Chapter

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

Figure 1.
Postharvest treatments used in strawberry.

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 CO_2 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 $\mu L\ L^{-1}$, 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 O_2 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 (O_3) 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 ($CaCl_2$) 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 (H_2S) 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 shell 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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