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REVIEW

Foliar Calcium Applications for Controlling Fruit Disorders and Storage Life in Deciduous Fruit Trees

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Abstract

Calcium is involved in several disorders and influences the storage life of different fruit species. Moreover, applying preharvest foliar Ca spray is a standard practice to control fruit Ca concentration in certain deciduous fruit trees. Conversely, the effects of foliar Ca spray on the Ca concentration in fruit and the incidence of disorder are sometimes inconsistent. This article provides an overview of recent works on foliar Ca application and discusses Ca application inconsistencies. Foliar Ca sprays reduced bitter pit, enhanced fruit firmness and storage time, and sometimes reduced the incidence of brown rot during storage in apples; reduced internal browning during storage and the incidence of brown rot in peaches; decreased postharvest decay and cork spot in pears; and increased shelf life in grapes. Experiments using ^{45}Ca or isolated cuticular revealed the effects of fruit growth stages, atmospheric conditions, and adjuvants on Ca penetration. Finally, three possible reasons for inconsistencies of foliar Ca application are discussed.

Disciplines: Soils, fertilizers, and plant nutrition
Additional key words: adjuvant, calcium chloride

Introduction

Calcium is involved in several disorders and is a factor affecting the storage life for fruit of different species, given its importance in stabilizing cell walls and membranes. The occurrence of bitter pit (BP) in apples is a typical Ca-related disorder. Ca translocates into fruit mainly through the xylem, and its concentration continues to decrease as the fruit develops, bottoming out at the ripening stage. Increasing the Ca concentration in fruit is an effective way to control disorders, although the soil application of Ca is known to be ineffective in increasing fruit Ca concentration in most cases. Apple orchards often display calcium deficiencies, despite sufficient calcium in the soil and plant[39]. Although Ca is the most abundant exchangeable cation in calcareous soils, the amount of Ca partitioned into fruit is relatively low[10]. In addition, soil calcium application is ineffective in improving fruit Ca nutrition and reducing the occurrence of BP[23]. Therefore, for certain fruit trees, preharvest foliar Ca spray is a common practice in controlling fruit Ca concentration. However, the effects of foliar Ca spray on Ca concentration and the incidence of disorder in fruit are sometimes inconsistent. Moreover, Ca concentration in fruit is not always correlated to the incidence of disorder[29]. Ca uptake and the incidence of disorder were affected by Ca application methods, e.g. the timing, rate and source of Ca application, and adjuvant types. These factors have been examined in various fruit, mainly apples. Controlling the fruit Ca concentration has long been evaluated and reviewed[13,29]. Recently, De Freitas and Mitcham[9] provided new evidence suggesting that abnormal cellular Ca^{2+} partitioning caused Ca deficiency. This article provides an overview of recent works on foliar Ca application and discusses Ca application inconsistencies.

Practical foliar Ca applications

1. Apples

In apples, the effects of foliar Ca application for reducing BP, enhancing fruit firmness and storage length, and sometimes reducing the incidence of brown rot during storage were evaluated. Holb et al.[16] showed that sev-

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en or eight applications of calcium chloride ($CaCl_2$) spray decreased the incidence of brown rot during storage.

The suitable stage at which foliar Ca application reduces BP has been evaluated. Benavides et al.[2] showed that the most effective results for increasing Ca concentration in apples were attained when Ca was applied six times at 15-day intervals, starting from 60 days after full bloom. Conversely, the application of foliar calcium nitrate ($Ca(NO_3)_2$) during midseason (from 40 days after full bloom (DAFB)) was shown to be more effective in increasing fruit Ca content and reducing BP than a later application for apples under South African conditions[18]. Since the penetration rate was high in the early fruit development stages (before the June drop) and decreased rapidly in the late stages[30], foliar Ca sprays in the early season were also assessed. Ca sprays earlier in the growing season remained unchanged the fruit Ca concentration compared to a control without Ca spray and had less effect than spraying during mid- or late season, but BP incidence decreased with Ca treatment, including early spray treatment[24]. Neilsen et al.[23] also showed that sprays of $CaCl_2$ in the early growing season were as effective as those in late season for reducing BP, despite the low Ca concentration in the harvested fruit. The reason early season Ca spray reduces BP despite the low fruit Ca concentration is unclear.

Many studies showed the efficiency of foliar Ca^{2+} sprays as nitrate and chloride, but there is less information on the effects of foliar sprays of Ca^{2+} as calcium carbonate ($CaCO_3$). Guerra et al.[15] used $CaCO_3$ as organic production and confirmed that preharvest foliar treatments of $CaCO_3$ decreased BP incidence only after 90 days of storage, but that the fruit Ca concentration remained unchanged.

Foliar Ca application also affected the K, Mg and N concentrations in fruit[6,15], while eight-time foliar Ca sprays decreased the K concentration and K/Ca ratio of fruit skin[15]. Six- or twelve-time Ca sprays decreased the N/Ca, K/Ca, (K+Mg)/Ca ratios in fruit, hence the conclusion that these ratios reflected the effects of Ca application better than the fruit Ca concentration[6].

Except for BP, foliar Ca application improved fruit firmness and helped improve its quality and shelf life[10]. Foliar Ca application enhanced the red skin color, juiciness, texture, and firmness of fruit[26]. Conversely, effects on fruit quality such as total soluble solids (TSS), titratable acidity, and fruit weight, remained unchanged when the foliar $CaCO_3$[15] spray was applied.

2. Peaches and apricots

In peaches, foliar Ca applications are often conducted to reduce internal browning during storage and the incidence of brown rot. Val and Fernández[38] showed that fruit Ca concentration decreased over the growing season, while four or five applications of $CaCl_2$ spray increased mesocarp Ca concentration only in June during the pit-hardening period. The Ca application did not increase mesocarp Ca concentration at harvest (September), but decreased internal browning after two weeks of cold storage. $CaCl_2$ was more effective than Ca propionate, although Ca propionate showed less leaf burn than $CaCl_2$ when sprayed at the same rate.

Brown rot caused by pathogens, such as *Monilinia fructicola* (G. Wint.) Honey, is a major fungal disease affecting all commercially grown *Prunus* spp. in most global regions, which can result in extensive crop losses[1]. Ca foliar spray has been widely adopted by stone fruit growers in New Zealand as a practical tool to reduce brown rot losses. Elmer et al.[11] focused on $CaCl_2$, since the nitrate form has the potential to encourage more vigorous shoot growth and divert xylem calcium away from fruit. Foliar Ca sprays started from two to three months before harvest at two-weekly intervals and for six times in total, increased epidermis Ca concentration by at least 50%, increased the fruit Ca concentration, and reduced the occurrence and severity of brown rot. $CaCl_2$ sprays were more effective than those of an ethylenediamine tetraacetic acid (EDTA)-chelated calcium[19]. Calcium concentration increased in the fruit's peel (25-42%) and flesh (11-17%), the increase corresponded to the calcium concentration in the insoluble pectin fraction but not the soluble pectin fraction[19]. Manganaris et al.[19] concluded that preharvest calcium spray seems effective in decreasing the susceptibility of peaches to brown rot. Additionally, Biggs et al.[3] tested the direct effects of several calcium salts on the growth of *Monilinia fructicola* and showed that calcium propionate strongly inhibited the growth on a medium. They also found that applications of calcium oxide and calcium hydroxide along with an inoculum for fruit inhibited brown rot severity.

As for fruit quality, Ca propionate spray decreased TSS within a year during a two-year test, but it remained unchanged with $CaCl_2$[38]. In another case, the foliar application of Ca did not alter TSS in peaches[33].

In apricots, foliar sprays of 0.5-0.8% $CaCl_2$ applied twice or three times before harvest increased the Ca concentration of fruit flesh by 30-76%, enhanced its firmness, and decreased ethylene production and respiration[36].

3. Pears

In pears, foliar Ca applications decreased postharvest decay and cork spot[25,27]. Three foliar applications of $CaCl_2$ at two-week intervals from mid-July boosted the effects of postharvest fungicides and reduced the postharvest decay of pears[34]. The efficiency of the postharvest fungicide treatments against postharvest decay declined with increasing duration between harvest and fungicide treatment, while preharvest $CaCl_2$ spray also reduced decay incidence due to delayed postharvest fungicide treatments[34]. Five applications of Ca spray throughout the fruit-growing season controlled cork spot more effectively than three applications during the early or late fruit-growing period[25]. Foliar $CaCl_2$ spray showed constant effects of improving fruit Ca concentration and controlling cork spot compared to several other Ca materials, such as calcium nitrate, various Ca chelates, and other materials containing calcium sulfate or calcium-boron combinations[25]. Dry forms of $CaCl_2$ foliar spraying products also increased fruit Ca at a high rate and reduced fruit disorders without spray markings on the fruit[27].

4. Grapes

In grapes, the effect of Ca spray on fruit storage life was evaluated. Spraying $CaCl_2$ twice or three times before veraison increased the Ca concentration of grape berries and improved flesh firmness and berry breaking force[7]. During storage, the spray also reduced rot caused by gray mold (*Botrytis cinerea* Pers.), which is the most economically important postharvest disease of grapes[7]. Foliar sprays of $CaCl_2$ twice at the pea and veraison stages of berry development improved the berry firmness, shelf life, and fruit quality of grapes[20], whereas Ca application after veraison was less effective in improving berry Ca concentration and fruit quality during storage[7]. A contradictory result was also shown; foliar and soil applications of $CaCl_2$ had no effect on leaf or fruit Ca concentration, yield, and berry sugar concentration[5].

Physical characteristics of Ca for penetration

For effective foliar Ca application, the physical characteristics of calcium salts can reveal significant information. Detailed experiments on the absorbance of sprayed Ca were conducted using ^{45}Ca as a tracer or isolated cuticular. Sprayed ^{45}Ca penetrated 40 to 70% into fruit within 48 hours, and a one-time application of 1% $CaCl_2$ spray was calculated to increase the total concentration of Ca in mature apple fruit by 1 mg per kg of fruit weight[21]. Ca sprayed in the early season increased Ca concentration in the peel, flesh, core, and seeds of apple at harvest, whereas late treatments mainly increased concentration in the peel and flesh[22]. The penetration of Ca decreased considerably during the growing period in apple; however the simultaneous increase in total fruit surface meant the total calcium uptake by fruit initially increased, peaking in late June and July[21]. Schlegel and Schönherr[30] also showed that penetration rates of $CaCl_2$ were affected by the fruit development stage in apples; the penetration rate was high in the early fruit development stages (before the June drop) and decreased rapidly in the late stages (after the June drop) when the trichomes had vanished and most stomata developed into lenticels.

As for the effects of humidity and temperature, Schönherr[32] evaluated the effects of physical characteristics of various calcium salts on the penetration of the pear leaf cuticular and indicated important results. He showed that the salt residue on the cuticle dissolved when humidity exceeded the point of deliquescence (POD); and below the POD, a solid residue formed and penetration ceased. $CaCl_2$ and $Ca(NO_3)_2$ have PODs of 32 and 55%, respectively, while the PODs of organic calcium salts (acetate, lactate, and propionate) were between 95 and 100%. He also showed that the aqueous solubility of inorganic calcium salts is one to two orders of magnitude higher than that of organic salt, meaning organic calcium salts are poorly suited for foliar nutrition, since PODs are very high and the driving forces of penetration are low due to low solubility, even at 100% humidity. When humidity exceeded POD, the rate constants of penetration rose with increasing humidity. Moreover, since the temperature did not affect the rate constants of penetration[31], penetration is thought to be most rapid overnight when humidity is high[32]. Conversely, Michalczuk and Kubik[21] showed that changes in relative air humidity from 60 to 90% did not affect the uptake of $^{45}CaCl_2$ into apple fruit. As for the humidity effects, the former result[32] was obtained from the cuticular membranes of the pear leaf, while the later one[21] was from the fruit of apple and these differences may cause inconsistent results.

As for the effects of adjuvants, the study of $^{45}CaCl_2$ confirmed that a decrease in the surface tension of the solution by adding a surfactant increased the calcium penetration[21]. Schönherr[31] showed that adding small amounts of wetting agents increased the rate constants of penetration almost 10 times and explained that wetting agents doubled the area of the salt residue and improved contact between salt solutions and the micro-relief of epicuticular. Adding rapeseed oil as a surfactant to $CaCl_2$ or calcium acetate ($Ca(CH_3COO)_2$) enhanced droplet spreading, which meant a greater area covered by Ca within the droplet residues, and increased penetration through isolated cuticular membranes of apple leaves[17]. Adding sodium salt of carboxymethyl ether of cellulose (0.5%, CMC, used as a food additive) as an adjuvant for Ca spray, meanwhile, increased the retention of Ca-containing solutions by the apple skin and prolonged the drying process of the solution at room temperature[4]. In Spain, peach fruit are bagged to avoid damage caused by the Mediterranean fruit fly (*Ceratitis capitata* Wied.); therefore, Ca spray does not reach the fruit directly. The application of Ca-containing gels to the fruit surface before fruit bagging increased fruit Ca concentration and shelf life with no phytotoxic effects on the fruit[14].

In another approach to evaluate Ca absorption, Rosen et al.[28] used strontium (Sr), which is an element with chemical properties resembling those of Ca, as a tracer for foliar and fruit applications of Ca. The results revealed that about 11 to 17% of the Sr in the fruit came from Sr applied directly to the leaves, and eight spray applications over the growing season more than doubled both the concentration and content of fruit Sr compared with four late-season sprays. The tested adjuvant also doubled Sr absorption.

Possible reasons for inconsistencies of foliar Ca application

The effects of foliar Ca application sometimes show inconsistencies for fruit Ca concentration and the incidence of disorder. For example, weekly foliar applications of Ca in the early fruit developmental period (from 21 - 70 DAFB) increased Ca concentration in fruitlets at 80 DAFB and in leaves in only the final year of a three-year treatment[39]. There are three possible reasons for inconsistencies of Ca treatments: (1) atmospheric effects of Ca absorption, (2) uneven distribution of Ca in fruit within a canopy, (3) condition and management of a tree.

First, as for the atmospheric effects, Val et al.[37] indicated that the effectiveness of Ca sprays is influenced by environmental conditions, particularly relative air humidity. In areas of high temperatures and low relative air humidity, Ca treatment is not very effective and gives inconsistent results. The effects of Ca spray under such conditions in Spain increased Ca concentration in the skin but not the flesh of apples. BP remained unchanged, although the $CaCl_2$ rate was as high as 1%[37].

Second, as for uneven distribution of Ca in fruit within a canopy, Wojcik[40] showed that foliar sprays of $CaCl_2$ did not increase Ca concentration in fruit at the top of the tree, although the Ca concentrations of fruit at the middle and bottom of the tree respectively increased. He suggested this may be attributable to high evaporation of fruit due to the high temperature of the fruit at the top of the canopy. Additionally, inappropriate sampling methods due to the significant variation of Ca among individual fruit were also indicated in kiwifruit[12]. In evergreen fruit trees, Cronje et al.[8] showed that the canopy position influenced mineral nutrient accumulation patterns in the flavedo of mandarins. Outside fruit flavedo accumulated higher concentrations of Ca and Mg, but inside fruit flavedo (shaded fruit) accumulated higher levels of K compared with outside fruit flavedo.

Third, as for the condition and management of a tree, fruit Ca concentration is affected by fruit size. Here, influential factors, such as tree vigor, soil management, climatic conditions, and thinning, affect fruit Ca concentration via changes in fruit size. Telias et al.[35] showed that thinning reduced fruit Ca concentration via increasing fruit size and mentioned that the Ca content in the whole fruit was relevant in determining BP development. Comparing the Ca concentrations of similar-sized fruit in each treatment would also be useful to distinguish the respective effects of Ca accumulation by treatment.

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