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## Preharvest sprays and their effects on the postharvest quality of fruit

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### Abstract

**Purpose of review:** This paper reviews studies on the effects of preharvest spray treatments on the postharvest quality and storage potential of fruits, with the objective of summarising the main effects in each case and identifying major topics requiring further research.

**Findings:** The literature survey shows that most of the studies on preharvest sprays have considered either calcium or growth regulator treatments. Calcium applications are generally reported to delay ripening, decrease postharvest rots and alterations, and extend the keeping period, but their effects are partially dependent on the calcium source and formulation used, and phytotoxicity has also been occasionally observed. Preharvest sprays with growth regulators such as aminoethoxyvinylglycine, gibberellins or polyamines have also been studied and have shown promising potential for delaying ripening and improving storage potential or particular quality traits.

**Directions for future research:** Although some common effects have been identified on fruit physiology for a particular treatment, a certain degree of variability across fruit types or cultivars has been observed in all cases. The suitability and the particular conditions of each treatment should be assessed and adjusted for each fruit type. In addition, because fruit metabolism is complex and strictly regulated, improved keeping potential may be contradicted by detrimental effects on eating quality, meaning that treatment effects should be evaluated as a whole. A third aspect worthy of more intense research efforts involves effects on key quality attributes such as aroma or bioactive compound contents, or on other traits relevant for quality preservation such as fruit cuticles.

**Keywords:** calcium applications; fruit; plant hormone applications; preharvest sprays; postharvest quality; storage potential

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### Introduction

Fruit condition at harvest is essential for postharvest performance of produce. This entails an appropriate maturity stage, but also involves other aspects such as nutritional status and content of particular minerals. For this reason, preharvest spraying with certain compounds has become a widely used practice during on-tree development of some economically relevant fruit species. This paper reviews published reports on the effects of such treatments on postharvest quality and storage potential of fruit.

Since a number of postharvest alterations arise at least partially from mineral deficiency, many preharvest sprays are aimed at supplementing the fruit with a higher content of that particular mineral element. Because of its impact on different aspects related to fruit quality, calcium has been particularly used for preharvest treatment of these commodities, and the object of intensive research efforts. However, this is not the only feasible approach for the modulation of

**Abbreviations**

|                       |  |
|-----------------------|--|
| <b>1-MCP</b>          | 1-Methylcyclopropene                       |
| <b>β-Gal</b>          | β-Galactosidase                            |
| <b>β-Xyl</b>          | β-Xylosidase                               |
| <b>AAT</b>            | Alcohol o-Acyltransferase                  |
| <b>ACO</b>            | 1-Aminocyclopropane-1-Carboxylate Oxidase  |
| <b>ACS</b>            | 1-Aminocyclopropane-1-Carboxylate Synthase |
| <b>ADH</b>            | Alcohol Dehydrogenase                      |
| <b>AFase</b>          | α-L-Arabinofuranosidase                    |
| <b>AVG</b>            | Aminoethoxyvinylglycine                    |
| <b>CPPU</b>           | N-(2-Chloro-4-Pyridyl)-N-Phenylurea        |
| <b>EGase</b>          | Endo-1,4-B-D-Glucanase                     |
| <b>Exp</b>            | Expansin                                   |
| <b>GA<sub>3</sub></b> | Gibberellic Acid                           |
| <b>HPL</b>            | Hydroperoxide Lyase                        |
| <b>IEC</b>            | Internal Ethylene Concentration            |
| <b>LOX</b>            | Lipoxygenase                               |
| <b>MJ</b>             | Methyl Jasmonate                           |
| <b>PA</b>             | Polyamines                                 |
| <b>PAL</b>            | Phenylalanine Ammonia-Lyase                |
| <b>PDC</b>            | Pyruvate Decarboxylase                     |
| <b>PDJ</b>            | Propyl Dihydrojasmonate                    |
| <b>PE</b>             | Pectin Esterase                            |
| <b>PG</b>             | Polygalacturonase                          |
| <b>PL</b>             | Pectate Lyase                              |
| <b>PME</b>            | Pectinmethylesterase                       |
| <b>POD</b>            | Peroxidase                                 |
| <b>Put</b>            | Putrescine                                 |
| <b>SAMDC</b>          | S-Adenosylmethionine Decarboxylase         |
| <b>Spd</b>            | Spermidine                                 |
| <b>Spm</b>            | Spermine                                   |
| <b>SSC</b>            | Soluble Solids Content                     |
| <b>TA</b>             | Titrateable Acidity                        |

fruit quality attributes prior to harvest. Postharvest quality of fruit produce can also be manipulated by preharvest application of a range of different compounds, including plant growth regulators such as gibberellins, polyamines, ethylene-inhibiting or -releasing chemicals, fungicides or chitosan. Among these, the effects of preharvest applications of fungicides and the ethylene antagonist 1-methyl-cyclopropene (1-MCP) on postharvest quality are reviewed elsewhere in this issue, and will not be covered here.

Although some common effects are usually recognisable for a given preharvest spray treatment (Tables 1 and 2), some variability may exist across fruit species or even cultivars. This means that it is necessary to confirm the suitability or to optimise the application protocol on a case-by-case basis. On the other hand, the beneficial effects on a given attribute may be counteracted by a detrimental influence on another trait.

Furthermore, most published studies on the influence of preharvest sprays on postharvest quality have targeted the extension of storage potential and marketing possibilities through the preservation of the usual commercial quality attributes or the control of the incidence of decay and physiological disorders. However, some major traits contributing to the sensory quality of fruit, such as aroma, have been largely overlooked, and would need intensive work in order to assure optimal quality of fresh fruit reaching the consumers.

**Calcium sprays**

The divalent calcium cation ( $\text{Ca}^{2+}$ ) is required for several key physiological processes related to ripening-related changes, including those in cell wall structure, membrane integrity and functionality, activity of particular enzymes, or signal transduction. Calcium deficiency in fruit produce can result in physiological disorders of considerable economic relevance such as cracking, vitrescence or bitter pit [1\*]. Therefore, calcium treatments have the potential to delay fruit ripening and senescence, and to show beneficial effects on a wide range of attributes related to quality and storability of produce. Different procedures have been used successfully for postharvest calcium treatment of fresh and minimally-processed fruit [2\*]. Yet calcium applications can also be undertaken prior to commercial harvest, in order to provide an extra supply of the mineral before the deficiency symptoms appear. Because calcium uptake from the soil and its movement to aerial plant organs are limited, direct spray applications onto the plant canopy are preferable, as they often allow effective increase of calcium content in the fruit [3]. Nevertheless, this may not necessarily be the case in all instances: cantaloupe melon fruit did not benefit from preharvest applications of either amino acid-chelated or mannitol-complexed calcium, while treated honeydew fruit displayed higher calcium concentrations associated with improved firmness and marketability [4]. Similarly, no consistent effects on calcium content in fruit have been reported occasionally for calcium-sprayed apples [5, 6]. In other cases, phytotoxic effects have been observed [7, 8], which indicates the need to optimise treatment conditions individually for each species or cultivar.

While the chloride salt is the most frequently used source of calcium for these preharvest sprays (Table 1), some studies have also been undertaken in which different calcium sources or formulations were applied and compared in relation to their suitability for increasing calcium content in the fruit or for extending the keeping period after harvest [4, 6, 9–17]. In some cases, the calcium formulation has been shown to influence the efficiency of treatment, particularly regarding the incidence of physiological alterations or decay. In addition to source or formulation, season-to-season variability in the effectiveness of preharvest calcium applications has also been observed occasionally for apple [18, 19] and kiwifruit [12].

Many studies have addressed the effects of preharvest calcium applications on the standard attributes generally used to

**Table 1: A summary of reported effects of preharvest calcium sprays on postharvest quality of fruit commodities.**

| Fruit       | Source  | Dosage  | Effect on postharvest quality  | Reference  |
|-------------|---|---|--|--|
| Apple       | CaCl <sub>2</sub>   |   | Higher fruit calcium, firmness, TA and juiciness; reduced incidence of bitter pit, scald and internal breakdown.   | [22]   |
|             | CaCl <sub>2</sub>   | 1.2%  | Better firmness retention; higher yields of pectins and hemicelluloses; lower β-Gal* activity.   | [30]   |
|             | CaCl <sub>2</sub>   | 0.2%  | Increased firmness and TA; lower SSC, SSC/TA ratio and incidence of physiological storage disorders.   | [23]   |
|             | CaCl <sub>2</sub>   | 0.5 to 2%   | Enhanced firmness and decreased incidence of physiological disorders. No effect on other quality traits.   | [24]   |
|             | CaCl <sub>2</sub>   | 0.15%   | Increased firmness; lower TA and incidence of bitter pit (season-dependent).   | [18]   |
|             | CaCl <sub>2</sub><br>Ca(NO <sub>3</sub> ) <sub>2</sub>        | 0.5%<br>1%  | Increased calcium content; decreased incidence of bitter pit, SSC, TA and dry matter (cultivar-related differences).   | [9]  |
|             | CaCl <sub>2</sub>   | 0.5%  | Lower incidence of bitter pit and lenticel blotch pit (season-dependent).  | [19]   |
|             | CaCl <sub>2</sub>   | 0.25 to 1%  | Increased fruit calcium in the skin; no change in flesh. Unchanged Mg <sup>+</sup> and K <sup>+</sup> contents.  | [5]  |
|             | CaCl <sub>2</sub><br>Ca-propionate                            | 120 and 250 mM<br>Ca <sup>2+</sup>                            | Decreased bitter pit incidence (formulation-dependent).  | [10]   |
|             | CaCl <sub>2</sub>   | 1.6%  | Higher firmness; delayed pectin solubilisation and matrix glycan breakdown; lower PME, PL, β-Gal, AFase and β-Xyl* activities. Higher emission of flavour-contributing esters; higher ADH and PDC* activity. | [31, 36**]   |
|             | Diverse<br>(commercial Ca <sup>2+</sup> -containing products) |   | No consistent effects on calcium content or bitter pit incidence.  | [6]  |
| Banana      | CaCO <sub>3</sub>   | 0.5%  | Non-significant.   | [64]   |
| Blueberry   | CaCl <sub>2</sub>   | 0.08 to 0.4%  | Non-significant.   | [65]   |
|             | CaSO <sub>4</sub>   | 60 g/m <sup>2</sup>   | Lower respiration rate and weight loss; delayed softening and pectin solubilisation. No effect on colour, anthocyanin content, TA or SSC.  | [32]   |
| Cactus pear | CaCl <sub>2</sub>   | 2%  | Delayed colour changes; decreased weight loss and pathogen development. Increased incidence of chilling injury. No effect on respiration, TA, SSC or ethanol and acetaldehyde contents.                      | [66]   |
| Kiwifruit   | CaCl <sub>2</sub>   | 0.375 to 1.5%   | Increased fruit calcium, firmness and TA at harvest. Slower softening rate during storage; extended shelf life.  | [67]   |
|             | Chelated calcium  | 200 mg/L  | Delayed firmness loss and starch degradation; higher TA and ascorbic acid content. Inhibited pectin solubilisation and delayed ABA accumulation.   | [20]   |
|             | CaCl <sub>2</sub> ; CaO                                       | 0.03%   | Non-significant.   | [11]   |
|             | CaCl <sub>2</sub>   | 1%  | Delayed softening and increased storage life potential; decreased incidence of low temperature breakdown.  | [26]   |
|             | CaCl <sub>2</sub>   | 0.25 to 1.5%  | Increased calcium in the flesh; no effect on firmness or pitting incidence.  | [68]   |
|             | CaCl <sub>2</sub>   | 0.8%  | Delayed softening; phytotoxic effects.   | [8]  |
|             |   | Diverse<br>(commercial Ca <sup>2+</sup> -containing products) |  | Increased calcium content; altered antioxidant power and total phenols and ascorbic acid contents (formulation-dependent). Increased firmness (season-dependent); no effects on SSC or TA. |

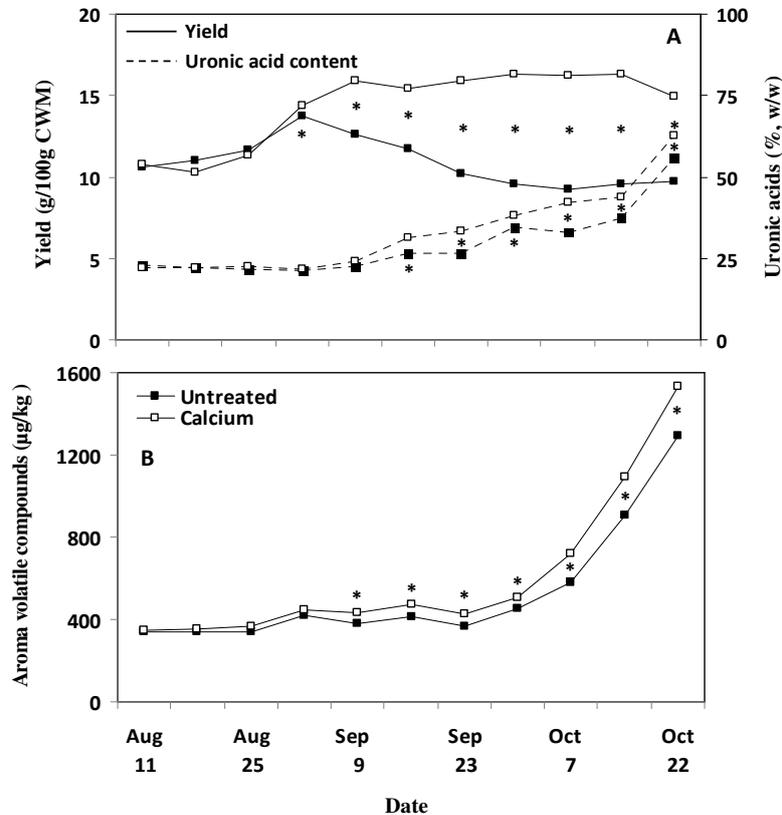
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**Table 1 continued: A summary of reported effects of preharvest calcium sprays on postharvest quality of fruit commodities.**

| <b>Fruit</b>        | <b>Source</b>   | <b>Dosage</b>   | <b>Effect on postharvest quality</b>  | <b>Reference</b> |
|---------------------|---|---|---|------------------|
| Litchi              | CaCl <sub>2</sub>   | 2%  | Increased fruit calcium, firmness and skin colour.  | [69]             |
| Mandarin            | Ca(NO <sub>3</sub> ) <sub>2</sub>   | 1 to 2%   | Higher firmness and TA; no effects on rind thickness, juice content, SSC or SSC/TA ratio.   | [59]             |
| Mango               | CaCl <sub>2</sub><br>Ca(NO <sub>3</sub> ) <sub>2</sub>                                | 1 to 2%<br>0.6 to 1.2%  | Delayed ripening; extended storability; lower weight loss and respiration rate; higher calcium content in both flesh and skin.  | [13]             |
| Melon               | Amino-acid-chelated (6% Ca <sup>2+</sup> ); mannitol-complexed (8% Ca <sup>2+</sup> ) | 2.3 L/ha  | Non-significant for cantaloupe fruit. Improved firmness, marketability and calcium content in honeydew fruit (no effect on sugars or taste).  | [4]              |
| Olive               | CaCl <sub>2</sub>   | 0.65%   | Delayed calcium loss, softening and pectin solubilisation. No effects on colour change, respiration or ethylene production rates.   | [33]             |
| Peach/<br>nectarine | Non-specified   | 0.1 mM Ca <sup>2+</sup><br>(+ 0.1 mM Mg <sup>2+</sup><br>+ 0.04 mM Ti <sup>4+</sup> ) | Lower weight loss, SSC/TA ratio and ethylene production; delayed climacteric, softening and colour changes; extended storability.   | [14]             |
|                     | CaCl <sub>2</sub><br>Chelated calcium   | 0.12% Ca <sup>2+</sup>  | Higher firmness; increased calcium content in skin, flesh and insoluble pectins; decreased severity of infection and PG activity (source-dependent). No effect on ethylene production, respiration, uronic acid content or disease incidence. | [15, 16]         |
|                     | CaCl <sub>2</sub><br>Ca-propionate  | 0.5 and 1% Ca <sup>2+</sup>   | Increased firmness; lower susceptibility to internal browning (formulation-dependent).  | [17]             |
| Pear                | CaCl <sub>2</sub>   |   | Higher fruit calcium; decreased incidence of cork spot. Increased firmness (formulation-dependent).   | [22]             |
|                     | CaCl <sub>2</sub>   | 0.3%  | Increased firmness; slower increase in internal ethylene.   | [70]             |
|                     | CaCl <sub>2</sub>   | 2 to 4 kg/ha  | Delayed softening and degreening; less sensitiveness to internal browning; higher content of organic acids. No effect on SSC or decay.  | [27]             |
| Pepper              | CaCl <sub>2</sub>   | 0.4%  | Higher firmness and pericarp wall thickness; decreased decay and pectin solubilisation. No effect on water loss.  | [34]             |
| Plum                | CaCl <sub>2</sub>   | 1.6 kg/ha   | Reduced postharvest decay in soft cultivar; no effect in firm cultivars. Non-significant effects on soluble solids or firmness.   | [71]             |
| Rambutan            | Chelated calcium  | 5.63 mg/L   | Decreased decay incidence and severity, weight loss and browning. Increased peel thickness. No effects on TA, SSC or ascorbic acid content.   | [28]             |
| Strawberry          | CaCl <sub>2</sub>   | 0.4%  | Increased firmness. Less sweet taste; necrotic brown spots after storage.   | [7]              |
|                     | CaCl <sub>2</sub>   | 0.4%  | Non-significant.  | [29]             |
|                     | CaSO <sub>4</sub>   | 0.04 to 0.2% Ca <sup>2+</sup>   | Non-significant.  | [72]             |
| Sweet cherry        | Ca(OH) <sub>2</sub>   | 0.7%  | Reduced cracking incidence; higher firmness, SSC and calcium content both in skin and flesh.  | [25]             |
|                     | CaCl <sub>2</sub>   | 0.5%  | Higher SSC and phenolics content; reduced decay and cuticular fractures. Non-significant effects on TA, colour or firmness. Increased weight loss during storage.   | [21]             |
| Table grape         | CaCl <sub>2</sub>   | 1%  | Non-significant.  | [73]             |
|                     | CaCl <sub>2</sub>   | 0.1%  | Increased firmness; decreased percentage of unmarketable fruit.   | [57]             |

\*β-Gal, β-galactosidase; β-Xyl, β-xylosidase; ADH, alcohol dehydrogenase; AFase, α-L-arabinofuranosidase; PDC, pyruvate decarboxylase; PL, pectate lyase; PME, pectinmethylesterase

**Figure 1: Yield and uronic acid content of the chelator-soluble fraction of cell walls (A), and total emission of flavour-related volatile compounds (B) in ‘Fuji Kiku-8’ apples throughout on-tree maturation after preharvest calcium (1.6%, w/v) sprays. Values are the means of three (cell wall analyses) or four (aroma volatiles) replicates. Asterisks stand for significant differences between treated and untreated fruit at  $P \leq 0.05$  (LSD test). Redrawn from [31, 36\*\*].**



evaluate commercial quality of fruit, such as firmness, titratable acidity (TA), soluble solids content (SSC) or postharvest rots and alterations. Calcium sprays have been generally reported to delay ripening as indicated by respiration rates or ethylene production, to increase fruit firmness and TA both at harvest and after storage, and to decrease the incidence of postharvest decay (Table 1). In a few instances, significant changes in antioxidant capacity or the content of antioxidant compounds such as phenols and ascorbic acid have also been found [12, 20, 21]. These treatments have also been shown to prevent to a large extent the occurrence of commercially relevant physiological and storage disorders. For example, preharvest calcium sprays reportedly reduced the incidence of bitter pit, lenticel blotch pit, scald and internal breakdown in apple [9, 10, 18, 19, 22–24], of cork spot in pear [22], and of cracking in sweet cherry [21, 25]. These treatments also help prevent or reduce chilling injury and internal browning in susceptible fruit species such as kiwifruit [26], peach [17], pear [27] and rambutan [28].

Whereas reported effects of preharvest calcium sprays on firmness, decay and alterations appear to be quite general,

their influence on other quality indicators such as SSC, SSC/TA ratios, colour or weight loss have been observed to be much more erratic, non-significant or even contradictory (Table 1). A part of this variability may be related to genotypic differences among fruit species or cultivars, or to the calcium concentration or formulation used. In other cases, though, these discrepancies may prove more difficult to ascribe; the same calcium source and concentration applied to the same fruit species resulting in clearly different effects (compare, for example, references [7] and [29]).

Although improved firmness retention is frequently cited as a major general effect of preharvest calcium applications, the biochemical basis for delayed firmness loss in treated fruit has received less attention. However, some information is available for apple, blueberry, kiwifruit, olive, peach, nectarine and pepper. Delayed softening has been observed to arise from delayed pectin solubilisation and matrix glycan breakdown in treated fruit [15, 16, 20, 30–34]. Indeed, exogenous calcium can favour the formation of non-covalent cross-links between polyuronides through calcium bridges, thus preventing the dissolution of the middle lamella and reinforcing the

cell wall structure. Accordingly, calcium applications often result in increased yields of the chelator-soluble fraction of pectins, comprised mainly of the non-covalently bound cell wall polyuronides (Figure 1A), associated with better retention of total uronic acids. In addition to directly reinforcing the cell wall structure, calcium may also improve firmness retention through the modulation of some cell wall-modifying enzyme activities, as treated apple and peach fruit have been found to display lower levels of PME, PL, PG,  $\beta$ -Gal, AFase or  $\beta$ -Xyl activity [15, 16, 30, 31]. The effects of calcium on flesh firmness and cell wall composition are not simply related to its electrostatic properties or to its properties as a divalent cation, but must involve some specific effect, as treatment of apple fruit with strontium chloride ( $\text{SrCl}_2$ ) failed to mimic the effects of a similar treatment with  $\text{CaCl}_2$  on cell wall properties or  $\beta$ -Gal activity [35].

The objectives of preharvest calcium applications have been focused fundamentally on the prevention of physiological alterations and on the extension of shelf life as indicated by the usual commercial quality attributes such as firmness, SSC or TA. In contrast, little information has been reported to date on the effects of calcium treatments on fruit aroma. This attribute has been largely disregarded, even though it is a major contributor to sensory quality and consumer acceptance of fruit. In the case of apple, for example, the usual practice of harvesting the fruit before reaching full ripeness, aimed at obtaining higher firmness levels and thus better storage potential, often leads to deficient aroma as the production of related volatile compounds develops with maturity stage. In this context, a recent report has shown the potential of preharvest calcium sprays for improving this important quality trait [36\*\*]; treated 'Fuji Kiku-8' apples not only displayed higher firmness and TA, but also showed increased production of aroma-related volatile compounds (Figure 1B), and particularly of the impact compounds contributing to the characteristic aroma. Improved emission of key volatile compounds was the result of the enhancement of major enzyme activities providing the necessary precursors for the final reaction in the biosynthetic pathway.

### Growth regulator sprays

Preharvest sprays with certain growth regulators can also be applied with the aim of modifying the ripening process of fruit, or of modulating the development of a particular attribute with influence on storage potential or commercial appeal (Table 2). Although some common effects of each particular compound on fruit physiology can be identified in each case, the results of such applications on postharvest quality have shown a certain degree of variability across fruit types or even cultivars.

### Ethylene-inhibiting and -releasing compounds

Aminoethoxyvinylglycine (AVG) acts as a competitive inhibitor in the conversion of *S*-adenosylmethionine (SAM) to the ethylene precursor 1-aminocyclopropane-1-carboxylic acid (ACC). Owing to this capacity to block reversibly the

ethylene biosynthesis pathway, pre- and postharvest AVG applications have been tested as a means to delay ripening and to enhance storage potential of climacteric fruits. In general, significant delays in fruit ripening have been reported to result from preharvest AVG sprays, with significant decreases in ethylene production and higher firmness levels in treated fruit (Table 2) resulting in extended shelf life.

The literature survey, though, also indicates that some other practical benefits of these treatments are species-specific: preharvest AVG applications have been shown to improve uniformity of maturity stage at harvest in peach [37], but not in melon [38]. No consistent influence on the control of decay incidence has been demonstrated either. Furthermore, sprays may be not a suitable method for AVG application in all cases: for example, no effects of AVG treatment were found in melon fruit when the compound was applied as a spray, whereas fruit firmness was increased significantly when it was directly injected to the soil into the root zone [39].

However, in spite of the generally beneficial effects of AVG applications on storage potential as indicated by the usual standard quality parameters, it should be kept in mind that treatment effects should be evaluated in all instances as a whole, since extension of storability could be counteracted by undesirable effects on sensory quality and consumer acceptance of produce. A preharvest AVG treatment has been reported to decrease the content of bitterness-contributing phenolics in olive [40], which suggests that eating quality was improved. Nevertheless, ripening delays will typically result in delayed development of the characteristic flavour, which is strictly dependent on maturity stage [36\*\*]. Since flavour is, together with texture, a major attribute contributing to consumer acceptance of the main fruit commodities with commercial importance, insufficient development of this important quality trait could result in detrimental effects on sensory quality. For example, total flavour-contributing ester production by 'Redchief Delicious' apple peel tissue after cold storage was reduced by 44% in response to preharvest AVG sprays [41], arising from a decreased supply of alcohol precursors for ester biosynthesis. Similarly, preharvest AVG application had a negative impact on the biosynthesis of aroma volatiles by 'Delbarde Estivale' apple fruit, particularly of those having the most impact on the characteristic aroma [42], also as a result of impaired precursor supply (Figure 2). Although no sensory analyses were undertaken in either study, it is apparent that the eating quality of produce must have been compromised, and thus that treatment benefits in terms of storage potential probably did not compensate for the loss of sensory quality.

In contrast to AVG, ethephon penetrates into tissues and decomposes to ethylene, phosphate and chloride ion in aqueous solutions above pH 4-5, and thus such treatments are expected to show opposite effects to those of AVG on fruit physiology. As an ethylene-liberating compound, preharvest

**Table 2: A summary of reported effects of preharvest sprays with growth regulators on postharvest quality of fruit commodities.**

| Compound   | Fruit  | Effect on postharvest quality  | Reference   |   |
|--|--|--|---|---|
| AVG  | Apple  | Little effect on softening or senescent internal browning.   | [74]  |   |
|  |  | Increased incidence of internal browning disorders; no effect on IEC.  | [75]  |   |
|  |  | Delayed colour changes; decreased respiration and IEC*; increased firmness (season-dependent).   | [76]  |   |
|  |  | No effects on TA or SSC.   |   |   |
|  |  | Delayed ripening during and after storage; higher firmness.  | [77]  |   |
|  |  | Decreased production of ethylene, TA and flavour-contributing volatile esters. No effect on SSC, respiration rates or AAT* activity.   | [41]  |   |
|  | Melon  | Lower ethylene production. No effect on firmness, SSC, decay incidence or uniformity of fruit maturity. Non-significant.   | [38]  |   |
|  |  |  | [39]  |   |
|  |  | Nectarine  | Decreased ethylene production; delayed firmness and TA losses; avoided increase in SSC and dry matter; decreased expression of <i>ACO*</i> and <i>SAMDC*</i> genes. | [52]  |
|  |  |  | Olive   | Delayed softening and degreening; lower content of bitterness-contributing phenolics; lower total antioxidant activity. |
| Peach  | Strongly suppressed ethylene production; delayed softening; decreased free-to-conjugate endogenous polyamine ratio and <i>SAMDC*</i> activity. | [53]   |   |   |
|  | Improved uniformity of fruit maturity at harvest.  | [37]   |   |   |
| Plum   | Higher firmness, TA, and resistance to flesh compression and penetration; delayed colour changes; lower SSC.                                   | [78, 79]   |   |   |
|  | Ethephon   | Apple  | Improved colour and anthocyanin content; no effect on firmness, TA or SSC.  | [43]  |
| Cactus pear  |  | Glochid abscission. No effects on SSC, TA, colour or weight.   | [46]  |   |
| Mango  |  | Standardisation of fruit harvesting; no postharvest climatisation required.  | [45]  |   |
| Sweet cherry   |  | Higher firmness (dehydration-related).   | [44]  |   |
| GA <sub>3</sub>  | Cactus pear  | Delayed changes in colour and epicuticular wax morphology; decreased ethanol levels and decay development.   | [47]  |   |
|  |  | Grapefruit   | Delayed degreening; slower peel softening and loss of cell wall galactosyl and arabinosyl residues.   | [80]  |
|  |  |  | Enhanced peel colour, firmness and oil content; reduced peel senescence.  | [81]  |
|  |  |  | Delayed fruit degreening.   | [82]  |
|  | Increased peel puncture resistance; delayed colour changes; decreased SSC and decay. No effect on juice content, TA or SSC/TA ratio.           | [83]   |   |   |
|  | Mandarin   | Decreased TA and juice content. Increased ascorbic acid content, SSC and SSC/TA ratio.   | [48]  |   |
|  | Mango  | Higher TA, ascorbic acid and total chlorophyll contents; lower SSC, SSC/TA ratios, total carotenoid content, and amylase and peroxidase activities.  | [49]  |   |
|  | Plum   | Higher firmness, TA, and resistance to flesh compression and penetration; delayed colour changes; lower SSC.   | [78, 79]  |   |
|  | Sour cherry  | Enhanced firmness and storage potential.   | [84]  |   |
|  | Sweet cherry   | Higher firmness and TA; delayed softening and fruit maturation; decreased PG* and cellulase activities (cultivar-dependent). No effect on SSC, $\beta$ -Gal* or $\beta$ -glucosidase activities. | [50]  |   |
| Firmer, heavier and larger fruit, better preservation of pedicels. No effect on colour or SSC. |  |  | [85]  |   |
| Firmer and larger fruit; higher SSC (cultivar-dependent).                                      |  | [86]   |   |   |
| Table grape  |  | Increased firmness; decreased percentage of unmarketable fruit.  | [57]  |   |
| Tangerine  | Increased peel puncture resistance; delayed colour changes; decreased SSC and decay. No effect on juice content, TA or SSC/TA ratio.           | [83]   |   |   |

...Table 2 continues on page 8

Table 2 continued: A summary of reported effects of preharvest sprays with growth regulators on postharvest quality of fruit commodities.

| Compound       | Fruit        | Effect on postharvest quality   | Reference |
|----------------|--------------|---|-----------|
| Jasmonates     | Peach        | Decreased ethylene production and SSC; increased firmness; delayed colour changes. Down-regulation of ACO, PG, and Exp3*. Enhanced expression of PL, Exp1* and several stress-regulated genes.          | [55]      |
|                | Sweet cherry | Reduced incidence of postharvest rot. Lowered $\beta$ -1,3-glucanase, PAL and POD activities*.  | [56]      |
| Polyamines     | Mango        | Higher firmness; delayed colour changes; decreased SSC, rot incidence and ascorbic acid content; increased TA and total carotenoids.  | [51, 87]  |
|                | Nectarine    | Decreased ethylene production; delayed firmness and TA losses; avoided increase in SSC and dry matter; decreased expression of ACO, ACS and SAMDC* genes (polyamine type-dependent).                    | [52]      |
|                | Peach        | Strongly suppressed ethylene production; delayed softening; decreased free-to-conjugate endogenous polyamine ratio and SAMDC* activity.   | [53]      |
|                | Plum         | Decreased ethylene production and respiration rate; lower ACS and ACO* activities; higher firmness; lower PE, PG and EGase* activities. Lower SSC, total carotenoids, vitamin C and total antioxidants. | [54, 88]  |
|                | Table grape  | Increased firmness; decreased percentage of unmarketable fruit.   | [57]      |
| Salicylic acid | Sweet cherry | Reduced incidence of postharvest rot. Lowered $\beta$ -1,3-glucanase, PAL and POD activities*.  | [56]      |
|                | Table grape  | Increased firmness; decreased percentage of unmarketable fruit.   | [57]      |

\* AAT, alcohol o-acyltransferase; ACO, 1-aminocyclopropane-1-carboxylate oxidase; ACS, 1-aminocyclopropane-1-carboxylate synthase; ADH, alcohol dehydrogenase;  $\beta$ -Gal,  $\beta$ -galactosidase; EGase, *endo*-1,4- $\beta$ -D-glucanase; Exp, expansin; HPL, hydroperoxide lyase; IEC, internal ethylene concentration; LOX, lipoxygenase; PAL, phenylalanine ammonia-lyase; PDC, pyruvate decarboxylase; PE, pectin esterase; PG, polygalacturonase; PL, pectate lyase; POD, peroxidase; SAMDC, S-adenosylmethionine decarboxylase.

ethephon applications can be used to promote fruit ripening or to aid harvest by stimulating abscission. Although reported research has demonstrated limited effect on the usual indicators of fruit quality [43, 44], preharvest ethephon treatments can also facilitate postharvest operations by improving uniformity of fruit maturity at harvest [45] or by helping with the removal of troublesome surface structures such as glochids of cactus pear [46].

### Gibberellins

Gibberellic acid (GA<sub>3</sub>) is a pentacyclic diterpene acid which promotes plant cell growth and elongation. It is considered a 'juvenile' plant growth regulator, and as such has been observed to delay ripening and senescence in some fruits, and to improve certain quality characteristics (Table 2). GA<sub>3</sub> sprays are actually a common horticultural practice in some production areas to control colour changes or to delay rind senescence in citrus fruit, or to increase fruit firmness in sweet cherry. Since gibberellins are actively synthesised in seeds, they are also used on seedless grapes to increase berry size.

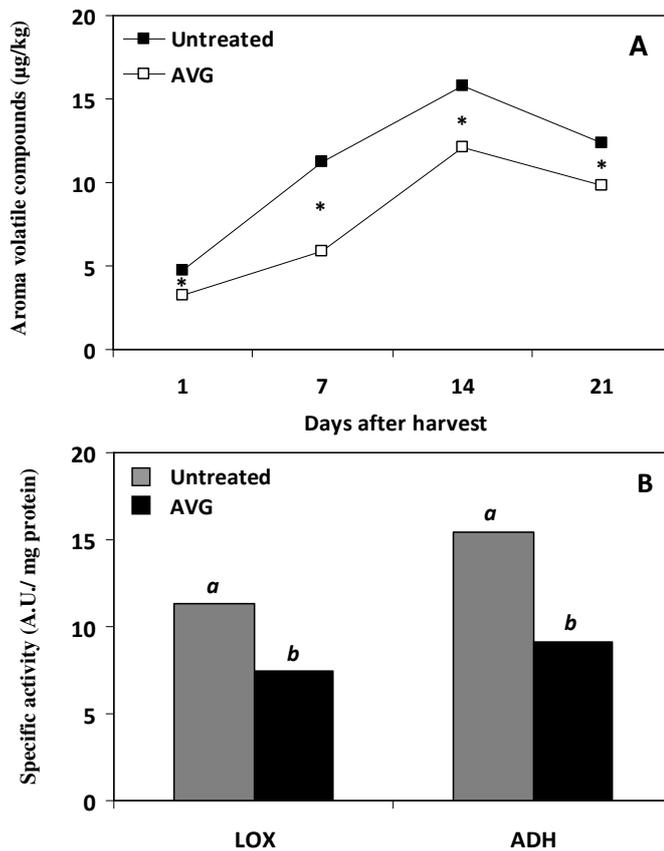
Studies on the effects on preharvest GA<sub>3</sub> sprays on postharvest fruit quality has shown generally delayed ripening in treated fruit, both climacteric and non-climacteric. Commonly observed effects include retention of higher firmness levels and delayed colour changes (Table 2). Additionally, treat-

ment-related changes in cuticular wax morphology have been found for cactus pear [47], and higher ascorbic acid content was also observed for mandarin [48] or mango [49]. Little research has been published on the biochemical mechanisms underlying improved firmness retention, but decreased polygalacturonase and cellulase activities were demonstrated for GA<sub>3</sub>-treated sweet cherry fruit, with some cultivar-dependent variability [50].

### Polyamines

Because polyamine (PA) and ethylene biosynthesis pathways share the precursor SAM, these cationic aliphatic amines have been targeted as potential antagonists of ethylene production. All three major polyamines found in plants (putrescine, spermidine and spermine) have an impact on fruit ripening-related events, and reported research has shown delaying effects of preharvest PA applications on the onset of ethylene production, with a concomitant extension of shelf life in a number of fruit species (Table 2). Ripening-delaying effects of preharvest PA sprays, though, are dependent to some extent on the specific PA applied. For example, spermine increased ascorbic acid content in mango, whereas spermidine and putrescine decreased it. In spite of this, general effects on fruit quality were similar, with enhanced firmness and delayed colour changes [51]. Such dependence on the specific polyamine compound used for the application has

**Figure 2.** Total emission of flavour-related volatile compounds (A), and specific LOX and ADH activities 14 days after harvest (B) during simulated commercial life at 20°C of ‘Delbarde Estivale’ apples submitted to a preharvest AVG (125 µL/L) spray application. Values are the means of three replicates. Asterisks (panel A) or different lower-case letters (panel B) stand for significant differences between treated and untreated fruit at  $P \leq 0.05$  (LSD test). Redrawn from [42].



also been reported for nectarine [52], with putrescine effects being generally stronger.

In contrast to experiments with calcium, which usually comprise several applications throughout on-tree fruit development, reported preharvest PA treatments have been implemented as a single application at a given time point prior to harvest. These treatments have been shown to delay ethylene production arising from lessened SAM decarboxylase (SAMDC), 1-aminocyclopropane-1-carboxylate oxidase (ACO) or 1-aminocyclopropane-1-carboxylate synthase (ACS) expression or activity [52–54], leading to deferred ripening-related changes while retaining acceptable quality of produce during subsequent storage and shelf life.

#### Other growth regulators

Compounds such as jasmonates or salicylic acid play key roles in plant responses to environmental stresses, being in-

involved in signal transduction in some biochemical pathways which lead to the biosynthesis of defence compounds such as phenolics and alkaloids. Accordingly, preharvest sprays with these substances have been shown to induce disease resistance or to enhance stress responses in fruit. For example, preharvest jasmonate sprays with methyl jasmonate (MJ) or propyl dihydrojasmonate (PDJ) were reported to induce many transcriptional changes in peach fruit [55]. Unlike most published studies on the effects of preharvest growth regulator sprays on postharvest quality of fruit, in this work the application was undertaken at three different developmental stages. Observed results included a complex set of transcriptional changes apparently resulting from an overlap between ripening and stress responses, with inhibited ethylene production and up-regulated defence-related pathways. In relation with postharvest quality, treatments resulted in increased fruit firmness associated with down-regulation of *PG* and *Exp3* gene expression. Ripening-related colour changes and increase in SSC were also delayed.

For sweet cherry, a single preharvest spray with either 0.2 mM MJ or 2 mM salicylic acid, undertaken 3 days before harvest, was significantly more effective than a postharvest treatment with the same substances in enhancing resistance to infection by *Monilinia fructicola*, with reduced lesion diameters in comparison with the postharvest applications [56]. These preharvest sprays increased defence-related enzyme activities such as  $\beta$ -1,3-glucanase, phenylalanine ammonia-lyase and peroxidase, showing a good potential as a strategy for the control of postharvest decay.

#### Miscellaneous sprays

Preharvest sprays with other substances have also been occasionally reported to affect postharvest quality of some fruit species. Urea and  $KNO_3$  applications were found to increase juice content, soluble solids and SSC/TA ratios of mandarin fruit after storage for 30 days [48]. Interestingly, ascorbic acid content was also increased in treated fruit, showing that not only eating, but also nutritional quality could benefit from this practice. For grape berries, a treatment comprised of three preharvest sprays with N-(2-chloro-4-pyridyl)-N-phenylurea (CPPU) led to higher firmness and juice content, and to decreased weight loss and percentage of unmarketable fruit after being kept one week at ambient temperature [57].

Although very scarcely, the influence of preharvest sprays with mineral elements other than calcium has also been explored. Boron sprays strongly suppressed browning disorders in ‘Conference’ pears throughout 4 months of cold storage under controlled atmosphere, apparently arising from reduced membrane leakage and increased content of ascorbic acid, the antioxidant properties of which may protect fruit tissues from these disorders [58]. In mandarin, preharvest sprays with potassium led to higher rind firmness and juice acidity, while other eating quality attributes such as juice content, SSC or SSC/TA ratios were unaffected [59], which disagrees with research by El Otmani *et al.* [48], maybe due to the different

potassium concentration used. However, peroxidase activity was lower in treated fruit during storage at 4°C, suggesting that treatment induced some tolerance to chilling injury. These reports indicate some potential for the prevention of physiological storage disorders, which is worthy of further research.

Finally, preharvest sprays with edible coatings such as chitosan, oligochitosan or sucrose have also been studied [60-63]. Besides beneficial effects on the eating quality of fruit, these treatments have been generally shown to increase fruit resistance to decay through the modification of enzyme activities related to the antioxidant status of the fruit, such as superoxide dismutase, polyphenol oxidase, peroxidase or phenylalanine ammonia-lyase.

## Conclusion

Review of the preharvest spray literature indicates good potential for some treatments to modulate postharvest quality and marketing possibilities of fruit produce, together with the need for further research. Because of the variability across species and cultivars, treatment conditions should be studied and optimised specifically for each particular case. In addition, treatment effects need to be evaluated as a whole, paying particular attention to quality traits so far disregarded, but yet largely relevant for the eating quality of produce, such as aroma.

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## References

Papers of interest have been highlighted as:

\* Marginal importance

\*\* Essential reading

- 1 White PJ and Broadley MR. Calcium in plants. *Annals of Botany* 2003; 92:487-511.
- \* A good review on the structural and physiological roles of calcium in plant tissues, including the mechanisms for its uptake, *in planta* mobility, and transport through cell membranes.
- 2 Martín-Diana AB, Rico D, Frías JM, Barat JM, Henehan GTM and Barry-Ryan C. Calcium for extending the shelf life of fresh whole and minimally processed fruits and vegetables: a review. *Trends in Food Science & Technology* 2007; 18:210-218.
- \* A very succinct overview of usual procedures for postharvest calcium applications and generally observed effects on commercial and nutritional quality of fruit.
- 3 Ferguson IB, Boyd LM. Inorganic nutrients and fruit quality. In: *Fruit Quality and its Biological Basis*. Edited by Knee M. Oxford: Blackwell Publishing Ltd; 2002: pp 17-45.
- 4 Lester GE, Grusak MA. Field application of chelated calcium: Postharvest effects on cantaloupe and honeydew fruit quality. *HortTechnology* 2004; 14: 29-38.
- 5 Val J, Monge E, Risco D, Blanco A. Effect of pre-harvest calcium sprays on calcium concentrations in the skin and flesh of apples. *Journal of Plant Nutrition* 2008; 31:1889-1905.
- 6 Katsurayama JM, Amarante CVT, Steffens CA, Pereira AJ. Preharvest spraying with commercial sources of calcium for bitter pit control in 'Catarina' apples. *Revista Brasileira de Fruticultura* 2011; 33:353-361.
- 7 Eaves CA, Leefe JS. Note on the influence of foliar sprays of calcium on the firmness of strawberries. *Canadian Journal of Plant Science* 1962; 42:746-747.
- 8 Cooper T, Gargiullo A, Streif J, Retamales J. Effects of calcium content and calcium applications on softening of 'Hayward' kiwifruit. *Acta Horticulturae* 2007; 753:297-303.
- 9 Moor U, Pöldma, Karp K, Asafova L, Pae A. Influence of preharvest calcium treatments on postharvest quality of some Stonian apple cultivars. *Acta Horticulturae* 2005; 682:1041-1048.
- 10 Blanco A, Fernández V, Val J. Improving the performance of calcium-containing spray formulations to limit the incidence of bitter pit in apples (*Malus × domestica* Borkh.). *Scinetia Horticulturae* 2010; 127:23-28.
- 11 Antunes MDC, Panagopoulos T, Neves N, Curado F, Rodrigues S. The effect of pre- and post-harvest calcium applications on 'Hayward' kiwifruit storage ability. *Acta Horticulturae* 2005; 682:909-916.
- 12 Koutinas N, Sotiropoulos T, Petridis A, Almaliotis D, Deligeorgis E, Therios I, Voulgarakis N. Effects of preharvest calcium foliar sprays on several fruit quality attributes and nutritional status of the kiwifruit cultivar Tsechelidis. *HortScience* 2010; 45:984-987.
- 13 Singh BP, Tandon DK, Kalra SK. Changes in postharvest quality of mangoes affected by preharvest application of calcium salts. *Scientia Horticulturae* 1993; 54:211-219.
- 14 Serrano M, Martínez-Romero D, Castillo S, Guillén F, Valero D. Effect of preharvest sprays containing calcium, magnesium and titanium on the quality of peaches and nectarines at harvest and during postharvest storage. *Journal of the Science of Food and Agriculture* 2004; 84:1270-1276.
- 15 Manganaris GA, Vasilakakis M, Mignani I, Diamantidis G, Tzavella-Klonari K. The effect of preharvest calcium sprays on quality attributes, physicochemical aspects of cell wall components and susceptibility to brown rot of peach fruits (*Prunus persica* L. cv. Andross). *Scientia Horticulturae* 2005; 107:43-50.
- 16 Manganaris GA, Vasilakakis M, Diamantidis G, Mignani I. Effect of in-season calcium applications on cell wall physicochemical properties of nectarine fruit (*Prunus persica* var. *nectarina* Ait. Maxim) after harvest or cold storage. *Journal of the Science of Food and Agriculture* 2006; 86:2597-2602.
- 17 Val J, Fernández V. In-season calcium-spray formulations improve calcium balance and fruit quality traits of peach. *J. Plant Nutr. Soil Sci.* 2011; 174:465-472.
- 18 Benavides A, Recasens I, Casero T, Puy J. Chemometric analyses of 'Golden Smoothee' apples treated with two preharvest calcium spray strategies in the growing season. *Journal of the Science of Food and Agriculture* 2001; 81:943-952.
- 19 Ermani PR, Dias J, Amarante CVT, Ribeiro DC, Rogeri DA. Preharvest calcium sprays were not always needed to improve fruit quality of 'Gala' apples in Brazil. *Revista Brasileira de Fruticultura* 2008; 30:892-896.
- 20 Xie M, Jiang GH, Zhang HQ. Effect of preharvest Ca-chelate treatment on the storage quality of kiwifruit. *Acta Horticulturae* 2003; 610:317-324.
- 21 Vangdal E, Hovland KL, Børve J, Sekse L, Slimestad R. Foliar application of calcium reduces postharvest decay in sweet cherry by various mechanisms. *Acta Horticulturae* 2008; 768:143-148.
- 22 Raese JT, Drake SR. Effects of preharvest calcium sprays on apple and pear quality. *Journal of Plant Nutrition* 1993; 16:1807-1819.
- 23 Dris R, Niskanen R. Calcium chloride sprays decrease physiological disorders following long-term cold storage of apple. *Plant Foods for Human Nutrition* 1999; 54:159-171.
- 24 Malakouti MJ, Tabatabaei SJ, Shahabil A, Fallahi E. Effects of calcium chloride on apple fruit quality of trees grown in calcareous soil. *Journal of Plant Nutrition* 1999; 22:1451-1456.
- 25 Demirsoy LK, Bilgener S. The effects of preharvest calcium hydroxide applications on cracking in '0900 Ziraat', 'Lambert' and 'Van' sweet cherries. *Acta Horticulturae* 1998; 468:657-662.

- 26 Gerasopoulos D, Drogoudi PD. Summer-pruning and preharvest calcium chloride sprays affect storability and low temperature breakdown incidence in kiwifruit. *Postharvest Biology and Technology* 2005; 36:303-308.
- 27 Wojcik P. Quality and 'Conference' pear storability as influenced by preharvest sprays of calcium chloride. *Journal of Plant Nutrition* 2012; 35:1970-1983.
- 28 Chiradej C, Punnawich Y, Warin I. Fungal disease control and postharvest quality during storage of rambutan (*Nephelium lappaceum* L. cv. Rong-Rien) fruits treated with preharvest application of *Trichoderma harzianum* and chelated calcium. *Philippine Agricultural Scientist* 2012; 95:312-316.
- 29 Toivonen PMA, Stan S. Effect of preharvest CaCl<sub>2</sub> sprays on the postharvest quality of 'Rainier' and 'Totem' strawberries. *Acta Horticulturae* 2001; 564:159-163.
- 30 Siddiqui S, Bangerth F. Effect of pre-harvest application of calcium on flesh firmness and cell-wall composition of apples – influence of fruit size. *Journal of Horticultural Science* 1995; 70:263-269.
- 31 Ortiz A, Graell J, Lara I. Preharvest calcium applications inhibit some cell wall-modifying enzyme activities and delay cell wall disassembly at commercial harvest of 'Fuji Kiku-8' apples. *Postharvest Biology and Technology* 2011; 62:161-167.
- 32 Angeletti P, Castagnasso H, Micelli E, Terminiello L, Concellón A, Chaves A, Vicente AR. Effect of preharvest calcium applications on postharvest quality, softening and cell wall degradation of two blueberry (*Vaccinium corymbosum*) varieties. *Postharvest Biology and Technology* 2010; 58:98-103.
- 33 Tsantili E, Christopoulos MV, Pontikis CA, Kaltsikes P, Kallianou C, Komaitis M. Texture and other quality attributes in olives and leaf characteristics after preharvest calcium chloride sprays. *HortScience* 2008; 43:1852-1856.
- 34 Toivonen PMA, Bowen PA. The effect of preharvest foliar sprays of calcium on quality and shelf life of two cultivars of sweet bell peppers (*Capsicum annuum* L.) grown in plasticulture. *Canadian Journal of Plant Science* 1999; 79:411-416.
- 35 Siddiqui S, Bangerth F. Differential effect of calcium and strontium on flesh firmness and properties of cell walls in apples. *Journal of Horticultural Science* 1995; 70:949-953.
- 36 Ortiz A, Graell J, Lara I. Preharvest calcium sprays improve volatile emission at commercial harvest of 'Fuji Kiku-8' apples. *Journal of Agricultural and Food Chemistry* 2011; 59:335-341.
- \*\* To the Author's knowledge, the only published report on the effects of preharvest calcium sprays on the biosynthesis of aroma-contributing volatile esters. It shows the potential of such preharvest treatments for improving aroma and sensory quality of fruit while allowing harvesting the produce at higher firmness levels.
- 37 Çetinbaş M, Koyuncu F. Effects of aminoethoxyvinylglycine on harvest time and fruit quality of 'Monroe' peaches. *Tarım Bilimleri Dergisi – Journal of Agricultural Sciences* 2011; 17:177-189.
- 38 Shellie KC. Muskmelon (*Cucumis melo* L.) fruit ripening and postharvest quality after a preharvest spray of aminoethoxyvinylglycine. *Postharvest Biology and Technology* 1999; 17:55-62.
- 39 Leskovar DI, Goreta S, Franco JA. Impact of AVG preharvest spray and soil injection on yield and quality of melón. *HortScience* 2006; 41:1249-1252.
- 40 Tsantili E, Kafkaletou M, Roussos PA, Christopoulos MV. Phenolic compounds, maturation and quality in fresh green olives for table use during exposure at 20 °C after preharvest ReTain treatment. *Scientia Horticulturae* 2012; 140:26-32.
- 41 Sigal Escalada V, Archbold DD. Preharvest aminoethoxyvinylglycine plus postharvest heat treatments influence apple fruit ripening after cold storage. *HortScience* 2009; 44:1637-1640.
- 42 Harb J, Lara I, Saleh O, Streif J, Khraiweh B. Treatments that suppress ethylene production or ethylene action modify *ADH* and *AAT* gene expression and aroma-related enzyme activities in 'Delbarde Estivale' apple: consequences for the aroma profiles of fruit. *Journal of Horticultural Science & Biotechnology* 2011; 86:182-188.
- 43 Singh Z, Shafiq M. Training systems and pre-harvest ethrel application affect fruit colour development and quality of 'Pink Lady™' apple at harvest and in controlled atmosphere storage. *Acta Horticulturae* 2008; 774:165-172.
- 44 Elfving DC, Auvil TD, Castillo F, Drake SR, Kunzel H, Kupferman EM, Lorenz B, McFerson JR, Reed AN, Sater C, Schmidt TR, Visser DB. Effects of preharvest applications of ethephon and 1-MCP to 'Bing' sweet cherry on fruit removal force and fruit quality. *Journal of the American Pomological Society* 2009; 63:84-100.
- 45 Pereira da Silva DF, Chambum Salomão LC, Cecon PR, Lopes Siqueira D, Rocha A. Anticipation of 'Uba' mango ripening with preharvest ethephon application. *Ciência Rural* 2011; 41:63-69.
- 46 Corrales-García J, González-Martínez P. Effect of gibberellic acid and (2-chloroethane) phosphonic acid on glochid abscission in cactus pear fruit (*Opuntia amyclaea* Tenore). *Postharvest Biology and Technology* 2001; 22:151-157.
- 47 Schirra M, D'hallewin G, Inglese P, La Mantia T. Epicuticular changes and storage potential of cactus pear [*Opuntia ficus-indica* Miller (L.)] fruit following gibberellic acid preharvest sprays and postharvest heat treatment. *Postharvest Biology and Technology* 1999; 17:79-88.
- 48 El-Otmani M, Ait-Oubahou A, El-Hassainate F, Kaanane A, Lovatt C. Effect of gibberellic acid, urea and KNO<sub>3</sub> on yield and on composition and nutritional quality of clementine mandarin fruit juice. *Acta Horticulturae* 2004; 632:149-157.
- 49 Khader SESA. Effect of preharvest application of GA<sub>3</sub> on postharvest behavior of mango fruits. *Scientia Horticulturae* 1991; 47:317-321.
- 50 Choi C, Wiersma PA, Toivonen P, Kappel F. Fruit growth, firmness and cell wall hydrolytic enzyme activity during development of sweet cherry fruit treated with gibberellic acid (GA<sub>3</sub>). *Journal of Horticultural Science & Biotechnology* 2002; 77:615-621.
- 51 Malik AU, Singh Z. Improved fruit retention, yield and fruit quality in mango with exogenous application of polyamines. *Scientia Horticulturae* 2006; 110:167-174.
- 52 Torrigiani P, Bregoli AM, Ziosi V, Scaramagli S, Ciriaci T, Rasori A, Biondi S, Costa G. Pre-harvest polyamine and aminoethoxyvinylglycine (AVG) applications modulate fruit ripening in Stark Red Gold nectarines (*Prunus persica* L. Batsch). *Postharvest Biology and Technology* 2004; 33:293-308.
- 53 Bregoli AM, Scaramagli S, Costa G, Sabatini E, Ziosi V, Biondi S, Torrigiani P. Peach (*Prunus persica*) fruit ripening: aminoethoxyvinylglycine (AVG) and exogenous polyamines affect ethylene emission and flesh firmness. *Physiologia Plantarum* 2002; 114:472-481.
- 54 Khan AS, Singh Z, Abbasi NA. Pre-storage putrescine application suppresses ethylene biosynthesis and retards fruit softening during low temperature storage in 'Angelino' plum. *Postharvest Biology and Technology* 2007; 46:36-46.
- 55 Ziosi V, Bonghi C, Bregoli AM, Trainotti L, Biondi S, Sutthiwal S, Kondo S, Costa G, Torrigiani P. Jasmonate-induced transcriptional changes suggest a negative interference with the ripening syndrome in peach fruit. *Journal of Experimental Botany* 2008; 59:563-573.
- 56 Yao H, Tian S. Effects of pre- and post-harvest application of salicylic acid or methyl jasmonate on inducing disease resistance of sweet cherry fruit in storage. *Postharvest Biology and Technology* 2005; 35:253-262.
- 57 Marzouk HA, Kassem HA. Improving yield, quality, and shelf life of Thompson seedless grapevine by preharvest foliar applications. *Scientia Horticulturae* 2011; 130:425-430.
- 58 Xuan H, Streif J, Pfeffer H, Dannel F, Römheld V, Bangerth F. Effect of pre-harvest boron application on the incidence of CA-storage related disorders in 'Conference' pears. *Journal of Horticultural Science & Biotechnology* 2001; 76:133-137.
- 59 El-Hilali F, Ait-Oubahou A, Remah A, Akhayat O. Effect of preharvest sprays of Ca and K on quality, peel pitting and peroxidases activity of 'Fortune' mandarin fruit in low temperature storage. *Acta Horticulturae*

- 2004: 632:309-315.
- 60 Meng X, Li B, Liu J, Tian S. Physiological responses and quality attributes of table grape fruit to chitosan preharvest spray and postharvest coating during storage. *Food Chemistry* 2008: 106:501-508.
  - 61 Meng X, Tian S. Effects of preharvest application of antagonistic yeast combined with chitosan on decay and quality of harvested table grape fruit. *Journal of the Science of Food and Agriculture* 2009: 89:1838-1842.
  - 62 Yan J, Cao J, Jiang W, Zhao Y. Effects of preharvest oligochitosan sprays on postharvest fungal diseases, storage quality, and defense responses in jujube (*Zizyphus jujube* Mill. cv. Dongzao) fruit. *Scientia Horticulturae* 2012: 142:196-204.
  - 63 Xuan H, Streif J. Effect of pre- and postharvest applications of 'Biofresh' coating on keepability of apple fruits. *Acta Horticulturae* 2000: 513:483-492.
  - 64 Tixier P, Bugaud C, Duguet R, Salmon F. Effect of preharvest and postharvest application of calcium on banana green-life. *Fruits* 2010: 65:201-208.
  - 65 Hanson EJ. Preharvest calcium sprays do not improve highbush blueberry (*Vaccinium corymbosum* L.) quality. *HortScience* 1995: 30:977-978.
  - 66 Schirra M, Barbera G, D'hallewin G, Inglese P, La Mantia T. Storage response of cactus pear fruit to CaCl<sub>2</sub> preharvest spray and postharvest heat treatment. *Journal of Horticultural Science* 1997: 72:371-377.
  - 67 Gerasopoulos D, Chouliaras V, Lionakis S. Effects of preharvest calcium chloride sprays on maturity and storability of Hayward kiwifruit. *Postharvest Biology and Technology* 1996: 7:65-72.
  - 68 Boyd LM, Ferguson IB, Thorp TG, De Silva N, Mowat AD, Barnett AM. Determining the relationship between fruit nutrient status and the development of physiological pitting in kiwifruit. *Acta Horticulturae* 2006: 721:279-284.
  - 69 Cronje RB, Sivakumar D, Mostert PG, Korsten L. Effect of different preharvest treatment regimes on fruit quality of litchi cultivar 'Mauritius'. *Journal of Plant Nutrition* 2009: 32:19-29.
  - 70 Gerasopoulos D, Richardson DG. Effects of exogenous propylene and fruit calcium on ripening of non-chilled and chilled Anjou pears. *Postharvest Biology and Technology* 1996: 8:111-120.
  - 71 Vangdal E, Børve J. Pre- and postharvest Ca-treatment of plums (*Prunus domestica* L.). *Acta Horticulturae* 2002: 577:125-128.
  - 72 Naradisorn M, Klieber A, Sedgley M, Scott E. Effect of preharvest calcium application on grey mould development and postharvest quality in strawberries. *Acta Horticulturae* 2006: 708:147-150.
  - 73 Bonomelli C, Ruiz R. Effects of foliar and soil calcium application on yield and quality of table grape cv. 'Thompson Seedless'. *Journal of Plant Nutrition* 2010: 33:299-314.
  - 74 Argenta LC, Vieira MJ, Krammes JG, Petri JL, Basso C. AVG and 1-MCP effects on maturity and quality of apple fruit at harvest and after storage. *Acta Horticulturae* 2006: 727:495-504.
  - 75 Robinson TL, Watkins CB, Hoying SA, Nock JF, Iungerman KI. Aminoethoxyvinylglycine and 1-methylcyclopropene effects on 'McIntosh' preharvest drop, fruit maturation and fruit quality after storage. *Acta Horticulturae* 2006: 727:473-480.
  - 76 Whale SK, Singh Z, Behboudian MH, Janes J, Dhaliwal SS. Fruit quality in 'Cripp's Pink' apple, especially colour, as affected by preharvest sprays of aminoethoxyvinylglycine and ethephon. *Scientia Horticulturae* 2008: 115:342-351.
  - 77 Amarante CVT, Steffens CA. Preharvest treatment with aminoethoxyvinylglycine, in association with ethylene absorption during cold storage preserves fruit quality of 'Gala' apples. *Revista Brasileira de Fruticultura* 2009: 31:334-342.
  - 78 Steffens CA, Amarante CVT, Chechi R, Silveira JPG, Brackmann A. Preharvest spraying with plant regulators aiming at fruit maturity delay of 'Laetitia' plums. *Ciência Rural* 2009: 39:1369-1373.
  - 79 Steffens CA, Amarante CVT, Chechi R, Silveira JPG, Corrêa TR. Maturation and postharvest quality of 'Laetitia' plums with preharvest treatment of AVG and GA<sub>3</sub>. *Revista Brasileira de Fruticultura* 2011: 33:21-31.
  - 80 Mitcham EJ, McDonald RE. Changes in grapefruit flavedo cell wall non-cellulosic neutral sugar composition. *Phytochemistry* 1993: 34:1235-1239.
  - 81 McDonald RE, Greany PD, Shaw PE, McCollum TG. Preharvest applications of gibberellic acid delay senescence of Florida grapefruit. *Journal of Horticultural Science* 1997: 72:461-468.
  - 82 Porat R, Feng X, Huberman M, Galili D, Goren R, Goldschmidt EE. Gibberellic acid slows postharvest degreening of 'Oroblanco' citrus fruits. *HortScience* 2001: 36:937-940.
  - 83 Ritenour MA, Burton MS, McCollum TG. Effects of pre- or postharvest gibberellic acid application on storage quality of Florida 'Fallglo' tangerines and 'Ruby' red grapefruit. *Proceedings of the Florida State Horticultural Society* 2005: 118:385-388.
  - 84 Lurie S, Weksler A. Optimizing short term storage of sour cherries. *Acta Horticulturae* 2008: 795:799-803.
  - 85 Horvitz S, Godoy C, López-Camelo AF, Yommi A. Application of gibberellic acid to 'Sweetheart' sweet cherries: effects of fruit quality at harvest and during cold storage. *Acta Horticulturae* 2003: 628:311-316.
  - 86 Canli FA, Orhan H. Effects of preharvest gibberellic acid applications on fruit quality of '0900 Ziraat' sweet cherry. *HortTechnology* 2009: 19:127-129.
  - 87 Malik AU, Singh Z, Dhaliwal SS. Exogenous application of putrescine affects mango fruit quality and shelf life. *Acta Horticulturae* 2003: 628:121-127.
  - 88 Khan AS, Singh Z. Influence of pre and postharvest applications of putrescine on ethylene production, storage life and quality of 'Angelino' plum. *Acta Horticulturae* 2008: 768:125-133.