Chapter

Application of Phytohormones, Growth Regulators, and Calcium to Preserve Fruit Quality in Pre- and Post-Harvest

Ismael Aguilar-Ayala and Diana Herrera-Rojas

Abstract

The technological levels used to reduce fruit losses in post-harvest are closely linked to those used in pre-harvest. Applications of phytohormones, growth regulators, and calcium to fruit in pre- and post-harvest are viable alternatives to increase and preserve quality attributes. Knowledge of the action and response of fruits to the exogenous application of different phytohormones, growth regulators, and calcium in pre-harvest are fundamental when considering that fruit quality is acquired at this stage and that the purpose of post-harvest technology is to preserve fruit quality. This chapter describes research carried out to evaluate the response of different fruits to the application of phytohormones, phytoregulators, and calcium, which showed favorable responses in increasing fruit quality in pre-harvest and preserving quality in post-harvest.

Keywords: auxins, gibberellins, cytokinins, ethylene, calcium, fruit, pre-harvest, post-harvest, application, preservation, quality

1. Introduction

Currently, the generation, application, and dissemination of new techniques and technologies in the conservation of fruits and vegetables in post-harvest are of vital importance when considering that 20–50% of the agricultural production obtained is lost [1–4]. The losses of fruits and vegetables are different according to the economic development of the countries, in nations considered developed, from 5 to 35% is lost, and in developing countries from 20 to 50%. In these regions, it is considered that losses of fruits and vegetables occur mainly in the retail and consumption stages, while in countries considered poor or low-income, losses of fruits and vegetables are related to poor pre-harvest handling where low technological levels are applied, harvesting techniques that damage the fruits, poor transport from the orchard to the warehouse, packaging without technical design, and the lack and inadequate infrastructure for storage [1, 2, 5]. On the other hand, fruit and vegetable losses are generally classified into five stages: Stage 1: pre-harvest handling. Stage 2: packing process. Stage 3: post-harvest handling and storage. Stage 4: distribution from the warehouse to the

retail market. Stage 5: consumption [6]. Fruits in post-harvest and without being subjected to any industrial process are living organisms with their own metabolism and enzymatic action, with high percentages of water content and susceptibility to attack by microorganisms, factors that determine the perishability of the fruit, i.e., the shelf life under storage conditions that can last from a few days [6] to years. To prolong the shelf life of fruits, different technologies have been implemented: use of low and high temperatures, refrigeration and freezing, immersion in chemical additives [7], controlled and modified atmospheres, vacuum packaging, and edible coatings [8]. The purpose of post-harvest handling technologies is to preserve fruit quality and minimize losses caused by transport and handling in storage. The quality of harvested fruit is not increased, only preserved; quality attributes are obtained pre-harvest, so it is very important to apply optimal technological levels both pre-harvest and post-harvest [8]. The application of phytohormones, growth regulators, and various chemical calcium compounds in the pre- and post-harvest handling of the fruit constitutes some alternative technologies to increase and preserve fruit quality. In this chapter, pioneering work and recent research on the application of phytohormones, growth regulators, and calcium to pre- and post-harvest fruit will be described in general terms.

2. Application of phytohormones and growth regulators to pre- and post-harvest fruits

Phytohormones are simple organic chemical compounds, without associated protein groups, which induce all morphogenic responses during plant ontogeny, and participate in most morphogenic responses in growth and development; they are synthesized in different plant structures such as shoot and root meristems, leaves, fruits, and seeds. Some plant hormones act at the same site of synthesis or have an effect on other plant structures and whose physiological response may last for a short or medium time. When phytohormones act in conjugation with others, they induce different morphogenic expression responses, for example, the formation of shoots and alternatively of roots and/or the production of amorphous cell masses [9]. Growth regulators are synthetic compounds of a different chemical nature from phytohormones, and they can generate similar or different effects to those expected and can even elicit more intense responses than plant hormones at the same molar concentration [9]. The main phytohormones and growth regulators used in pre- and post-harvest fruit management are auxins, gibberellins, cytokinins, and ethylene.

2.1 Auxins

In 1933, Kögl and collaborators synthesized indole-3-acetic acid from the amino acid tryptophan, a low-molecular-weight organic acid found in plants, and named it auxin, the word auxin comes from the Greek ¨auxein" meaning ¨to grow¨ [9]. Auxins synthesized in the vegetative structures of the plant are translocated through the phloem in a basipetal and cell-to-cell manner and have been found in both algae and fungi [10]. Indole-3-acetic acid elicits plant physiological responses when it binds to a receptor and undergoes signal transduction to generate diverse responses in plant growth and development (see **Table 1**). Auxins induce growth by cell division and elongation, and cell differentiation of apical, root, and cambium meristematic zones. Endogenous and exogenous auxins generate adventitious roots, and promote apical dominance and fruit growth and development [11].

Phytohormone, growth regulator, calcium	Put it in the column Physiological response in post-harvest	Physiological response in post-harvest
Auxin	• Promotes fruit growth and development [11]. • Delays physiological maturity [9, 11]. • Increases mass and size [12].	• Preserves quality [13, 14].
Gibberellin	• Induces parthenocarpy [15]. • Promotes growth and development [15]. • Promotes bud sprouting [16]. • Increases quality [17]. • Delays senescence in citrus [16]. • Advances production by reducing the period of physiological maturity [18]. • Prevents cracking [19, 20].	
Cytokinins	• Induce sprouting of axillary buds [21, 22]. • Induce fruit growth and development [21, 22]. • Increases yield [23, 24].	
Ethylene	• Increases quality [25]. • Increases mass and size [26]. • Increases color [25].	• Induces respiration in climacteric fruits [25]. • Destroys chlorophylls in non-climacteric fruit [25]. • Causes softening of epicarp and pulp in non-climacteric fruits [25]. • Promotes quality [26]. • Induces loss of mass and size [27]. • Decreases firmness [26]. • Decreases shelf life [26].
Calcium		• Promotes firmness [28]. • Preserves quality [28–30]. • Minimizes pathogen attack [31]. • Decreases physiological disorders [31]. • Reduces loss of mass [29]. • Decreases respiration [29, 32].

Table 1.
Physiological responses of fruit to the application of phytohormones, growth regulators, and calcium in pre- and post-harvest.

In plant growth and development, auxins act in conjugation with gibberellins, cytokinins, and ethylene [33].

Plant growth regulators with auxin effect such as indole-3-propionic acid, naphthaleneacetic acid, 2,4-dichlorophenoxyacetic acid, and 2,4,5-trichlorophenoxyacetic acid are synthetic organic substances considered agrochemicals, and they are used to promote

seed germination, rooting of cuttings, sprouting of differentiated buds, fruit setting, delaying the physiological maturity of fruits, and preserving the quality of some fruits in post-harvest [9, 11]. Exogenous application of auxins to plants in high concentrations induces vegetative growth by inhibiting flowering, growth, and fruit development [34].

The use of indole-3-butyric acid (IBA) by Solis et al. [13] in red pomegranate *(Punica granatum* L.) 'Apaseo tardía' had the purpose of evaluating the effect of indole-3-butyric acid on the preservation of fruit quality in post-harvest. The treatments applied were 0, 20, 40, and 80 mg/L^{-1} of IBA by immersion for 10 minutes, and the fruits were stored for 60 days under refrigeration at a temperature of 4 ± 1°C. The response variables evaluated were mass (g), size (cm) in diameter and length of the fruit, concentration of total anthocyanins, percentage of titratable acidity, ascorbic acid concentration, chlorophylls "a," "b," and total. The results indicate that the 20 mg/L^{-1} AIB treatment significantly preserved fruit size in length, while, in the mass variables, ascorbic acid concentration and anthocyanin concentration did not present significant statistical differences compared with the 0 mg/L^{-1} AIB treatment. However, the mass variables, ascorbic acid concentration, and total anthocyanins showed statistical trends for the preservation of fruit quality significantly to the application of AIB, so it is suggested to increase the immersion time of the fruit.

In another research conducted by Bustamante and Gómez [12], they applied auxins and calcium in commercial chemicals products to banana bunches to improve fruit quality, considering that the mass and size are important for their commercialization. The purpose of the research was to generate technology to increase fruit quality in preharvest with the application of commercial auxin and calcium chemicals. The treatments applied were as follows: Basfoliar Kelp (Auxins) + Basfoliar Calcium (Ca) [75 cc + 75 cc / L^{-1} water]; Basfoliar Kelp (Auxins) + Basfoliar Calcium (Ca) [100 cc +100 cc /L^{-1} water]; and Basfoliar Kelp (Auxins) + products containing Basfoliar Calcium (Ca) [12.5 cc + 12.5 cc/L^{-1} water] and the control and two applications were made, the first at 4 days after the beginning of flowering and the second at 10 days after flowering. The results found indicate that all treatments significantly increased fruit mass and size in length and diameter.

With the purpose of delaying fruit senescence and thus preserving the quality for a longer time, Da silva et al. [14] applied indole-3-acetic acid to fruits of Spondias (*Spondias dulcis*). The treatments evaluated were 0, 50, 100, 150, and 200 mg L^{-1} of AIA applied by immersion for 20 min, the evaluations were carried out at 5 and 10 days after application of AIA, the response variables were pulp firmness, titratable acidity, soluble solids, ascorbic acid content, and pulp and peel color. Univariate analysis was applied for each variable, and regression analysis was applied to determine the effect of auxin concentration. There was no correlation between the concentration of auxins applied on the concentration of total soluble solids and flesh color. There were no significant differences in the variables of titratable acidity, pH, and skin color. The concentrations of 50 and 100 mg L^{-1} of AIA showed the best results in reducing the ripening of Spondia fruits.

2.2 Gibberellins

Gibberellins (GAs) are phytohormones of plant growth and development involved in various physiological processes of plants, the fungus was isolated by Eichi Kurosawa in 1926 from cultures of *Gibberella fujikoroi*, a fungus parasite of rice plants causing the ¨bakanae¨ disease, and the attack of the fungus induces excessive growth by elongation of stems and shoots and a strong decrease in productivity [35, 36]. In 1955, gibberellic acid (Ga3) was isolated from the secreted filtrate of *Gibberella fujikoroi* [37]. The synthesis of gibberellins occurs in various plant structures: buds, leaves and fruits, and

their movements are basipetal. Endogenous gibberellins mainly induce height growth [38], and promote inflorescence development and flowering in long-day plants. In association with phytochromes, they induce the differentiation of vegetative meristems to reproductive meristems promoting flowering [39]. They induce parthenocarpy, and growth and development in many fruits [15]; likewise, gibberellins and other phytohormones that synthesize seeds within the fruit largely regulate their size. It has also been shown that the number and size of fruits attached to the plant correlate with the number of seeds contained in them and the absence of pollination causes seed-bearing fruits to drop. Genetically parthenocarpic fruits contain normal gibberellin levels [7], seedless fruits with relatively high gibberellin concentrations show adequate growth and development [37]. Commercial gibberellic acid obtained from extracts of the fungus *Gibberella* applied exogenously affects the growth and development stages of the plant passing from vegetative to intermediate stage and vice versa [40]. In long-day plants, it induces flowering [41, 42] and can affect sex determination by modifying the floral structure and leading to female or male flowers [39]. Gibberellins generate multiple responses when applied at different stages of fruit growth and development: It induces bud differentiation, and promotes fruit growth and development and parthenocarpy (see **Table 1**). In apples, it promot fruit development after pollination; in citrus, it delays senescence [16]. It is used to increase quality in seedless grape fruits, in apples, peaches, apricots, cherries, and in citrus fruits, it increases fruit yellowing; in the latter, GAs delay the coloration from green to orange and prevent alterations in the rind [17].

On the other hand, there are compounds of different chemical constitution that inhibit plant growth known as growth inhibitors or retardants: Chlormequat-Cl, Cycocel, AMO-1618, Phosphon-D, Ancymidol, Paclobutrazol, Uniconazole-P that reduce meristematic growth mainly by inhibiting cell division by preventing the development of the gibberellin synthesis cycle. The application of these chemical compounds reduces plant size but does not affect productivity. Plant growth arrest generated by the application of these chemicals is reversed if gibberellins are applied, even if they are mixed with the inhibitory chemical [43]. Some investigations conducted with applications of gibberellins to different fruits are described below.

The concentration of Mexican plum (*Spondias purpurea* L.) production causes this fruit to have unattractive prices for producers, so research was done [18] to phase production. Gibberellic acid was applied to pre-harvest fruit. The treatments were: 0.0, o.1, 0.2, and 0.4 mM Activol, and the application was made by spraying. The response variables evaluated were: blossom to harvest period in days, % bud burst, % flower buds, mass (g), size in length and diameter (cm), starch concentration, total soluble solids, ascorbic acid, and titratable acidity. The results indicate that production was advanced by 36 days with the 0.4 mM treatment, and this same treatment significantly induced fruit set with 51.92% with respect to the control treatment that achieved 2.67%. The 0.2 mM treatment showed a significant growth of fruit size in length with 4.32 cm compared with 3.97 cm of the control treatment, and fruit size in diameter was 3.44 cm significantly different from the control treatment with 3.17 cm; fruit mass(g) was significantly different with the 0.2 mM Activol treatment, which was 29.37 (g), and the control treatment was 23.39 (g). In the other evaluated variables such as starch, total soluble solids, total sugars, ascorbic acid, and titratable acidity, no significant statistical differences were found between treatments.

The fruit of red pomegranate cv. Apaseo tardía is very susceptible to fruit cracking. In consideration of the above, an investigation was carried out [19] where gibberellic acid was applied to fruits of red pomegranate cv, Apaseo tardía in pre-harvest. Gibberellic acid was used in treatments of 0, 50, 100, and 200 mg/l in three direct

applications to the fruit at intervals of 15 days each. The results showed that the treatments of 50, 100, and 200 mg/l of acigigib showed highly significant differences in avoiding 100% of fruit cracking compared with the control treatment, which showed 62% of cracked fruit. In the quality variables, the 0 mg/l gibberellic acid treatment showed significant statistical differences in the concentration of total sugars compared to the other treatments. The concentration of chlorophyll "a" in the pericarp of red pomegranate showed significant differences between treatments. As for the concentration of chlorophyll "b" in the pericarp of the red pomegranate fruit, the control treatment was the only one in which chlorophyll "b" was observed. No significant statistical differences were found between treatments in the following quality variables: total soluble solids, ascorbic acid, titratable acidity, anthocyanins, hydrogen potential, fruit mass (g), size (cm) in length and diameter.

In order to evaluate the effectiveness of a pre-harvest application of gibberellic acid to fruits of late red pomegranate cv. Apaseo tardía to prevent fruit cracking and conserve fruit quality, treatments of 0 and 50 mg/l of gibberellic acid applied once were evaluated. The variables evaluated were the number of uncracked and cracked fruit, fruit size in length and diameter, mass (g), total soluble solids, ascorbic acid content, total sugars, hydrogen potential, anthocyanin concentration, titratable acidity, and fruit maturity index. The results showed that, out of a total of 250 fruits evaluated per treatment, the 50 mg/l gibberellic acid treatment showed a statistically significant decrease of only 30 cracked fruits against 77 of the control treatment. The fruit quality variables, size in length and diameter, mass(g), total soluble solids, ascorbic acid, total sugars, anthocyanins, hydrogen potential, titratable acidity and maturity index, did not show significant differences between treatments [20].

2.3 Cytokinins

Plant cytokinins were discovered in 1963 by Miller and Letham in corn kernels (*Zea mays*), and the first cytokinin was identified as 6-(4-hydroxy-3-methylbut-trans-2-enyl-amino) purine called zeatin. Naturally synthesized cytokinins of importance as zeatins are benzyladenine and kinetin, and natural plant cytokinins are synthesized at sites of continuous cell division such as the root and shoot meristems of the plant. Synthetic cytokinins such as benzyladenine (BA) or furfurylaminopurine and thidiazuron (TDZ) are more efficient than endogenous hormones because they are not degraded or metabolized by the tissue. Cytokinins promote cell division and differentiation, sprouting of axillary buds, delay leaf senescence, induce sprouting of dormant buds and fruit growth, stimulate nutrient mobilization, synthesis and degradation of pigments such as chlorophyll and protein degradation, and increase the movement of sugars, amino acids, and trace elements to developing organs and generate protein synthesis [21, 22].

The application of growth regulators such as cytokinins in the plant has been a very important practice for producers, because new production technologies are applied in fruit trees and thus ensure the production yield in flowers and fruits, inducing flowering and decreasing the number of aborted flowers, being factors that affect the production yield of any fruit tree.

Barbosa [23] used the application of cytokinins to ensure the yield in the production of papaya because it is a fruit of great economic importance, and it has a high percentage of flower drop during the flowering stage affecting the percentage of fruit set. The purpose of the research was to determine the effect of the combination of three doses of cytokinins (X-Cyte) and three doses of gibberellins (RyzUp) on fruit set, growth and development in a commercial papaya plantation. The treatments

applied were 2, 7, and 12 ppm concentrations of cytokinins and 5, 10, and 15 ppm concentrations of gibberellins. As results, cytokinins (X-Cyte) at a dose of 12 ppm obtained the highest papaya production with 13.02 tm ha^{-1}, and gibberellins (Ryz-Up) had no effect on papaya production with the exception of the number of fruits harvested. Statistical significance was found in the interaction C x G: fruit mass, number of fruits tied, and polar diameter, which implies that both factors act jointly on these characteristics, stimulating fruit growth. The yield in papaya production was in relation to the number of fruits harvested, there were significant differences in relation to the control in the number of buds and flowers, and the application of gibberellins had no effect on the yield of papaya production.

In order to evaluate the effect of cytokinins on blueberry fruit production, Cano [24] applied Agrocimax Plus (cytokinin) to blueberry (*Vaccinium corimbosum* L.) Biloxi variety. The treatments consisted of the addition of Agrocimax Plus at concentrations of 1.25ml/L, 2.5ml/L, and the control without Agrocimax Plus. Applications were made from pre-flowering to fruit ripening. The variables evaluated were productivity, yield, and fruit size. The results obtained were that the treatment at a concentration of 1.25 ml/L obtained a yield of 3.19 kg per plant and a production of 15950 kg per hectare; for the 10–17 mm size, the yield was 1.54 kg per plant and a production of 7700 kg per hectare. In the 18–28 mm size a yield of 1.65 kg per plant and a production of 8250 kg per hectare were obtained. The economic evaluation of the use of Agrocimax Plus on the production of blueberry fruit (*Vaccinium corimbosum* L.) was with the Agrocimax Plus treatment (1.25ml/L) with a profitability index of 187% of the production cost.

In the research conducted by Tamalá [44], the inductor effect of cytokinins on flowering and fruit setting was determined in a soursop (*Annona muricata*) crop of approximately 2 years and 6 months of age, the treatments were cytokinin 1.5 ml/L of water, 1.25 ml/L of water, and the control, with a completely randomized block design, and the study variables were days of flowering, total number of flowers, aborted flowers, fruit set, and fruit circumference. The results obtained were that the concentration of 1.5 ml/L of water accelerated flower production and fruit formation compared to the control, because cytokinins increased the number of inflorescences, decreased flower drop compared to the other treatments, increased fruit size in length and diameter, and increased fruit production.

2.4 Ethylene

Ethylene is a gaseous type phytohormone that is synthesized from the amino acid methionine to form S-adenosyl-L-methionine (SAM) catalyzed by the enzyme SAM synthetase, to form 1-aminocyclopropane-1-carboxylic acid (ACC) from SAM through the participation of the enzyme ACC synthase (ACS) and finally the conversion of ACC to ethylene [45–47]. It is of great importance in physiology and pre- and post-harvest technology; it is responsible for various physiological responses in the plant and fruit in pre-harvest and in post-harvest it has a decisive influence on fruit preservation. Neljubow observed in etiolated plants of Pisum sativum the triple response induced by this gas: reduction of growth by elongation, thickening of the hypocotyl, and change in growth orientation. Ethylene has been studied in biological models such as Arabidopsis thaliana to know and understand its mode of action and effect on growth and development of flowering plants [34, 45].

The application of ethylene known as the plant hormone of fruit ripening provariety of different effects; in plants (see **Table 1**), it induces growth by cell division, causes leaf abscission, promotes the sprouting of differentiated buds, and increases fruit quality;

and when ethylene is applied post-harvest, it modifies the quality of climacteric and non-climacteric fruits [25]. Climacteric fruits continue with the ripening process after being harvested, and increase their respiration rate and synthesize ethylene; non-climacteric fruits once harvested do not continue with the ripening process [25]. Ethylene, as a growth regulator, is used to modify the ripening of many non-climacteric fruits, since it induces the destruction of chlorophylls and facilitates the appearance of pigments that give the typical color of these fruits. In general, it causes softening of the epicarp and pulp [25]. In climacteric fruits, it increases color, total soluble solids, odor, flavor, and sugars, and decreases firmness and acidity, among other quality attributes [26].

"Ethephon" or "Ethrel" (2-chloroethyl phosphonic acid) is a commercial chemical that is applied by spraying or dipping. Treated fruits release ethylene in response. In an investigation, 2-chloroethyl phosphonic acid (¨Ethrel¨) was applied at doses of 0, 50, 100, 200, and 400 mg/l to fruits of 2 phenotypes of pink and white Ilama (*Annona diversfolia Saff*) in post-harvest. The treatments were by immersion for 5 minutes and subsequent storage for 5 days at room temperature at an average of 17 °C. Total soluble solids, fruit mass (g), % malic acid, total soluble solids ratio, and total sugar concentration were evaluated. The results showed the responses of fruits subjected to different Ethrel concentrations: loss of mass, increase in soluble solids, decrease in malic acid, increase in Brix [27].

In saladette tomato (*Solanum lycopersicum* L.), pre-harvest application of Ethephon (Ethrel 240) has been used by Martinez-Damian [48], to determine the physicochemical quality of the fruit. The variables evaluated were color, weight, equatorial and polar diameter, roundness index, firmness, total soluble solids, titratable acidity, and lycopene concentration. The results of the individual application of Ethephon in combination with iodine and/or sodium selenite increased fruit weight, firmness, and citric acid with respect to the control.

Currently, there is a need to look for possible solutions that contribute to homogenize the ripening of coffee fruits, and for this Alvarado and Vera [49] worked on the proposal to evaluate growth regulators and sugar mobilizers in the ripening of Arabica coffee fruits. They applied 10 treatments with three replicates per treatment, and the phytoregulators applied were Ethefon, Mepiquat Chloride, and the combination of both. The treatments consisted of the application of the regulators to pre-harvest fruit and foliage, the variables measured were the weight of ripe fruit per plant, % of ripe fruit per plant, % of empty fruit, fruit harvested per plant, and number of harvests. The results showed significant differences between the treatments in relation to the control.

3. Calcium application to fruits in pre- and post-harvest

Calcium is an essential nutrient for plant growth and development, participates in the formation and structuring of the cell wall, provides selective permeability and preserves cell membranes, and generates cell signaling responses [50]. Calcium moves in the plant by xylem, and in phloem is very little mobile and accumulates during the period of fruit growth and development [51]. Calcium deficiency directly affects cell wall formation and development, and by causing the cell wall to lose its integrity, physiological disorders are induced by modifying extra- and intracellular processes, decreasing fruit firmness, and increasing senescence [52]. In post-harvest, calcium applied to fruit promotes tissue firmness and cell turgor, extending the shelf life of the fruit [28]; it also minimizes pathogen attack, reduces physiological disorders, and reduces mass loss by increasing the stability of the cell wall by presenting greater resistance to water leakage [31] (see **Table 1**).

The calcium application technique in pre-harvest consists of spraying the calcium solution directly to the fruits of the plant, the most commonly used calcium salts are calcium chloride and calcium nitrate, and in post-harvest the technique of immersing the fruits in a calcium solution for a previously established period of time is used; in this technique, the fruits must be in constant movement within the solution to avoid and prevent oxidation reactions that could generate alterations in the quality of the fruit. Different calcium salts are used, such as calcium lactate, calcium chloride, calcium phosphate, calcium propionate, and calcium gluconate. The factors to be considered for the application of this technique in post-harvest are pH of the solution, immersion time, temperature, and concentration [53].

Regarding the results obtained in different investigations with the application of calcium in pre- and post-harvest, the one is carried out on Logan cultivar blackberry, a very perishable fruit that preserves its post-harvest quality attributes for a maximum period of 24 hours. The research consisted of 2 experiments in which the treatments applied were obtained from the combination of 1000, 3000, and 5000 mg/l of CaCl2 with 0.03% Twinn-20, 1% urea, and 1% starch plus a control treatment: In the first experiment, the application of the treatments was carried out in three periods, the first consisted of three applications of the treatments to the same fruit, at intervals of 10 days each, starting 25 days after flower opening (anthesis); in the second period, the treatments were applied twice to the same fruit at 35 and 45 days after anthesis; the third period consisted of a single application at 45 days after anthesis. In the second experiment, four epochs were considered, and in the first three epochs, the treatments were applied only once at 25, 35, and 45 days after anthesis: The fourth epoch consisted of three applications of the treatments mentioned above at 38 days after anthesis and two subsequent applications with an interval of 3 days each. The evaluation of the quality variables of 'Logan' blackberry fruit in post-harvest was carried out at 0, 24 and 48 hours after harvest. The results found indicate that the variables such as firmness, color, titratable acidity, ascorbic acid, brix/acid ratio, calcium content in pulp, and respiration showed significant statistical differences, while the variables of total soluble solids and % dry matter did not show significant statistical differences [29].

Among other research [30] where calcium was applied to apple fruit in pre-harvest, it was found that the application of calcium significantly reduced fruit rot in post-harvest for 6 months, likewise in [32] calcium nitrate was applied to mango cv. Haden in pre-harvest, evaluating treatments of 0, 5, 10, 10, 15, and 29 g/l with 5 sprays of calcium nitrate foliar and to the fruit. The results indicate that there was a significant increase in the production of the trees that received treatment compared with the control treatment, and the mango fruits that were kept at a temperature of 20 ± 2°C and 74 ± 4% relative humidity presented significant differences in the following response variables: respiration, weight loss, acidity, and total soluble solids as for the variables that did not present significant statistical differences were: firmness, color, and enzymatic activity of pectin methyl esterase. Other studies showed significant inhibition of the presence of fungi and spores and consequently a decrease in fungal infections [54].

4. Conclusion

The application of phytohormones, growth regulators, and calcium to fruit in pre- and post-harvest is an important alternative to preserve the shelf life of fruit due to the diversity of physiological responses that they induce in the fruit.

Author details

Ismael Aguilar-Ayala* and Diana Herrera-Rojas
Universidad Nacional Autónoma de México, Facultad de Estudios Superiores Iztacala, Mexico

*Address all correspondence to: biofrut94@gmail.com

IntechOpen

References

[1] Kitinoja L, Saran SS, Roy SK, Kader AA. Postharvest technology for developing countries: Challenges and opportunities in research, outreach and advocacy. Journal of the Science of Food and Agriculture. 2011;**91**:597-603

[2] Ahmad MS, Siddiqui MW. Postharvest Quality Assurance of Fruits. Suiza: Springer; 2015

[3] Yang Q, Wang H, Zhang H, Zhang X, Apaliya MT, Zheng X, et al. Effect of *Varrowia lipolytica* decay of grape caused by *Talaromyces rugulosus* and the protein expression profile of *T. rugulosus*. Postcosecha Biology and Technology. 2017;**26**:15-22

[4] Anaya-Esparza LM, Pérez-Larios A, Ruvalcaba-Gómez JM, Sánchez-Burgos JA, Romero-Toledo R, Montalvo-González E. Funcionalización de los recubrimientos a base de quitosano para la conservación postcosecha de frutas y hortalizas. Revista especializada en Ciencias Químico-Biológicas. 2020;**23**:1-4

[5] Kitinoja L, Kader AA. Medición de las pérdidas poscosecha de frutas y hortalizas frescas en los países en desarrollo. Documento de la Fundación de Educación Poscosecha. 2015. Available from: http://postharvest.org/PEF_White_Paper_15-02_PHFVmeasurement.pdf

[6] Porat R, Lichter A, Terry LA, Harker R, Buzby J. Postharvest losses of fruits and vegetables during retail and in consumers homes: Quantifications, causes and means of prevention. Postharvest Biology and Technology. 2018;**139**:135-149

[7] Lurie S. Temperature management. In: Knee M, editor. Fruit Quality and Its Biological Basis. USA: Sheffffield Academic Press; 2002. pp. 106-121

[8] Mir N, Beaudry R. Atmosphere control using oxygen and carbón dioxide. In: Knee M, editor. Fruit Quality and Its Biological Basis. USA: Sheffffield Academic Press; 2002. pp. 121-153

[9] Jordán M, Casaretto J. Hormonas y reguladores del crecimiento: Auxinas, Giberelinas y Citocininas. In: Squeo FA, Cardemil L, editors. Fisiología vegetal. La serena Chile: Ediciones Universidad de la Serena; 2006. pp. 1-27

[10] Acosta EM, Sánchez BJ, Bañón AM. Auxinas. In: Azcón-Bieto J, Talón M, editors. Fundamentos de Fisiología Vegetal. 2nd Edición ed. Barcelona: McGraw-Hill–Interamericana; 2013. pp. 377-399

[11] Munguía RAG, Martínez TM. Las auxinas: síntesis, transporte y señalización. Biológicas. 2018;**20**(1):1-7

[12] Solís-Guzmán CE, Aguilar-Ayala I, Molina GMG. Efecto del ácido indol-3-butírico sobre la calidad poscosecha de granada roja (*Punica granatum* L.) 'Apaseo tardía'. BIOCYT. 2019;**12**(46):855-868

[13] Paque S, Weijers D. Auxin: The plant molecule that influences almost anything. BMC Biology. 2016;**14**(67):1-5

[14] Bustamante GV, Gómez TD. Efecto de la aplicación de auxinas y calcio a las últimas manos del racimo del banano para mejorar calibración y largo de dedos de la fruta. Economía y Desarrollo. 2019;**20**(3):48-53

[15] Yu H, Ito T, Zhao Y, Peng J, Kumar P, Meyerowitz EM. Floral homeotic genes

are targets of gibberellin signaling in flower development. PNAS. 2004;**101**(20):7827-7832

[16] King RW, Evans LT. Gibberellins and flowering of grasses and cereals: Prizing open the lid of the ¨Florigen¨ black box. Annual Review of Plant Biology. 2003;**54**:307-328

[17] García-Martínez JL, Hedden P. Gibberellins, and fruit development. In: Tomas-Barberan FA, Robins RJ, editors. Phytochemistry of Fruit and Vegetables. Oxford, UK.: Clarendon Press; 1997. pp. 263-285

[18] Lozano-Trenado L. Efecto del ácido 2-cloroetil fosfónico (ethephon) y ácido giberélico en el desfasamiento de la producción y la calidad de la Ciruela Mexicana (*Spondias purpurea* L.). [Tesis de Licenciatura]. Universidad Nacional Autónoma de México. Facultad de Estudios Superiores Iztacala. 2008

[19] Escudero MYE. Efecto del acigigib sobre el agrietamiento y la calidad del fruto de la granada roja cv. Apaseo tardía (*Punica granatum*). [Tesis de licenciatura] Universidad Nacional Autónoma de México. Facultad de Estudios Superiores Iztacala. 2016

[20] Velázquez PMA. Evaluación del efecto del nitrato de potasio en la brotación de yemas y efecto del ácido giberélico en la calidad del fruto de granada roja (*Punica granatum* L.) 'Apaseo tardía'. [Tesis de Licenciatura]. Universidad Nacional Autónoma de México. Facultad de Estudios Superiores Iztacala.2017

[21] Segura J. Fundamentos de Fisiología Vegetal. 2nd Edición ed. Barcelona: McGraw-Hill–Interamericana; 2013. pp. 421-441

[22] Díaz D. Las Hormonas Vegetales en las Plantas. México: Artículos Técnicos de INTAGRI; 2017. p. 2022

[23] Barboza IME. "Efecto de la combinación de diferentes dosis de citoquininas y giberelinas sobre el cuajado, retención y crecimiento de frutos en el cultivo de papaya (*Carica papaya* L.) en cieneguillo sur- sullana, 2016." [Tesis de Licenciatura]. Universidad Nacional de Piura. Facultad de Agronomía. Perú. 2018

[24] Cano CEG. "Efecto de aplicación de diferentes dosis de Agrocimax plus (citoquinina), sobre el rendimiento de fruta en arándano (*Vaccinium corimbosum* L.) variedad biloxi en la provincia de Huaylas-Ancash". [Tesis de Licenciatura]. Universidad Nacional Santiago Antúnez de Malayo. Perú. 2018

[25] Watkins CB. Ethylene synthesis, mode of action, consequences and control. In: Knee M, editor. Fruit Quality and Its Biological Basis. USA: Sheffffield Academic Press; 2002. pp. 181-224

[26] Martínez-González ME, Balois-Morales R, Alia-Tejacal I, Cortes-CruzMA,Palomino-HermosilloYA, López-Gúzman GG. Poscosecha de frutos: maduración y cambios bioquímicos. Rev. de Cien. Ağrı. 2017;**19**:4075-4087

[27] Piña-Soto L. Fenología de Ilama (*Annona diversifolia Saff.)* y efecto del ácido 2-cloroetil fosfónico en la maduración del fruto [Tesis de Licenciatura]. México D. F. Universidad Nacional Autónoma de México. Facultad de estudios Superiores Iztacala; 2006

[28] Ciccarese A, Stellacci AM, Gentilesco G, Rubino P. Effectiveness of pre- and post-veraison calcium applications to control decay and maintain table grape fruit quality during storage. Biología y Tecnología de Postcosecha. 2013;**75**:135-141

[29] Aguilar AI. Influencia del cloruro de calcio (CaCL2) sobre la calidad de

frutos de zarzamora 'logan'. [Tesis de Maestría] Montecillo, México Colegio de postgraduados. 1989

[30] Imre JH, Ball B, Vámos A, Gáll JM. Influence of Preharvest calcium applications fruit injury, and storage atmospheres on postharvest brown rot of Apple. Postharvest Biology and Technology. 2012;**67**:29-36

[31] Angeletti P, Castagnasso H, Miceli E, Terminiello L, Concellon A, Chaves A, et al. Vicente. Effect of preharvest calcium applications on postharvest quality, softening and cell wall degradation of two blueberries (*Vaccinium corymbosum*) varieties. Biología y Tecnología de Postcosecha. 2010;**58**(2):98-103

[32] Romero-Gomezcaña NR, Sanchez-Garcia P, Rodríguez-Alcazar J, Saucedo-Veloz C. Calcium foliar sprinkling and its relation with fruit quality of mangoes cv. Haden. Agric. Téc. Méx. 2006;**32**(1):5-15

[33] Garay-Arroyo A, Sánchez MP, García-Ponce B, Álvarez-Buylla RE, Gutiérrez C. La homeostasis de las auxinas y su importancia en el desarrollo de *Arabidopsis thaliana*. Rebrape. 2014;**33**(1):13-22

[34] Alcántara CJS, Acero GJ, Alcántara CJD, Sánchez MRM. Principales reguladores hormonales y sus interacciones en el crecimiento vegetal. NOVA. 2019;**17**(32):109-129

[35] da Silva FC, Amaral SH, De MJO S, Carvalho TM, Martins RD, SAP S. Uso de ácido indol-3-ácetico (IAA) en postcosecha de cajá-manga (*Spondias dulcis*). Colombian Journal of Horticultural Science. 2020;**14**(2):201-208

[36] Tamura S. In: Takahasshi N, Phinney BO, Macmillan J, editors. Historical Aspects of Gibberelliins. New York: Springer-Verlag; 1990. pp. 1-8

[37] Malonek S, Bomke C, Bornberg-Bauer E, Rojas MC, Hedden P, Hopkins P, et al. Distribution of gibberellin biosynthetic genes and gibberellin production in the *Gibberella fujikuroi* species complex. Phytochemistry. 2005;**66**:1296-1311

[38] Domingo J, Giberelinas TM. Fundamentos de Fisiología Vegetal. 2nd ed. Barcelona: McGraw-Hill-Interamericana; 2013. pp. 399-417

[39] Hedden P, Kamilla Y. Gibberellin biosynthesis: Enzymes, genes and their regulation. Annual Review in Plant Physiology. 1997;**48**:431-460

[40] Kato K, Ohara H, Takahashi E, Matsui H, Nakayama M. Endogenous gibberellin-induced parthenocarpy in grape berries. Acta Horticulture. 2000;**514**:233-239

[41] Stuart NW, Cathey HM. Applied Aspects of gibberellins. Annual Review of Plant Physiology. 1961;**12**:369-394

[42] Gocal GF, Poole AT, Gubler F, Watts RJ, Blundell C, King RW. Long day up-regulation of a GAMYB gene during *Lolium temulentum* inflorescence formation. Plant Physiology. 1999;**119**:1271-1278

[43] Rademacher W. Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways. Annual Review of Plant Physiology and Plant Molecular Biology. 2000;**50**:502-531

[44] Tamalá POS. Efecto de inductor de floración sobre la formación de frutos en el cultivo de guanábana (*Annona muricata*) en la comuna Bambil Collao, Santa Elena. [Tesis de Licenciatura]. Universidad Estatal Península de Santa

Elena. Facultad de Ciencias Agraria. Carrera Agropecuaria. Ecuador. 2020

[45] Zacarías L. Fundamentos de Fisiología Vegetal. 2nd Edición ed. Barcelona: McGraw-Hill–Interamericana; 2013. pp. 445-453

[46] Balaguera-López HE, Salamanca-Gutiérrez FA, Camilo GJ, Herrera-Arévalo C. Etileno y retardantes de la maduración en la poscosecha de productos agrícolas. una revisión. Colombian Journal of Horticultural Science. 2014;**8**(2):302-313

[47] Depaepe VDS. Regulators of Growth: Ethylene. 2nd ed. pp. 403-410

[48] Martínez-Damián MT, Cano-Hernández R, Moreno-Pérez CEC, Sánchez-del Castillo F, Cruz-Álvarez O. Efecto de biorreguladores del crecimiento en precosecha sobre la calidad fisicoquímica de tomate saladette. Rev. Chapingo Serie Horticultura. 2019;**25**(1):29-43

[49] Alvarado INM, Vera VRS Efecto de fitorreguladores y movilizadores de azúcares sobre la maduración homogénea de frutos de café (*Coffea arabica L*). [Tesis de Licenciatura]. Escuela Superior Politécnica Agropecuaria de Manabí "Manuel Félix López" Carrera de Ingeniería Agrícola. Calceta, Ecuador. 2021

[50] Morteza SA, Hassanpouraghdam PMB, Farmani B. The language of calcium in postharvest life of fruits, vegetables and flowers. Scientia Horticulturae. 2012;**144**:102-115

[51] Rogiers SY, Keller M, Holzapfel BP, Virgona JM. Accumulation of potassium and calcium by ripening berries on field vines of *Vitis vinifera* (L) cv. Shiraz. Australian Journal of grape Wine Research. 2000;**6**:240-243

[52] Penter MG, Stassen PJ. The effect of pre-and postharvest calcium applications on the postharvest quality of Pinkenton avocados. South African Avocado Grower Association yerabppk. 2000;**23**:1-7

[53] Martín-Diana R, Frías JM, Barat JM, GTM H, Barry-Ryan C. Calcio para extender la vida útil de todo fresco y frutas y verduras mínimamente procesadas: una revisión. Trends in Food Science & Technology. 2007;**18**(4):210-218

[54] Elmer PAG, Spiers TM, Wood PN. Effects of pre-harvest foliar calcium spray on fruit calcium levels and Brown rot of peaches. Crop Protection. 2007;**26**:11-18