Additive Effects of Controlled-Atmosphere Storage and Calcium Chloride on Decay, Firmness Retention, and Ethylene Production in Apples

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ABSTRACT

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After 3 mo in 0 C normal-atmosphere storage, Golden Delicious apples pressure-infiltrated with $CaCl_2$ were 7–15% firmer and had 20–35% less decay than the control fruit not treated with $CaCl_2$. When stored in 3% O_2/2% CO_2 or in 1% O_2/0% CO_2 controlled-atmosphere, noninfiltrated fruit were 26 and 43% firmer and had 51 and 58% less decay, respectively, than the control. Fruit treated with 4% $CaCl_2$ and held at 3% O_2/2% CO_2 or at 1% O_2/0% CO_2 were 43 and 46% firmer and had 71 and 73% less decay, respectively, than the control. All treatments resulted in decreased ethylene production, but the 4% $CaCl_2$-treated fruit stored at 0 C plus 7 days at 20 C in the two atmospheres had 30–50% lower ethylene production rates than the 4% $CaCl_2$-treated fruit stored in normal atmosphere.

Controlled-atmosphere (CA) storage has been found effective in delaying the onset of storage disorders in apples (12). Softening, bitter pit, and internal breakdown have been significantly reduced in CA storage. The effect of CA on growth and development of various decay-causing fungi, including *Penicillium expansum* Link: Thom, is variable and temperature-related (14). Another study has indicated that growth of *P. expansum* on apples at 4 C is retarded under CA conditions of 3% O_2/5% CO_2 but only slightly retarded when held in an atmosphere of 3% O_2/0% CO_2 (2). Also, the development of decay caused by *P. expansum* is much more effectively inhibited in CA than in normal cold storage (8,10).

Storage in low-O_2 levels has been shown to delay the onset of fruit storage problems; however, a minimum of 1–3% O_2, depending on the commodity, is required to avoid a shift from aerobic to anaerobic respiration (7). At 1% O_2, concentrations must be controlled within ±0.1%, and apples must be cooled to 4 C before establishing the low-O_2 atmosphere to avoid anaerobic respiration (9). Low-O_2 effects on decay also depends on the particular host-pathogen interaction involved (6).

Previous research comparing the effectiveness of postharvest calcium treatment and CA (either 3% O_2/2% CO_2 or 1% O_2/0% CO_2) in reducing decay of apples caused by *P. expansum* indicated that either increasing the calcium content of fruit before storage or placing them in the proper CA conditions retarded decay and maintained fruit firmness (11).

Because either CA or calcium treatments individually have a beneficial effect on various pathological and physiological problems occurring in stored fruit as shown in previous work (11), the objective of this experiment was to determine if there was an additive effect on decay, firmness, and ethylene production in Golden Delicious apples by combining CA and calcium treatments.

MATERIALS AND METHODS

Cultivar Golden Delicious apples (*Malus domestica* Borkh.) were harvested in the preclimacteric stage (as indicated by the pattern of CO_2 and ethylene production) from a commercial orchard and randomized. Initial firmness was

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91.3 newtons as determined with the Magness-Taylor pressure tester (5). These apples were divided into three lots, each of which was further divided into four sublots that were pressure-infiltrated (68.95 kPa) for 2 min with laboratory-grade USP calcium chloride ($CaCl_2$, 76%) made up as 0, 1, 2, or 4% solutions. There were 25 fruits per treatment. After treatment, the fruits were placed on Kraft paper and allowed to drain for 4 hr. All three lots of fruit were then wound-inoculated with *P. expansum* as previously described (3). After 18 hr at 0 C, the two lots of fruit to be stored in CA were placed in the appropriate chambers in the same storage room (0 C) as the third lot of fruit, which was stored under normal-atmosphere conditions. Stainless steel chambers (220 L) were used as test chambers, and the desired CA (either 3% O_2/2% CO_2 or 1% O_2/0% CO_2) conditions were established as previously described (11). The gas concentrations were monitored throughout the test and averaged 2.92% O_2 and 2.21% CO_2 in CA and 0.94% O_2 and 0% CO_2 in the low-O_2 environment.

Fruit was removed from storage after about 3 mo, when the decay lesions on untreated fruit (0% $CaCl_2$, 0 C normal-atmosphere storage) attained an average diameter of 32 mm. Apples were then rated for decay severity and firmness and analyzed for calcium content as previously described (3). Ethylene production was determined on fruit that had been treated similarly but not inoculated. Ethylene production was monitored by an automated system (13) during the 7-day period at 20 C after removal from storage. The experiment was repeated.

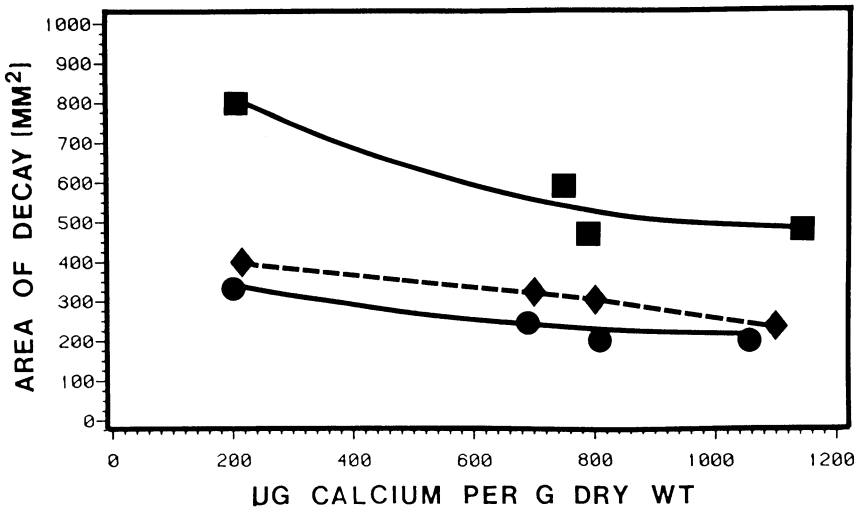

Fig. 1. Relationship between area of decay and calcium concentration of apple tissue when fruit were pressure-infiltrated with calcium chloride ($CaCl_2$) solutions. Regression curves indicate fruit placed in 0 C ambient storage (■) ($y = 979.46 - 0.890\ X + 0.000400\ X^2$, $r^2 = 0.94$), 0 C controlled-atmosphere storage with 3% O_2 and 2% CO_2 (◆) ($y = 404.50 - 0.050\ X - 0.000090\ X^2$, $r^2 = 0.99$), or 0 C controlled-atmosphere storage with 1% O_2 (●) ($y = 396.43 - 0.320\ X + 0.000100\ X^2$, $r^2 = 0.95$). Data points indicate concentrations of $CaCl_2$ solutions (0, 1, 2, or 4%) from left to right.

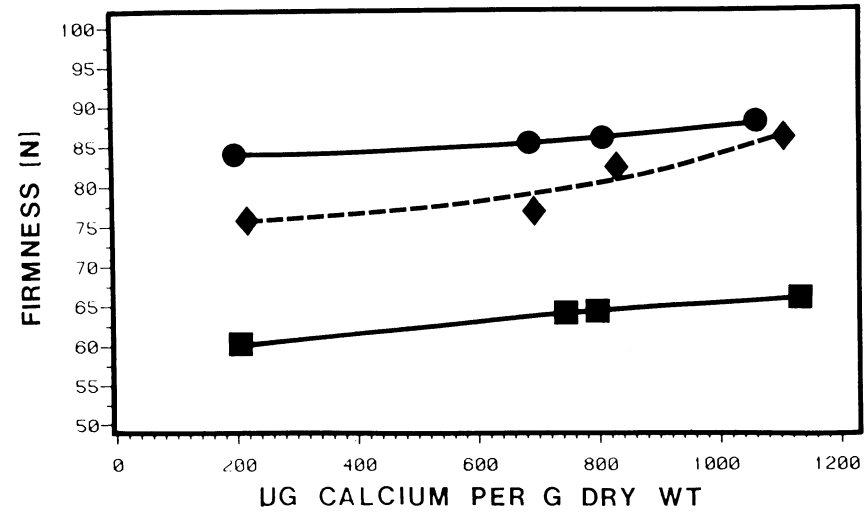

Fig. 2. Relationship between fruit firmness and calcium concentration of apple tissue when fruit were pressure-infiltrated with calcium chloride ($CaCl_2$) solutions. Regression curves indicate fruit placed in 0 C ambient storage (■) ($y = 58.12 + 0.010\ X - 0.000002\ X^2$, $r^2 = 0.95$), 0 C controlled-atmosphere storage with 3% O_2 and 2% CO_2 (◆) ($y = 77.04 - 0.009\ X + 0.000020\ X^2$, $r^2 = 0.90$), or 0 C controlled-atmosphere storage with 1% O_2 (●) ($y = 84.14 - 0.001\ X + 0.000005\ X^2$, $r^2 = 0.99$). Data points indicate concentrations of $CaCl_2$ solutions (0, 1, 2, or 4%) from left to right.

RESULTS

The combination of calcium and Ca treatments significantly decreased decay development, increased firmness, and decreased ethylene production compared with treatment with calcium of CA alone.

Fruit treated with 1 or 4% $CaCl_2$ solutions had 20 and 35% less decay, respectively, than the control (0% $CaCl_2$, 0 C normal-atmosphere storage) (Fig. 1). Fruit stored in 3% O_2/2% CO_2 and treated with 0 or 4% $CaCl_2$ solutions had 51 and 71% less decay, respectively, than the control, whereas fruit stored in 1% O_2/0% CO_2 and treated with similar $CaCl_2$ solutions had 58 and 73% less decay, respectively, than the control.

Fruit treated with 1 or 4% $CaCl_2$ solutions only were 7 and 15% firmer, respectively, than the control (Fig. 2). The 0% $CaCl_2$ solution treatments stored in 3% O_2/2% CO_2 or 1% O_2/0% CO_2 CA were 26 and 43% firmer, respectively, than the control, whereas fruit treated with 4% $CaCl_2$ solutions and held in the above CA conditions were 43 and 46% firmer than the control.

All treatments resulted in decreased ethylene production (Fig. 3). However, the 4% $CaCl_2$-treated fruit stored in 3% O_2/2% CO_2 or 1% O_2/0% CO_2 CA conditions had about 30 and 50% lower ethylene production rates (after storage at 0 C plus 7 days at 20 C) than the 4% $CaCl_2$-treated fruit stored in normal atmosphere.

The calcium content of apple flesh ranged between 200 μg/g in the untreated apples to almost 1,200 μg/g in the fruit treated with the 4% $CaCl_2$ solution (Fig. 1). These results indicate that the effect of calcium on the parameters studied is directly related to the amount taken into the fruit.

DISCUSSION

Generally, harvested fruits can show resistance to potential pathogens during much of their postharvest life. The onset of ripening and senescence in fruits, however, results in their becoming more susceptible to infection by pathogens (7). Consequently, reactions associated with ripening, which can be delayed, such as rise in respiration rate, increased ethylene production, synthesis of ripening enzymes, softening, and changes of pectic substances in the cell wall, should also delay the time at which fruit becomes more susceptible to decay, thus prolonging storage life.

Increasing the calcium content of fruit before storage, as well as storing fruit under CA conditions, tends to delay the onset of many of those parameters associated with fruit ripening, thus delaying senescence and prolonging a more resistant condition in the fruit. Fruit firmness was maintained and decay development was retarded by increasing calcium concentration in apples or by CA storage (11). This study shows that combining the two treatments can result in an even greater reduction in decay and better firmness maintenance than CA or calcium treatments alone.

Calcium reduces decay by delaying senescence, mainly by stabilizing the cell wall and maintaining fruit firmness, and conferring resistance to the macerating action of fungal enzymes (1). CA storage affects both the pathogen and the host. Decay development is retarded because growth, sporulation, and enzyme activity of the pathogen is reduced, and the improved physiological condition of the host enables it to resist decay more effectively. This condition is achieved in part by the decrease in ethylene production and decreased sensitivity to ethylene by the host. The decrease in the area of decay as a result of these treatments would have been greater had a more realistic inoculum concentration been used, as shown by a recent study (4). This study (4) has concluded that as the calcium content of apple increased and the inoculum concentration decreased, the amount of decay decreased. The results indicate that as the inoculum concentration decreases, the relative effectiveness of increased calcium in reducing decay development increases. Because few fungicides are being developed specifically for postharvest application, and those that are being used have become less effective because of the presence of resistant strains of the target pathogen, postharvest calcium treatment of apples before placing them in CA storage may help reduce losses. Increasing the calcium concentration of host tissues has the additional benefit of continuing to retard the rate of decay development once the fruits are removed from storage and placed in marketing channels (11).

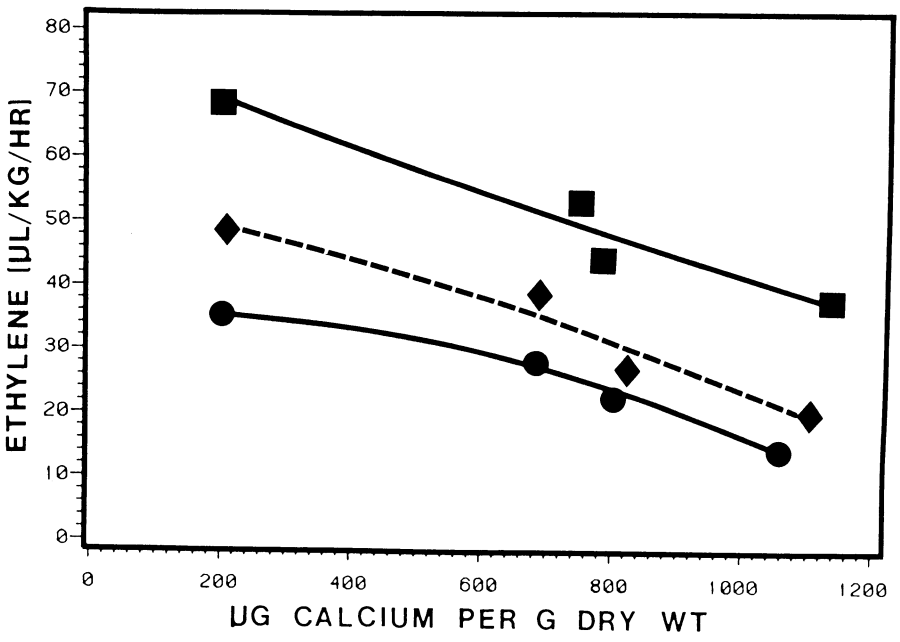

Fig. 3. Relationship between ethylene production and calcium concentration of apple tissue when fruit were pressure-infiltrated with calcium chloride ($CaCl_2$) solutions. Regression curves indicate fruit placed in 0 C ambient storage (■) ($y = 77.42 - 0.040\ X + 0.000005\ X^2$, $r^2 = 0.97$), 0 C controlled-atmosphere storage with 3% O_2 and 2% CO_2 (◆) ($y = 52.64 - 0.020\ X - 0.000010\ X^2$, $r^2 = 0.97$), or 0 C controlled-atmosphere storage with 1% O_2 (●) ($y = 35.34 + 0.003\ X + 0.000020\ X^2$, $r^2 = 0.99$). Data points indicate concentrations of $CaCl_2$ solutions (0, 1, 2, or 4%) from left to right.

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LITERATURE CITED

1. Bateman, D. F. 1964. An induced mechanism of tissue resistance to polygalacturonase in *Rhizoctonia*-infected hypocotyls of bean. Phytopathology 54:438-445.
2. Borecka, H. W. 1976. Effect of BCM fungicides on the incidence of fungi rots of apple, strawberry, and raspberry fruit, and degradation of BCM residues in fruits in CA storage. Res. Inst. Pomol., Skierniewice, Poland PL-ARS-29, FG-PO-308.
3. Conway, W. S. 1982. Effect of postharvest calcium treatment on decay of Delicious apples. Plant Dis. 66:402-403.
4. Conway, W. S., Gross, K. C., and Sams, C. E. 1986. Relationship of bound calcium and inoculum concentration to the effect of postharvest calcium treatment on decay of apples caused by *Penicillium expansum*. Plant Dis. 71:78-80.
5. Conway, W. S., and Sams, C. E. 1983. Calcium infiltration of Golden Delicious apples and its effect on decay. Phytopathology 73:1068-1071.
6. El-Goorani, M. A., and Sommer, N. F. 1981. Effects of modified atmospheres on postharvest pathogens of fruits and vegetables. Hortic. Rev. 3:412-461.
7. Kadar, A. A. 1985. Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables. Food Technol. 40:99-104.
8. Nilsson, F., Nyhlen, A., Nilsson, R., Stoy, V., and Nilson, T. 1956. Carbon dioxide storage of apples and pears, 1951-1954. J. R. Swed. Acad. Agric. 93:318-347. [Hortic. Abstr. 27:1174]
9. North, C. J., Bulb, M., and Cockburn, J. T. 1976. Storage of Cox's Orange Pippin apples in 1% oxygen. Pages 76-77 in: East Malling Annual Report, 1975.
10. Nyhlen, A., and Nilson, T. 1960. Gas storage of apples, 1954-1957. K. Skogs. Lantbruksakad. Tidskr. 99:171-211. [Hortic. Abstr. 31:2059]
11. Sams, C. E., and Conway, W. S. 1985. Effects of controlled atmosphere and calcium infiltration on decay of Delicious apples. Plant Dis. 69:747-750.
12. Smock, R. M. 1979. Controlled atmosphere storage of fruits. Hortic. Rev. 1:301-336.
13. Watada, A. E., and Massie, D. R. 1981. A compact automated system for measuring CO_2 and C_2H_4 evolution by harvested horticultural crops. HortScience 16:39-41.
14. Yackel, W. C., Nelson, A. I., Wei, L. S., and Steinberg, M. P. 1971. Effect of controlled atmosphere on growth of mold on synthetic media and fruit. Appl. Microbiol. 22:513-516.