberry [3, 4]. Studies on the effect of the application of carbon dioxide have shown that it generates stress in the tissue of the fruit generating an increase in the γ-aminobutyric acid (GABA), which, in intermediate levels, activates mechanisms that allow the fruit to maintain the color and texture suitable for consumption [5].

Short exposure to high levels of carbon dioxide has shown that it is able to reduce the chemical and physical phenomena associated with deterioration of the fruit, decreasing tissue ATP levels and generating a low ethanol metabolism, unlike when stored in the presence of air, which generates an increase in the ATP and an explosion of the processes of fermentation in the tissue, leading to its putrefaction [6].

The use of carbon dioxide also has an effect on the proliferation of microorganisms such as Botrytis cinerea, which is responsible for the loss of strawberry quality. The studies showed that use of concentrations between 5% and 10% of CO₂ helps to reduce the proliferation of Botrytis, without generating negative impacts on parameters such as TSS and TA, in addition to maintaining a uniform and attractive color for the consumer [7, 8].

The application of 1-methylcyclopropene (1-MCP) has been an alternative studied to manage the deterioration process in strawberry. Several studies have been applied dose of the gas to decrease the rate of senescence, with positive results without affecting quality in doses from 0.5 μL⁻¹ to 5 μL L⁻¹, however, at higher doses, the effects of deterioration accelerated [9–13].

The management of the production and/or presence of ethylene in the packing atmosphere or in post-harvest treatment is one of the most used techniques for managing the ripening speed in fruits and vegetables, sometimes, it is desirable to decrease the presence of this gas, but supplementation is also used to improve the post-harvest quality of various agricultural products. In the case of strawberry, some studies have been conducted in this direction and in search of the elucidation of the biochemical processes responsible for the response of the tissue against this gas [14–16].

The use of atmospheres saturated with oxygen has been studied with mixed results. At high concentrations of O₂ the rate of deterioration was lower [17] but studies on the release of volatile compounds from the treated fruits showed that the application of supplemental oxygen stress generated in the metabolism leading to the production of compounds related to alcoholic fermentation, raising questions about the effectiveness of such treatment [18, 19]. On the other hand, the use of ozone (O₃) as a treatment in strawberry showed dissimilar results in the control of the proliferation of pathogens [20, 21], but the use of water enriched with ozone as a cleaning method proved to reduce the biological load on the surface of the fruit without affecting its turgidity or firmness [22]. Another approach to the use of oxygen compounds for post-harvest treatment is the in-situ generation of reactive oxygen species (ROS), which showed positive effects in variables measured as TSS, acidity, maturity stage, among others [23].

Among the studies analyzed, one stands out where nitrous oxide was used as a regulating agent for the growth of fungi and molds, with positive results [24]. In the aspect of modified atmospheres, packages have been developed that directly regulate the concentrations of different gases throughout the transport and storage of the product, managing to extend the useful life of strawberry in about 10 days in comparison to standard packages [25, 26].

3. Physical elicitors

The use of postharvest physical elicitors has been studied for several decades. This type of technology has the advantage of low operating costs and the rapid
amortization of the initial investment, in addition to generating positive responses such as the generation of metabolites of interest in the treated products, but its main disadvantage is the time for standardization of the process and the variability of the generated responses that depend on the matrix subjected to the stimulation.

Most of the studies consulted that applied a physical elicitor used ultraviolet (UV) radiation with special emphasis on ultraviolet C radiation (UV-C), which has a higher energy than A and B radiation. Different studies on the use of radiation UV-C have demonstrated their ability to decrease the biological load of the fruit without affecting sensory properties such as color, firmness, texture, humidity, among others. [27–30].

Studies on the impact of the application of ultraviolet C radiation on phytochemical processes in tissue products have shown that it has a direct impact on the synthetic route of phenylpropanoids and phenylalanine ammonia-lyase (PAL) [31–34], which it has effects on the production of secondary metabolites such as polyphenols, anthocyanins and oxygenates, that have been identified as families of compounds of interest for their antioxidant activity, increasing the benefits of strawberry intake for the final consumer [35, 36].

The application of ultraviolet B radiation (UV-B) showed similar effects as those found with UV-C, but the exposure and dose times are higher to achieve the same results. This increase in time and dose generates an increase in the cost of its application as a post-harvest treatment, but UV-B radiation is more secure at the genetic level, since its impact is lower in the DNA chains, decreasing the possibility of death cellular or generation of mutations in the tissue, and in turn, is less dangerous to the operator than UV-C radiation [37].

The use of pulsed light (PL) as post-harvest treatment was investigated by Duarte-Molina et al. Finding that it has positive effects on the texture and firmness of the product compared to the control samples, diminishing the effect of pathogens and longer shelf life without negative effects on other postharvest parameters, turning this technology into a promising alternative in the handling of strawberry [38].

Gamma radiation used as a process of sanitization in food and post-harvest treatments was booming in the last decades of the twentieth century [39], However, the consumer’s fear of the presence of residual radiation in the products led to the labeling of these products as subject to gamma rays and the subsequent rejection of these by consumers. But its use as a means of sanitization with low effect on the texture of the product has been tested in strawberry with positive effects at low levels of radiation [40].

Another of the alternatives for handling the biological load naturally present in strawberry is its exposure to low pressures in, obtaining positive effects at 0.25 atm per 24 hours [41]. These treatments at reduced pressures also showed effects on the antioxidant capacity, which suggests a positive effect on the stimulation of various metabolic pathways such as those mentioned above [42].

Using the response surface methodology (RSM) parameters were optimized for the use of ultrasound as post-harvest treatment in strawberry, finding an optimum in the power parameters and exposure time to 250 kw and 9.8 minutes respectively [43], decreasing the incidence of fungi and molds without affecting the quality of the product.

4. Thermal treatments

The thermal treatments used in postharvest seek to eliminate the biological load that is in the skin of the products through the application of heat or cold for a certain period. In the case of heating, the temperature used must be high enough to eliminate fungal spores and mold, but not so much to generate changes in the fruit
such as Maillard reactions, caramelization or oxidation. The time of exposure to these temperatures is also critical. In the case of treatments based on the application of cold, the temperature should not be so low to generate tissue damage by freezing the water inside the cells, but enough to inactivate the biological load.

In the case of the application of heat, this can be done through the immersion of the strawberry in water, as was done in [44]. Four temperatures (25, 35, 45 and 55°C) were tested for 15 minutes. The best results were obtained at 45°C, where the lowest losses were obtained in comparison to the other treatments and to the control, however, the color of the strawberry was affected in a negative way, which was confirmed by another study [45].

Other studies used hot air at temperatures between 35 and 55°C in forced air ovens, with an exposure time between 1 and 5 hours. Subsequent analyses showed that hot air treatment had a positive impact on strawberry shelf-time, and on parameters such as firmness, respiratory rate, anthocyanin content, titratable acidity and TSS [46–50], however, the loss of color measured through a colorimeter was also observed in this technique. Further investigation determined that the use of hot air affects the expression of several genes in strawberry (FaPG1, FaPLB, FaPLC, FaAra1, FaβGal4) and the greater stress load is evident in the cell wall, which generates an increase in the amount of cellulose, hemicellulose, and lignin in fruits, which in turn explains the preservation of cell structure, which decreases the incidence of Botrytis cinerea [51].

An alternative to the use of hot air for heating strawberry is the use of Far Infrared Radiation (FIR), which provides the possibility of uniform heating on the surface [48]. Simulations carried out using the Monte Carlo method and validated through a thermal imaging camera showed that an optimal control over the surface temperature in strawberry can be achieved below the critical limit of 50°C along with a uniform heating, which would be maintained the post-harvest quality and the shelf life would be lengthened. The use of low temperatures for the preservation of strawberry has been studied as a traditional alternative for the preservation of shelf life in long periods of storage, however, the temperature used for cooling, as well as the cooling rate are decisive factors on product quality. A first approach is to use temperatures above 0°C that will reduce the natural biological processes of both the fruit and biological contaminants. In the study carried out by Ayala-Zavala and others [52] temperatures of 0, 5 and 10°C were tested, finding that parameters such as antioxidant capacity and the profile of volatile compounds were better at temperatures above 0°C.

Under more extreme conditions, strawberry was stored at temperatures of −40°C for 6 months to subsequently measure parameters such as reducing sugars, total phenols, color, antioxidant capacity, brightness and firmness of the skin of the fruit [53]. It was found that storage at that temperature maintains the chemical and physical characteristics of the fruits, finding only difference between the cultivation techniques used, which was part of the reported research.

As mentioned above, the cooling rate is a critical parameter when performing cold treatments. If a fruit cools or freezes quickly, prevents large ice crystals form inside the cells, which could cause damage to the cell wall, decreasing the quality of the product and increasing the possibility of infection by pathogens. The simulation of cooling systems for strawberry packaging has been studied in order to define the optimal parameters of air speed and temperature of the same to achieve a uniform and fast cooling [54].

5. Chemical treatments

The use of chemical substances to promote or delay the maturation and senescence processes in fruits and vegetables has been widely studied. They have been
used from inorganic salts to a wide variety of organic compounds that have been shown to have an impact on the metabolism of plant tissue. Generally, the application of said compounds is carried out by immersing the product in a solution of the compound or by spraying it. The compounds used must be safe for human consumption and their concentration must not alter the organoleptic properties of the treated product.

To facilitate the review of the articles, it is convenient to divide the chemical treatments into three large areas; inorganic compounds, organic compounds, and essential oils. Essential oils have become very important in post-harvest processing, as well as in industries such as food and cosmetics. It has been found that essential oils have different properties ranging from antioxidant capacity to inhibit the proliferation of fungi, bacteria and viruses.

Calcium chloride (CaCl₂) is one of the most used inorganic compounds in post-harvest treatment in various products in concentrations between 1–4%. In the studies consulted, positive results were obtained by stopping the deterioration process in strawberry, maintaining the parameters of sensory quality [55–57].

Hydrogen sulfide (H₂S) is a compound that plays a vital role in the metabolism of the maturation and senescence of the fruits. The supplementation of this compound through the fumigation of the fruits prolongs the useful life of the product directly depending on the dose used. It was also identified that hydrogen sulfide maintains the activity of families of enzymes such as catalase, guaiacol peroxidase, ascorbate peroxidase, and glutathione reductase [58].

Another possible use of inorganic compounds in postharvest is the sanitization of products. A mixture of peracetic acid (PAA) and hydrogen peroxide is nebulized in strawberry samples in concentrations ranging from 3.4 to 116 μL PAA L⁻¹ air chamber. The quantification of the concentration of phenolic compounds showed degradation of this class of compounds at certain concentrations of PAA, being the anthocyanins the most affected, followed by the proanthocyanidins with low level of polymerization and hydroxycinnamic acid derivatives [59].

The addition of organic compounds in solution or through their vaporization in the post-harvest stage or packaging has various mechanisms of action to preserve the quality of the products. One of the most studied compounds in strawberry pure methyl jasmonate (MJ) or in solution with ethanol [60]. The different studies concluded that the use of MJ in strawberry increases the concentration of volatile compounds such as Methyl acetate, isoamyl acetate, ethyl hexanoate, butyl acetate, and hexyl acetate. Also, the useful life increased in comparison to those that were not submitted to the treatment, as well as the antioxidant capacity of the fruit [61, 62]. Similar results were obtained when using 2-nonanone in strawberry systematically released by packaging and tested under shelf conditions [63].

In floriculture the use of salicylic acid as a preservative in flowers and foliage is very common, studies have also been carried out on the possibility of its use as an agent that modulates the release of ethylene in fruits such as strawberry. The effect of salicylic acid is independent of the concentration and has as an additional advantage its ability to control the proliferation of fungi, extending the shelf life [64–66].

The gibberellic acid (GA3) is a maturation retarder commonly used in postharvest and its application in strawberry has been investigated. Using partially mature samples, the application of gibberellic acid delays the process of color generation in fruits, together with the activity of PAL and other enzymes such as chlorophyllase and peroxidase, decreasing the speed of fruit ripening [67].

Apart from the aforementioned compounds studies have been conducted with Ethyl pyruvate [68], melatonin [69, 70] and acetic acid from baby corn [71] with
very promising results, however, the high specialization of these compounds, as well as the necessary infrastructure for their application in post-harvest, make it difficult to implement treatments based on these results for small and medium producers of strawberry.

Essential oils are a mixture of a large number of organic compounds of the family of volatile terpenoids (monoterpenes, sesquiterpenes), mixed with other compounds such as aldehydes, ketones, esters, ethers among others. The amount and which compounds are present in an essential oil depend directly on the source from which it is extracted and on the extraction methodology. Essential oils are obtained through steam distillation, by cold pressure extraction and dissolution in vegetable oils.

In the case of strawberry, tea tree oil (TTO) has been tested as an antifungal agent, obtaining positive results in the decrease of the proliferation of *Botrytis cinerea* and *Rhizopus stolonifer* in strawberry, which are mainly responsible for the damage by pathogens in postharvest [72]. This same essential oil was tested as a pre-harvest treatment in strawberry, also obtaining a decrease in the impact of fungi on the fruits, although positive effects were also evidenced in parameters such as the firmness, color and quantity of polyphenols [73].

Essential oils are alternatives generally considered safe against the use of conventional chemicals in products for human consumption. The use of essential oil of Satureja species (*S. hortensis*, *S. spicigera*, and *S. khuzistanica*) as a fungicidal agent has been investigated. The essential oils were characterized using gas chromatography coupled to mass spectrometry, determining that the major compounds were carvacrol, thymol, γ-terpinene and p-cymene [74]. The essential oils tested showed ability to inhibit the growth of *Penicillium digitatum*, *Botrytis cinerea* and *Rhizopus stolonifer* in strawberry under storage conditions.

6. Edible coatings

Edible packaging has become one of the most booming research topics in recent decades in food and post-harvest. An edible package must have characteristics such as generating a uniform coating on the surface of the fruit, allowing and/or regulating the rate of respiration of the fruit to maintain the sensory quality thereof, be inert and harmless to the human being, be easily applicable and fast dry. An edible package can be applied either through immersion in the coating solution or by sprinkling using air under pressure.

Chitosan is one of the most commonly used coatings at industrial level thanks to its null toxicity and generation of a semipermeable membrane that allows the passage of moisture and gases, preventing the start of anaerobic fermentation processes [75].

In studies conducted in strawberry, the application of chitosan decreased the proliferation of fungi and molds that affect the quality of the fruit [1, 76, 77]. The use of additives such as glycerol, olive oil, extracts of essential oils, among others, have been studied to improve certain qualities of chitosan, such as tensile strength, gas exchange capacity, antifungal and antibacterial capacity, among others. [78–81]. The study of the application of nanocomposites based on titanium and other elements have proven to provide functional properties to the coatings, from being only a coating to extend the useful life to provide functional food properties to the products in which they are used [81–84].

But not only has chitosan been tested in strawberry, other substrates and substances have been tested in search of economic and technical alternatives to traditional methods. The substances used range from coatings based on gluten, methylcellulose, quinoa protein, *Aloe vera*, silk fibroin, a mixture of various polysaccharides and arabic gum [85–92].
7. Combined treatments

Sometimes, the application of two or more post-harvest treatments generates a synergistic effect on the quality and maintenance of the product’s useful life. The order in which the treatments are applied determines the effectiveness of the final result [93]. Immersion of strawberry in calcium gluconate subsequently be coated with a formulation of 1% chitosan or chitosan-sodium gluconate was assayed by Hernández-Munoz; better results are obtained when using the formulation of both components [94]. The use of a mixture of chitosan together with organic acids, calcium and vegetable extracts demonstrated a positive impact on fungal control in pre-harvest and post-harvest [95, 96] and the use of an edible coating based on a mixture of Aloe vera and beeswax, coupled with the control of temperature and humidity in storage, decreased the percentage of post-harvest losses in strawberry as reported by Affan [97].

On the other hand, the use of physical elicitors in combination of controlled atmospheres has been shown to generate an additive effect in the conservation of strawberry quality. The combination of ozone, atmospheres with high concentrations of oxygen and carbon dioxide together with the application of UV-C proved to extend the useful life as well as increase the content of polyphenols and ascorbic acid present in the fruit [98]. Likewise, the application of chlorine dioxide, fumaric acid linked to UV-C, decreased the biological load on the fruits [99]. Other compounds or treatments used in combination with UV-C radiation are hot water and salicylic acid [100–102].

Other combined treatments include the use of nitric oxide, ethylene and low temperatures [103], low density polyethylene with nanoparticles of titanium oxide to actively control the respiration of the fruit [104], Use of specific light intensities after washing the fruits in chlorine solution [105] and the use of nitrogen for strawberry freezing at −20°C after sanitization with 50 ppm chlorine [106].

8. Conclusions

The strawberry is a fruit of worldwide interest for its sensory properties and nutritional quality, but its physical and chemical characteristics generate problems in storage and transport. In order to face these challenges, several post-harvest techniques have been tried to know the impact on the quality and characteristics of the fruit. Each technique has advantages and disadvantages and the implementation of one or more of these post-harvest techniques will depend on economic, technical and social factors of the growing region.

In the case of strawberry, the most used techniques are those associated with modified atmospheres, since they allow to regulate the process of senescence of the fruit, but have the disadvantage that, if this atmosphere is altered, the quality of the product will be altered. Physical elicitors have also been widely studied with positive results.

Conflict of interest

There is no conflict of interest on the part of the authors.
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References

[1] Hernández-Muñoz P et al. Effect of chitosan coating combined with postharvest calcium treatment on strawberry (*Fragaria × ananassa*) quality during refrigerated storage. Food Chemistry Food Chemistry. 2008;110(2):428-435

[2] Pelayo C, Ebeler SE, Kader AA. Postharvest life and flavor quality of three strawberry cultivars kept at 5°C in air or air + 20 kPa CO₂. Postharvest Biology and Technology. 2003;27(2):171-183

[3] Gil MI, Holcroft DM, Kader AA. Changes in strawberry anthocyanins and other polyphenols in response to carbon dioxide treatments. Journal of Agricultural and Food Chemistry. 1997;45(5):1662-1667

[4] Almenar E et al. Controlled atmosphere storage of wild strawberry fruit (*Fragaria vesca* L.). Journal of Agricultural and Food Chemistry. 2006;54(1):86-91

[5] Deewatthanawong R, Nock JF, Watkins CB. G-Aminobutyric acid (GABA) accumulation in four strawberry cultivars in response to elevated CO₂ storage. Postharvest Biology and Technology. 2010;57(2):92-96

[6] Blanch M et al. CO₂-driven changes in energy and fermentative metabolism in harvested strawberries. POSTEC: Postharvest Biology and Technology. 2015;110:33-39

[7] Franco-Gaytán I et al. Quality and shelf life of three strawberry (*Fragaria ananassa*) cultivars treated with high concentrations of CO₂ for short period. Agrociencia. 2018;52(3):393-406

[8] Park DS, Jeong CS. Effect of CO₂ and ClO₂ gas pre-treatment for maintain shelf-life of summer strawberries.

[9] Huber DJ. Suppression of ethylene responses through application of 1-methylcyclopropene: A powerful tool for elucidating ripening and senescence mechanisms in climacteric and nonclimacteric fruits and vegetables. Hortscience. 2008;43(1):106-111

[10] Chaiprasart P. Effect of 1-methylcyclopropene on postharvest qualities of Parajchatan #72 strawberry fruit. Acta Horticulturae. 2016;1117:227-230

[11] Ku VVV, Wills RBH, Ben-Yehoshua S. 1-Methylcyclopropene can differentially affect the postharvest life of strawberries exposed to ethylene. Hortscience. 1999;34(1):119-120

[12] Li L et al. Effects of the ethylene-action inhibitor 1-methylcyclopropene on postharvest quality of non-climacteric fruit crops. Postharvest Biology and Technology. 2016;111:322-329

[13] Tian MS et al. Responses of strawberry fruit to 1-Methylcyclopropene (1-MCP) and ethylene. Plant Growth Regulation. 2000;32:83-90

[14] Elmi F et al. Effect of ethylene on postharvest strawberry fruit tissue biochemistry. Acta Horticulturae. 2017;1156:667-672

[15] Lopes PZ et al. Effect of ethylene treatment on phytochemical and ethylene-related gene expression during ripening in strawberry fruit *Fragaria × ananassa* cv. Camino real. Genetics and Molecular Research. 2015;14(4):16113-16125

[16] Wills RBH, Kim GH. Effect of ethylene on postharvest
life of strawberries. POSTEC: Postharvest Biology and Technology. 1995;6(3):249-255

[17] Zheng Y, Yang Z, Chen X. Effect of high oxygen atmospheres on fruit decay and quality in Chinese bayberries, strawberries and blueberries. JFCO Food Control. 2008;19(5):470-474

[18] Wszelaki AL, Mitcham EJ. Effects of superatmospheric oxygen on strawberry fruit quality and decay. POSTEC: Postharvest Biology and Technology. 2000;20(2):125-133

[19] Wang A-Z, Fernando J, Wang SY, Wang CY, González-Aguilar, Gustavo A. High oxygen treatment increases antioxidant capacity and postharvest life of strawberry fruit. Food Technology and Biotechnology. 2007;45(2):166-173

[20] Pérez AG et al. Effects of ozone treatment on postharvest strawberry quality. Journal of Agricultural and Food Chemistry. 1999;47(4):1652-1656

[21] Tzortzakis N, Singleton I, Barnes J. Deployment of low-level ozone-enrichment for the preservation of chilled fresh produce. Postharvest Biology and Technology. 2007;43(2):261-270

[22] Contigiani EV et al. Postharvest quality of strawberry fruit (Fragaria × ananassa Duch cv. Albion) as affected by ozone washing: Fungal spoilage, mechanical properties, and structure. Food and Bioprocess Technology. 2018;11(9):1639-1650

[23] Ramirez RA et al. Evaluation of the use of reactive oxygen species (ROS) generated through oxyion® technology in strawberry (Fragaria × ananassa Duchesne ex Weston) Duchesne ex Rozier cv. Monterrey) storage. Acta Agronómica. 2018;67(2):223-230

[24] Qadir A, Hashinaga F. Inhibition of postharvest decay of fruits by nitrous oxide. Postharvest Biology and Technology. 2001;22(3):279-283

[25] Almenar E et al. Equilibrium modified atmosphere packaging of wild strawberries. Journal of the Science of Food and Agriculture. 2007;87(10):1931-1939

[26] Giuggioli NR et al. Influence of modified atmosphere packaging storage on postharvest quality and aroma compounds of strawberry fruits in a short distribution chain. Journal of Food Processing & Preservation. 2015;39(6):3154-3164

[27] Charles MT, Arul J. UV treatment of fresh fruits and vegetables for improved quality: A status report. Stewart Postharvest Review. 2007;3(3):1-8

[28] Nigro F, Ippolito A, Lattanzio V, Di Venere D, Salerno M. Effect of ultraviolet-C light on postharvest decay of strawberry. Journal of Plant Pathology. 2000;82(1):29-37

[29] Xie Z et al. Effects of preharvest ultraviolet-C irradiation on fruit phytochemical profiles and antioxidant capacity in three strawberry (Fragaria × ananassa Duch.) cultivars. Journal of the Science of Food and Agriculture. 2015;95(14):2996-3002

[30] Xie Z et al. Preharvest ultraviolet-C irradiation: Influence on physicochemical parameters associated with strawberry fruit quality. Plant Physiology and Biochemistry. 2016;108:337-343

[31] de Oliveira IR et al. Preharvest UV-C radiation influences physiological, biochemical, and transcriptional changes in strawberry cv. Camarosa. Plant Physiology and Biochemistry. 2016;108:391-399

[32] Pan J, Vicente AR, et al. Combined use of UV-C irradiation and heat treatment to improve postharvest
life of strawberry fruit. Journal of the Science of Food and Agriculture. 2004;84(14):1831-1838

[33] Pombo MA et al. UV-C irradiation delays strawberry fruit softening and modifies the expression of genes involved in cell wall degradation. POSTEC: Postharvest Biology and Technology. 2009;51(2):141-148

[34] Pombo MA et al. UV-C treatment affects the expression and activity of defense genes in strawberry fruit (Fragaria × ananassa, Duch.). Postharvest Biology and Technology. 2011;59(1):94-102

[35] Xie Z et al. Preharvest exposure to UV-C radiation: Impact on strawberry fruit quality. Acta Horticulturae. 2015;1079:589-592

[36] Yan C, Liyu S, Wei C. Effect of UV-C treatment on fruit quality and active oxygen metabolism of postharvest strawberry fruit. Zhongguo shipin xuebao =. 2015;15(3):128-136

[37] Nechet K dL et al. Effect of the increase of UV-B radiation on strawberry fruit quality. Scientia Horticulturae. 2015;193:7-12

[38] Duarte-Molina F et al. Storage quality of strawberry fruit treated by pulsed light: Fungal decay, water loss and mechanical properties. Innovative Food Science & Emerging Technologies. 2016;34:267-274

[39] D’Amour J et al. Gamma-radiation affects cell wall composition of strawberries. Journal of Food Science—Chicago. 1993;58(1):182

[40] Nassur RDCMR et al. Doses de radiação gama na conservação da qualidade de morangos. Comunicata Scientiae. 2016;7(1):38-48

[41] Romanazzi G et al. Effect of short hypobaric treatments on postharvest rots of sweet cherries, strawberries and table grapes. POSTEC: Postharvest Biology and Technology. 2001;22(1):1-6

[42] Yousheng W, Meng Z, Dan W. Multivariate analysis of hypobaric treatment on fruit quality and active oxygen metabolism of strawberry during postharvest ripening. Zhongguo shipin xuebao =. 2015;15(6):231-239

[43] Cao S, Hu Z, Pang B. Optimization of postharvest ultrasonic treatment of strawberry fruit. POSTEC: Postharvest Biology and Technology. 2010;55(3):150-153

[44] Garcia JM, Aguilera C, Albi MA. Postharvest heat treatment on Spanish strawberry (Fragaria × ananassa cv. Tudla). Journal of Agricultural and Food Chemistry. 1995;43(6):1489

[45] Caleb OJ et al. Hot water dipping: Impact on postharvest quality, individual sugars, and bioactive compounds during storage of sonata strawberry. Scientia Horticulturae. 2016;210:150-157

[46] Vicente AR et al. Effect of heat treatment on strawberry fruit damage and oxidative metabolism during storage. POSTEC: Postharvest Biology and Technology. 2006;40(2):116-122

[47] Vicente AR et al. Quality of heat-treated strawberry fruit during refrigerated storage. Postharvest Biology and Technology. 2002;25(1):59-71

[48] Tanaka F et al. Investigation of far infrared radiation heating as an alternative technique for surface decontamination of strawberry. Journal of Food Engineering. 2007;79(2):445-452

[49] Civello PM et al. Heat treatments delay ripening and postharvest decay of strawberry fruit. Journal of Agricultural and Food Chemistry. 1997;45(12):4589-4594
[50] Jin P et al. Hot air treatment activates defense responses and induces resistance against *Botrytis cinerea* in strawberry fruit. Journal of Integrative Agriculture. 2016;15(11):2658-2665

[51] Langer SE et al. Effects of heat treatment on enzyme activity and expression of key genes controlling cell wall remodeling in strawberry fruit. PLAPHY: Plant Physiology and Biochemistry. 2018;130:334-344

[52] Ayala-Zavala JF et al. Effect of storage temperatures on antioxidant capacity and aroma compounds in strawberry fruit. Food Science and Technology—Zurich. 2004;37(7):687-695

[53] Barbieri G et al. Effect of the farming system and postharvest frozen storage on quality attributes of two strawberry cultivars. Fruits Fruits. 2015;70(6):351-360

[54] Nalbandi H et al. Innovative parallel airflow system for forced-air cooling of strawberries. Food and Bioproducts Processing: Part A. 2016;100:440-449

[55] Lara I, Garcia P, Vendrell M. Modifications in cell wall composition after cold storage of calcium-treated strawberry (*Fragaria × ananassa* Duch.) fruit. Postharvest Biology and Technology. 2004;34(3):331-339

[56] Garcia JM, Herrera S, Morilla A. Effects of postharvest dips in calcium chloride on strawberry. Journal of Agricultural and Food Chemistry. 1996;44(1):30

[57] Chen F et al. Quality attributes and cell wall properties of strawberries (*Fragaria × ananassa* Duch.) under calcium chloride treatment. Food Chemistry. 2011;126(2):450-459

[58] Hu LY et al. Hydrogen sulfide prolongs postharvest shelf life of strawberry and plays an antioxidative role in fruits. Journal of Agricultural and Food Chemistry. 2012;60(35):8684-8693

[59] Van de Velde F et al. Impact of a new postharvest disinfection method based on peracetic acid fogging on the phenolic profile of strawberries. POSTEC: Postharvest Biology and Technology. 2016;117:197-205

[60] Ayala-Zavala JF et al. Methyl jasmonate in conjunction with ethanol treatment increases antioxidant capacity, volatile compounds and postharvest life of strawberry fruit. European Food Research and Technology. 2005;221(6):731-738

[61] Asghari M, Hasanlooe AR. Methyl jasmonate effectively enhanced some defense enzymes activity and total antioxidant content in harvested Sabrosa strawberry fruit. Food Science & Nutrition. 2016;4(3):377-383

[62] Saavedra GM et al. Effects of preharvest applications of methyl jasmonate and chitosan on postharvest decay, quality and chemical attributes of *Fragaria chiloensis* fruit. Food Chemistry. 2016;190:448-453

[63] Almenar E et al. Optimization of an active package for wild strawberries based on the release of 2-nonanone. LWT—Food Science and Technology. 2009;42(2):587-593

[64] Asghari M, Hasanlooe AR. Interaction effects of salicylic acid and methyl jasmonate on total antioxidant content, catalase and peroxidase enzymes activity in Sabrosa strawberry fruit during storage. Scientia Horticulturae. 2015;197:490-495

[65] Babalar M et al. Effect of pre- and postharvest salicylic acid treatment on ethylene production, fungal decay and overall quality of Selva strawberry fruit. Food Chemistry. 2007;105(2):449-453
[66] Yu L-L et al. Effects of salicylic acid treatment at different concentrations on postharvest storage of strawberry. Zhiwu shengli xuebao =. 2015;51(11):2047-2053

[67] Martínez GA, Chaves AR, Añón MC. Effect of exogenous application of gibberellic acid on color change and phenylalanine ammonia-lyase, chlorophyllase, and peroxidase activities during ripening of strawberry fruit (Fragaria × ananassa Duch.). Journal of Plant Growth Regulation: Published in Cooperation with the Plant Growth Regulator Society of America and the International Plant Growth Substances Society. 1996;15(3):139-146

[68] Bozkurt F et al. Effect of vaporized ethyl pyruvate as a novel preservation agent for control of postharvest quality and fungal damage of strawberry and cherry fruits. Lebensmittel-Wissenschaft + Technologie =. 2016;65:1044-1049

[69] Aghdam MS, Fard JR. Melatonin treatment attenuates postharvest decay and maintains nutritional quality of strawberry fruits (Fragaria × anannasa cv. Selva) by enhancing GABA shunt activity. Food Chemistry. 2017;221:1650-1657

[70] Liu C et al. Effects of melatonin treatment on the postharvest quality of strawberry fruit. Postharvest Biology and Technology. 2018;139:47-55

[71] Krusong W et al. Baby corn fermented vinegar and its vapour control postharvest decay in strawberries. New Zealand Journal of Crop and Horticultural Science. 2015;43(3):193-203

[72] Shao X et al. Effects and possible mechanisms of tea tree oil vapor treatment on the main disease in postharvest strawberry fruit. Postharvest Biology and Technology. 2013;77:94-101

[73] Wei Y et al. Effect of preharvest application of tea tree oil on strawberry fruit quality parameters and possible disease resistance mechanisms. Scientia Horticulturae. 2018;241:18-28

[74] Farzaneh M et al. Chemical composition and antifungal effects of three species of Satureja (S. hortensis, S. spicigera, and S. khuzistanica) essential oils on the main pathogens of strawberry fruit. Postharvest Biology and Technology. 2015;109:145-151

[75] Romanazzi G et al. Effectiveness of postharvest treatment with chitosan and other resistance inducers in the control of storage decay of strawberry. POSTEC: Postharvest Biology and Technology. 2013;75:24-27

[76] Trevio-Garza MZ et al. Edible active coatings based on pectin, pullulan, and chitosan increase quality and shelf life of strawberries (Fragaria × ananassa). Journal of Food Science—Chicago. 2015;80(8):M1823-M1830

[77] Wang SY, Gao H. Effect of chitosan-based edible coating on antioxidants, antioxidant enzyme system, and postharvest fruit quality of strawberries (Fragaria × ananassa Duch.). LWT—Food Science and Technology. 2013;52(2):71-79

[78] Badawy MEI et al. Strawberry shelf life, composition, and enzymes activity in response to edible chitosan coatings. International Journal of Fruit Science. 2017;17(2):117-136

[79] Khalifa I et al. Effect of chitosan-olive oil processing residues coatings on keeping quality of cold-storage strawberry (Fragaria × ananassa. Var. festival). Journal of Food Quality. 2016;39(5):504-515

[80] Pagliarulo C et al. Preservation of strawberries with an antifungal edible coating using Peony extracts in chitosan. Food and Bioprocess
Technology: An International Journal. 2016;9(11):1951-1960

[81] Perdones Á et al. Effect of chitosan-lemon essential oil coatings on volatile profile of strawberries during storage. Food Chemistry: Part A. 2016;197:979-986

[82] Hajji S et al. Optimization of the formulation of chitosan edible coatings supplemented with carotenoproteins and their use for extending strawberries postharvest life. Food Hydrocolloids. 2018;83:375-392

[83] Resende NS et al. Chitosan/cellulose nanofibril nanocomposite and its effect on quality of coated strawberries. Journal of Food Quality. 2018;2018:1-13

[84] Sharma S, Barman K, Siddiqui MW. Chitosan: Properties and roles in postharvest quality preservation of horticultural crops. Eco-Friendly Technology for Postharvest Produce Quality; 2016. p. 269-296

[85] Tanada-Palmu PS, Grosso CRF. Effect of edible wheat gluten-based films and coatings on refrigerated strawberry (Fragaria × ananassa) quality. Postharvest Biology and Technology. 2005;36 (2):199-208

[86] Nadim Z et al. Effect of methylcellulose-based edible coating on strawberry fruit’s quality maintenance during storage. Journal of Food Processing and Preservation. 2015;39 (1):80-90

[87] Valenzuela C et al. Effect of edible quinoa protein-chitosan based films on refrigerated strawberry (Fragaria × ananassa) quality. Electronic Journal of Biotechnology. 2015;18(6):406-411

[88] Nasrin TAA, et al. Postharvest quality response of strawberries with aloe vera coating during refrigerated storage. The Journal of Horticultural Science and Biotechnology The Journal of Horticultural Science and Biotechnology. 2017;92(6):1-8

[89] Sogvar OB, Koushesh Saba M, Emamifar A. Aloe vera and ascorbic acid coatings maintain postharvest quality and reduce microbial load of strawberry fruit. POSTEC: Postharvest Biology and Technology. 2016;114:29-35

[90] Marelli B, Brenckle MA, Kaplan DL, Omenetto FG. Silk Fibroin as Edible Coating for Perishable Food Preservation. Scientific Reports. 2016;6:25263

[91] Li L, et al. Effects of Polysaccharide-Based Edible Coatings on Quality and Antioxidant Enzyme System of Strawberry during Cold Storage. IJPS International Journal of Polymer Science. 2017;2017:1-8

[92] Tahir HE, Xiaobo Z, Jiyong S, Mahunu GK, Zhai X, Mariod AA. Quality and postharvest-shelf life of cold-stored strawberry fruit as affected by gum arabic (Acacia senegal) edible coating. Journal of Food Biochemistry. 2018;42(3):125-127

[93] Nunes MCN et al. Controlling temperature and water loss to maintain ascorbic acid levels in strawberries during postharvest handling. Journal of Food Science. 2006;63(6):1033-1036

[94] Hernández-Muñoz P et al. Effect of calcium dips and chitosan coatings on postharvest life of strawberries (Fragaria × ananassa). POSTEC: Postharvest Biology and Technology. 2006;39(3):247-253

[95] Feliziani E, Landi L, Romanazzi G. Preharvest treatments with chitosan and other alternatives to conventional fungicides to control postharvest decay of strawberry. Carbohydrate Polymers. 2015;132:111-117
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[96] Harris M, Llorens MC, Frezza D. A calcium lactate treatment at harvest, growing system and refrigerated modified atmosphere can affect strawberries ‘Camarosa’ postharvest quality? Advances in Horticultural Science. 2017;31(1):3-10

[97] Affan FFM et al. Controlled temperatures and edible coating treatments on fresh strawberry (Fragaria sp. 'Holibrite') in a tropical environment. Acta Horticulturae. 2018;1201:7-14

[98] Allende A et al. Impact of combined postharvest treatments (UV-C light, gaseous O$_3$, superatmospheric O$_2$ and high CO$_2$) on health promoting compounds and shelf-life of strawberries. POSTEC: Postharvest Biology and Technology. 2007;46(3):201-211

[99] Kim JY et al. The effects of aqueous chlorine dioxide or fumaric acid treatment combined with UV-C on postharvest quality of Maehyang strawberries. Postharvest Biology and Technology. 2010;56(3):254-256

[100] Tekin O, Cavusoglu S. The effects of different postharvest applications on some physicochemical properties in rubygem and sabrina strawberry (Fragaria × ananassa duch.) cultivars. Applied Ecology and Environmental Research. 2018;16(4):5299-5310

[101] Samadi S, Ghasemnezhad A, Imani J. Extending shelf life of strawberry using some prestorage treatments. Acta Horticulturae. 2017;1156:643-652

[102] Shafiee M, Taghavi TS, Babalar M. Addition of salicylic acid to nutrient solution combined with postharvest treatments (hot water, salicylic acid, and calcium dipping) improved postharvest fruit quality of strawberry. Scientia Horticulturae. 2010;124(1):40-45

[103] Wills RBH, Ku VVV, Leshem YY. Fumigation with nitric oxide to extend the postharvest life of strawberries. Postharvest Biology and Technology. 2000;18(1):75-79

[104] Li D et al. Effects of nano-TiO2-LDPE packaging on postharvest quality and antioxidant capacity of strawberry (Fragaria × ananassa Duch.) stored at refrigeration temperature. Journal of the Science of Food and Agriculture. 2017;97(4):1116-1123

[105] Rasiukeviciute N et al. New non-chemical postharvest technologies reducing berry contamination. Zemdirbyste-Agriculture. 2015;102(4):411-416

[106] Kang J-H, Song KB. Non-thermal treatment of postharvest strawberry and establishment of its optimal freezing condition. Journal of Applied Biological Chemistry. 2015;58(1):55-60