ROLE OF CALCIUM IN PROLONGING STORAGE LIFE OF FRUITS AND VEGETABLES

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CALCIUM HAS RECEIVED considerable attention in recent years because of its desirable effects in delaying senescence and controlling physiological disorders in fruits and vegetables. For fruits and vegetables to function and adapt efficiently to different environmental conditions, their cells must communicate with one another. It is becoming increasingly evident that calcium ions are important intracellular messengers in plants. Changes in cell wall structure, membrane permeability, and enzyme activation are known to influence various aspects of cell physiology. Since the recent discovery of calmodulin, it has become clear that the calcium messages are often relayed by this ubiquitous calcium-binding protein (Cheung, 1980; Pooverah, 1985). Recent experimental evidence suggests that certain cell functions are regulated, in part, by calcium and calmodulin.

Studies on leaf senescence (Pooverah and Leopold, 1973; Ferguson, 1984) and fruit ripening (Tingwa and Young, 1974; Pooverah, 1979a; Suwann and Pooverah, 1978) have indicated that the rate of senescence often depends on the calcium status of the tissue and that by increasing calcium levels, various parameters of senescence such as respiration (Faust and Shear, 1972; Bangert et al., 1972), protein and chlorophyll content (Pooverah and Leopold, 1973), and membrane fluidity (Paliyah et al., 1984) are altered. Recently, we have used the fluorescence polarization of 1,6-diphenyl-1,3,5-hexatriene (DPH) as a deep membrane probe to examine the fluid properties of membranes from calcium-treated and nontreated apples (Paliyah et al., 1984). Our results indicate that a postharvest calcium treatment reduces the senescence-associated increase in microviscosity of apple membranes. Therefore, it appears that the effect of calcium in delaying senescence is partly due to reductions in microviscosity of membranes associated with senescence.

Control of Physiological Disorders

It is well known that calcium plays an important role in maintaining quality of fruits and vegetables (Shear, 1975; Bangert, 1979; Hopfinger and Pooverah, 1979; Artefa et al., 1980; Collier and Tibbits, 1982; Huber, 1983). For example, in apples, calcium treatments help to retain fruit firmness (Table 1), increase vitamin C content (Fig. 1), reduce carbon dioxide and ethylene evolution (Fig. 2), and decrease storage breakdown and rot (Conway and Sams, 1984). Calcium also decreases browning in apples (Hopfinger et al., 1984).

Even though numerous investigations have been carried out in many parts of the world, physiological disorders still remain a major cause of fruit and vegetable wastage. Many physiological disorders affecting fruits and vegetables are known to be related to the calcium content of the tissue. Increasing the calcium level normally decreases the incidence of the disorder. Apples constitute about 20% of the fruit consumed by Americans. One of the most common calcium-related physiological disorders in apples is bitter pit (Fig. 3). This disorder is particularly troublesome because it appears during both storage and shipping, thus making the fruits unsalable after they arrive at the market.

Calcium is essential for structure and function of cell walls and membranes. There are three types of evidence for the role of calcium in membranes. First, under calcium-deficient conditions, there is a profound deterioration of membranes

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Peel (ppm)</th>
<th>Flesh (ppm)</th>
<th>Fruit firmness (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>890</td>
<td>190</td>
<td>12.20</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>1,442</td>
<td>287</td>
<td>13.27</td>
</tr>
<tr>
<td>350 mm Hg</td>
<td>1,642</td>
<td>359</td>
<td>14.72</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>1,642</td>
<td>359</td>
<td>14.72</td>
</tr>
</tbody>
</table>

*Mean values in the same column followed by different letters are significantly different at the 5% level by Duncan's multiple range test.

Second, calcium alters the actual architecture of membranes; its introduction into natural (Paliyah et al., 1984) or artificial membranes of phospholipids (Gary Bobo, 1970) results in an enormous change in fluidity and water permeability. Third, calcium can powerfully alter an array of physiological activities which are specifically associated with the membrane function; e.g., it can turn on the active transport of some ions through membranes (Hanson, 1983).

Calcium plays a special role in maintaining the cell wall structure in fruits and other storage organs by interacting with the pectic acid in the cell walls to form calcium pectate. Thus, fruits treated with calcium are generally firmer than controls (Table 1). A simplified scheme summarizing the role of calcium in maintaining the cell wall structure and membrane integrity is shown in Figure 4.

Protein Phosphorylation and Cellular Control

In recent years, major interest has been directed toward post-translational modification of proteins by calcium-regulated protein phosphorylation in plants and animals (Trewayas, 1976; Cohen, 1982; Hetherington and Trewayas, 1982; Paliyah and Pooverah, 1984; 1985a; b; Veluthambi and Pooverah, 1984a; b). The role of protein kinases in phosphorylation and phosphatases in dephosphorylation has been clearly demonstrated (Cohen, 1982; Veluthambi and Pooverah, 1984b). Reversible protein phosphorylation offers a unique advantage in cellular regulation, since an enzyme activated after phosphorylation by a protein kinase can be inactivated as a result of dephosphorylation by a phosphatase. It is becoming clear that protein kinases play a major role in calcium-regulated cell function.

An example of calcium-dependent protein phosphorylation in mature and ripening tomatoes is shown in Figure 5. Phosphorylation of many soluble polypeptides is promoted...
Fig. 1 (above)—Effect of Calcium Infiltration on Ascorbic Acid Content in Golden Delicious apple fruit. Fruits were vacuum infiltrated with calcium soon after harvest and stored at 0°C prior to analysis.

Fig. 2 (above)—Effect of Calcium Infiltration on Ethylene and Carbon Dioxide Evolution in Golden Delicious apples. The apples were vacuum infiltrated with 3-4% CaCl₂ soon after harvest, stored at 0°C for about 3 mo and brought to 20°C to accelerate senescence.

Fig. 3—Symptoms of Bitter Pit in Golden Delicious and Red Delicious apples. This is a typical example of a calcium-related physiological disorder. Symptoms generally appear predominantly on the calyx end of the fruit (left), while the stem end of the same fruit (right) is free of the disorder.

Fig. 4 (at left)—How Calcium Deficiency may lead to physiological disorders in fruits and vegetables.
Role of Calcium (continued)

by calcium in immature fruits, whereas calcium-dependent phosphorylation decreases dramatically as soon as the fruits start to ripen. This suggests the presence of stage-specific changes in calcium-regulated protein phosphorylation in fruits.

Postharvest Treatments

The common method for prolonging storage life of fruits and vegetables is cold storage. Low temperature decreases respiration and retards ripening and senescence. However, it is not always practical to use cold storage. For example, in most developing countries, little or no refrigeration is used during storage and shipping of fruits and vegetables to markets. Even in developed countries, produce awaiting processing may be held for some time at ambient temperatures. In these instances, postharvest treatment with calcium chloride may prove to be beneficial.

Various postharvest calcium treatment methods are being studied to increase the calcium content of fruits and vegetables. Postharvest dipping or vacuum or pressure infiltration of produce in calcium chloride solution is effective in increasing the calcium content of the tissue (Scott and Wills, 1975; Poovaiah et al., 1978; Poovaiah, 1979b; 1980; Poovaiah and Moulton, 1982; Drake and Spady, 1983; Paliyath et al., 1984). A mobile fruit-treatment unit capable of vacuum or pressure infiltration of calcium is shown in Figure 6. The process first requires thorough washing of the produce, either in plain water or in a suitable active substance, to remove surface dust and residues. The amount of calcium uptake is controlled by: (1) the calcium concentration in the solution, (2) the degree of vacuum or pressure applied, (3) how long the produce is submerged in the solution, and (4) the temperature of the solution. The design shown in Figure 6 is good for fruits and vegetables with porous skins, such as apples.

Prospects Are Promising

Since there is now considerable evidence that the rate of senescence of fruits and vegetables is influenced by the calcium content of the tissue, we may be able, as postharvest technology develops, to efficiently manipulate calcium responses to suit our needs. Though various roles of calcium in cell function have been studied extensively in recent years, the mechanism of calcium action at the molecular level is just beginning to be unraveled. Undoubtedly, our capability to manipulate calcium effects in postharvest systems will be enhanced as the understanding of calcium action advances in the future. The prospects are promising.

References


Cohen, P. 1982. The role of protein phosphorylation in neural and

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Fig. 6 (above) — Mobile Calcium Infiltration Unit (side view). Food-grade CaCl₂ solution (2.4%) is prepared in the holding tank (at left). After fruits are thoroughly washed, the bin is pushed over the roller conveyor into the treatment tank (at right). The door is then closed, and the centrifugal pump is turned on to pump calcium solution from the holding tank into the treatment tank. Desired pressure or vacuum or a combination of vacuum followed by pressure is applied as needed. After the treatment, the calcium solution is pumped back into the holding tank, and the fruits are quickly rinsed in water and stored.

Fig. 5 (at left) — Autoradiograph Showing the Effect of Calcium on Phosphorylation of soluble polypeptides from mature tomatoes. A) 40 days after anthesis and ripening and B) 50 days after anthesis. Protein phosphorylation was carried out as reported by Veluthambi and Poovaiah (1984a, b) using [γ-³²P] ATP. In vitro phosphorylations were performed in the presence (0.2 mM EGTA and 0.2 mM CaCl₂) or absence (0.2 mM EGTA) of calcium.

Based on a paper presented during the IFT Fruit and Vegetable Products Technology Group symposium, “Postharvest Storage of Fruits and Vegetables as Related to Processing Quality,” at the 45th Annual Meeting of the Institute of Food Technologists, Atlanta, Ga., June 9-12, 1985.


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Postharvest Treatment (continued from page 80)

Handling of Fruit and Vegetables." AVI Pub. Co., Westport, CT.


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