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Effects of Postharvest Calcium and Fruit Coating Treatments on Postharvest Life, Quality Maintenance, and Fruit-surface Injury in 'Golden Delicious' Apples

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Abstract. **The effects of postharvest pressure infiltration of calcium chloride ($CaCl_2$) solutions, fruit coatings and shrink-wrap film treatments of apples (*Malus domestica* Borkh. 'Golden Delicious') on peel injury, quality attributes, respiration and internal atmospheres after storage at 0 °C for 2 to 6 months, and during subsequent ripening at 20 °C were investigated. $CaCl_2$ treatments (0.14 to 0.34 mol·L^{-1}) reduced internal and evolved ethylene and softening of fruits, but they also caused distinctive injury to the fruit surface. Following the $CaCl_2$ treatments with a water rinse and a wax- or shellac-based coating or a shrink-wrap film reduced surface injury in fruits treated with 0.24 or 0.34 mol·L^{-1} solutions of $CaCl_2$ and eliminated injury resulting from a 0.14 mol·L^{-1} $CaCl_2$ treatment. The fruit coatings delayed ripening; as indicated by better retention of fresh mass, green peel color, titratable acidity and flesh firmness, and the reduced respiration and ethylene production rates that were observed upon transferring the fruits to 20 °C. Sequential treatments with $CaCl_2$ and a shrink-wrap film also reduced fresh mass loss, respiration and ethylene production rates, but had no effect on other quality characteristics. Internal CO_2 levels increased and O_2 and ethylene levels decreased in surface coated fruits during storage at 0 °C. Coating fruits without the use of $CaCl_2$ also delayed ripening though not as well as that for fruits sequentially treated with $CaCl_2$ and a surface coating.**

Calcium, as its chloride salt, has great potential as a postharvest shelf life-extending treatment for apples. Postharvest pressure infiltration of Ca decreases the incidence of bitter pit, scald, water core, and internal breakdown (Yuen, 1994), maintains fruit firmness and quality (Lau et al., 1983; Mason et al., 1975; Sams and Conway, 1984), and reduces decay caused by postharvest pathogens (Conway et al., 1992). $CaCl_2$ is natural, inexpensive, edible and has been approved by the FDA for postharvest use. However, a major disadvantage of postharvest Ca treatments has been the inability to predict potential injury (lenticel pitting, surface discoloration) to the fruits (Conway et al., 1994; Yuen, 1994). Injury probably is a phytotoxic response to too much Ca in the fruits (Conway and Sams, 1985). At least part of the Ca-induced injury appears to be due to salt stress since the severity of the injury increases with concentration (Sharples and Johnson, 1976) and decreases when fruits are rinsed of surface Ca immediately after the Ca treatment (Scott and Wills, 1977). Ca-induced injury to apples can also be reduced, but not eliminated, by storing fruits in high humidity (Lidster et al., 1977). Recently, Ca-induced injury in mango was reduced by packaging the fruit in polymeric films that modified the atmosphere and increased the humidity in the air surrounding the fruit (Yuen et al., 1994). To our knowledge, fruit coatings and films have not been tested for their ability to protect Ca-treated apples from injury.

Coating apples with hydrophobic wax- or shellac-based emulsions or individual packaging of apples in heat-shrinkable polymeric films can extend postharvest life; enhance retention of quality attributes such as surface color, firmness, and titratable acidity; reduce moisture loss; modify concentrations of internal gases and reduce respiration and ethylene production (Anzueto and Rizvi, 1985; Smith et al., 1987). The control of fruit deterioration by application of diffusion barriers has been explained as modifications of concentrations of CO_2, O_2, ethylene and water vapors (Banks et al., 1993; Ben-Yehoshua et al., 1983). A major disadvantage of fruit coatings and films is the potential for the fruits to become anaerobic with the associated development of off-flavor (Hagenmaier and Shaw, 1992). Currently, the commercial use of fruit coatings in apples is primarily restricted to applications seeking cosmetic effects, e.g., increased gloss, and reducing transpiration losses poststorage.

The objective of this study was to examine the ability of postharvest Ca and fruit coatings to delay fruit ripening while reducing the risk of Ca-induced injury to the fruit surface.

Materials and Methods

'Golden Delicious' apples were harvested in the preclimacteric stage (ethylene production <2 pmol·kg^{-1}·s^{-1} and the climacteric rise in CO_2 production had not yet begun) from a commercial orchard and randomized. The fruit were held at 20 °C. Within 3 d after harvest, fruit were pressure infiltrated (3 min at 103 kPa) with distilled water or 0.14, 0.24, or 0.34 mol·L^{-1} solutions of $CaCl_2$•$2H_2O$ without and with 0.03 mol·L^{-1} L-malic acid/KOH, pH 4 to 6. In experiments with buffered $CaCl_2$ solutions, KCl was added as needed to maintain the K concentration constant among all treatments. Following infiltration, fruit were allowed to dry or rinsed by dipping for ≈10 s in distilled water at 20 ± 1 °C before drying. Rinsed fruit in 120-fruit sets were hand coated (0.4 mL per fruit)

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with a wax- or shellac-based microemulsion or individually packaged with a shrink-wrap film. The wax coating was prepared by Robert Hagenmaier, USDA–ARS, Winter Haven, Fla.; and has as its major ingredients, candelilla wax and water, and as its minor ingredients, oleic acid, morpholine and isopropyl alcohol. A sample of a commercially formulated shellac-based microemulsion (Apl Lustr 221) was obtained from Elf Atochem/Decco, Monrovia, Calif., and is reported to contain water, shellac, fatty acid soaps, fast-drying solvents and other minor ingredients. The shrink-wrap film was type D955, 60 gauge (0.015 mm) from Cryovac, Duncan, S.C. For shrink wrapping, fruit were individually sealed in packages of the film and then shrunk with a blast of hot air (≈80 °C for 20 s) while rotating the fruit to form a close contact with the fruit. The wrapped fruit were immediately dipped in 20 ± 1 °C water to avoid heat injury. Treated and untreated (control) fruit were then stored at 0 °C for 2, 4, or 6 months.

Ethylene production and respiration rate of 0.14 mol·L^{-1} $CaCl_2$-infiltrated and untreated fruit without and with coatings or shrink wrap were monitored every 6 h during a 7-d period at 20 °C using an automated system (Izumi et al., 1996). Three six-fruit replications were measured after 2, 4, and 6 months of cold storage. Results are reported as nmol·kg^{-1}·s^{-1} CO_2 and nmol·kg^{-1}·s^{-1} ethylene produced. At the end of each 7-d period at 20 °C, fruit cavity CO_2, O_2 and ethylene levels were determined by inserting a steel hypodermic needle into the cavity through the calyx region of individually submerged fruit, then drawing 2-mL samples with a gas-tight syringe. Gas samples from three identically treated fruit were combined and six three-fruit replications were analyzed. Percent CO_2 and O_2 were measured using a gas chromatograph (model GC-3BT; Shimadzu, Kyoto, Japan) fitted with Porapak Q and Molecular Sieve 0.5-nm columns (each ≈2 m × 3 mm) and a thermal conductivity detector. Ethylene was determined with a gas chromatograph (model AGC-211; Carle, Tulsa, Okla.) fitted with an alumina column (2 m × 3 mm) and photoionization detector.

Fresh mass loss, Ca content, injury rating, and quality attributes of firmness, peel color, and titratable acidity were determined on the same sets of treated and untreated fruit. The fresh mass of five 20-fruit replications of untreated, coated, and shrink-wrapped fruit were measured at harvest and again after 2, 4, and 6 months of cold storage. The fresh mass of shrink-wrapped fruit was determined before packaging the fruit and after removing the film after cold storage. Fresh mass loss is presented as a percentage of the initial fresh mass.

Table 1. Effects of wax- and shellac-based coatings and shrink wrap on peel injury of 'Golden Delicious' apples pressure infiltrated (3 min; 103 kPa) with distilled water or calcium chloride solutions and stored at 0 °C for 4 months.

Treatment	Internal Ca (mmol·kg^{-1}) dry mass basis	Injury rating ± SD[z]	Fruit injured[y] (%)
Untreated			
Uncoated	5.5	5.0 ± 0.1	2
Wax	5.2	5.0 ± 0.1	2
Shellac	5.2	5.0 ± 0.2	4
Shrink wrap	5.5	5.0 ± 0.0	0
Distilled H_2O			
Uncoated	4.7	2.1 ± 0.8	96
Wax	4.7	3.2 ± 0.8	66
Shellac	4.5	4.1 ± 0.7	60
Shrink wrap	5.0	4.2 ± 0.7	50
0.14 mol·L^{-1} $CaCl_2$			
Uncoated	25.0	3.5 ± 0.7	84
+ Water rinse	21.2	4.0 ± 0.5	68
Wax	22.5	5.0 ± 0.2	2
Shellac	22.2	4.9 ± 0.3	4
Shrink wrap	20.5	4.8 ± 0.5	18
0.24 mol·L^{-1} $CaCl_2$			
Uncoated	35.4	2.8 ± 0.8	98
+ Water rinse	32.4	2.9 ± 0.9	96
Wax	30.9	3.8 ± 0.5	78
Shellac	32.7	4.0 ± 0.6	60
Shrink wrap	29.9	3.3 ± 0.8	92
0.34 mol·L^{-1} $CaCl_2$			
Uncoated	46.4	1.8 ± 1.1	100
+ Water rinse	36.2	1.7 ± 1.2	98
Wax	32.7	2.4 ± 1.0	82
Shellac	38.7	2.7 ± 0.9	68
Shrink wrap	31.4	2.2 ± 0.9	94
0.14 mol·L^{-1} $CaCl_2$ + 0.03 mol·L^{-1} L-malic acid-KOH at			
pH 4.0, water rinse	---	4.0 ± 0.6	76
pH 5.0, water rinse	---	4.1 ± 0.5	72
pH 6.0, water rinse	---	4.3 ± 0.4	64

[z]Injury rating: 5 = no fruit surface injury; 3 = 10% to 25% of fruit surface injured; 1 = >50% of fruit surface injured.
[y]Percent fruit injured indicates the percent of the 50 fruit evaluated showing any sign of injury.

Fruit from each treatment were rated for injury to the fruit surface after removal from cold storage. Injury was assessed on a five-point scale based on the percentage area of the fruit surface injured. The injury ratings were as follows: 1 = >50% of fruit surface injured, 2 = 25% to 50% of fruit surface injured, 3 = 10% to 25% of fruit surface injured, 4 = fruit surface injury localized and not exceeding 10% of fruit surface, and 5 = no fruit surface injury. On our scale, an injury rating below four is unmarketable as fresh fruit due to lenticel pitting, surface discoloration or both. However, only fruit with a rating of one would be unsuitable for processing. Injury rating indicates the severity of injury on individual fruit, whereas percent fruit injured indicates the percentage of the fruit showing any indication of injury.

The CIELAB a values for greenness of peels were measured with a spectrophotometer (Handy-spec with 1.1 cm aperture; Gardner, Silver Spring, Md.) at two points on each of 40 fruit per treatment both at harvest and after a 7-d period at 20 °C following 2, 4, and 6 months of cold storage. Care was taken to avoid peel areas that were injured, russeted or had blush.

Fruit firmness was measured on 40-fruit sets with a manually controlled digital penetrometer (EPT-1 with an 11.1 mm tip; Lake City Technical Products, Kelowna, B.C., Canada) set in the Magness-Taylor mode. Firmness was measured at two opposite points on the equator of the fruit after removal of a 2-mm slice with a fixed-blade slicer at the end of an 8-d period at 20 °C.

Titratable acidity, expressed as malic acid, was determined on four, 10-fruit replications. Fruit in sets of 10 were ground in an electric juice extractor, then 100 mL of juice from the bulked sample was titrated to pH 8.2 with NaOH (Mitcham and Kader, 1996).

The preparation of fruit tissue for Ca content analyses was as previously described (Saftner et al., 1997). Prepared samples were analyzed for Ca content by inductively coupled plasma emission spectroscopy (model 61E; Thermo Jarrell Ash, Franklin, Mass.). Calcium content is reported on a dry mass basis (in $mmol \cdot kg^{-1}$). Each sample consisted of the flesh from seven apples, and four samples were obtained from each treatment.

Harvests were made from the same commercial orchard in 1995 and 1996. In the first year of experimentation, treatments were limited to buffered and unbuffered Ca infiltrations, water rinses and shellac-based coatings; and fresh mass losses, internal and external gases were not determined. In the second year, all treatments described above were made and only results from the second year are reported since overlapping results from both years were similar.

Data were analyzed as a two-way ANOVA (SigmaStat 2.0; Jandel, San Rafael, Calif.). The treatment means were separated at $P \leq 0.05$ using the Tukey multiple range test. Injury data were not statistically analyzed since variance heterogeneity of such data could not be corrected by data transformation. Except for the injury data, only results significant at $P \leq 0.05$ are discussed.

Results

Fruit injury in the form of skin discoloration and/or superficial pitting in the lenticel region occurred after treating the fruit with Ca (Table 1). For uncoated fruit, the severity of the injury appeared to increase with increasing Ca concentrations as previously reported (Beavers et al., 1994; Sharples and Johnson, 1976) and with increasing Ca content of fruit. Water infiltration also injured the lenticel region of the fruit and additionally caused some superficial cracking of the fruit. A water rinse to remove unbound surface Ca immediately following Ca infiltration sometimes appeared to reduce surface injury as did buffering the Ca infiltration solutions between pH 4 to 6. In particular, less injury was noted in the calyx region of the fruit following a water rinse. Following the Ca treatments with a water rinse and a wax- or shellac-based coating reduced the severity of injury in fruit treated with 0.24 or 0.34 $mol \cdot L^{-1}$ solutions of $CaCl_2$ and eliminated injury in fruit treated with a 0.14 $mol \cdot L^{-1}$ $CaCl_2$ solution (Table 1). The shrink-wrap film treatment had a similar but less protective effect on Ca-infiltrated fruit than the application of a wax- or shellac-based coating. Calcium chloride treatments increased the Ca content to at least 20 $mmol \cdot kg^{-1}$ dry mass (Table 1), a level needed to reduce decay development and maintain firmness during storage (Conway et al., 1994). Injury ratings were similar following 2 or 6 months of cold storage (data not shown).

Coating or shrink wrapping fruit at harvest reduced subsequent fresh mass losses during cold storage (Fig. 1). Shrink-wrapped fruit was the slowest at losing fresh mass followed by waxed and shellac-coated fruit.

Sequential 0.14 $mol \cdot L^{-1}$ Ca and coating treatments delayed fruit ripening, as indicated by greater retention of green peel color, titratable acidity and flesh firmness (Table 2), and reduced respiration and ethylene production rates (Table 3) that were observed upon transferring fruit to 20 °C. Sequential treatments with higher Ca concentrations (0.24 or 0.34 $mol \cdot L^{-1}$ Ca) and a fruit coating sometimes had a more pronounced ability to delay fruit ripening (data not shown). Sequential treatments with Ca and a shrink-wrap film also reduced respiration and ethylene production rates (Table 3), but had no effect on several other quality maintenance characteristics (Table 2). Calcium or a coating treatment alone were less effective than sequential treatments in retaining green peel color, titratable acidity, and flesh firmness (Table 2) and in reducing respiration and ethylene production rates (Table 3). Sequential treatments with Ca and shellac were generally more effective in delaying ripening than sequential treatments with Ca and wax (Tables 2 and 3).

Sequential treatments with Ca and a coating or film modified the atmosphere in the fruit cavity (Table 4). The combination treatments generally reduced the internal O_2 and ethylene levels while increasing the internal CO_2 level. No treatment caused the internal O_2 level of the fruit to drop below 5 kPa where anaerobic respiration might become a problem. Coating and, to a lesser degree, film treatments alone modified the internal atmosphere of fruit.

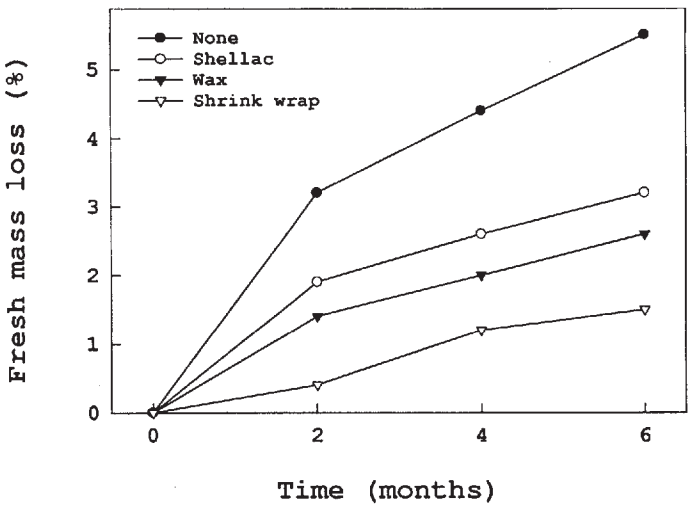

Fig. 1. Fresh mass loss in apples without and with a wax- or shellac-based coating or a shrink-wrap film during cold storage at 0 °C. Each point is the mean of five 40-fruit replications. For each time period, means are significantly different by Tukey's multiple range test ($P \leq 0.05$).

Table 2. Quality attributes of 'Golden Delicious' apples after a 7- to 9-d period at 20 °C following 4 months of storage at 0 °C.[z]

Treatment	Firmness[y] (N)	Peel color[y] (a)	Titratable acidity[y] ($mmol \cdot L^{-1}$)
Uncoated	53 a	–4.6 a	25 a
+ 0.14 $mol \cdot L^{-1}$ $CaCl_2$	64 b	–7.8 ab	23a
Shrink wrap	52 a	–5.1 a	22 a
+ 0.14 $mol \cdot L^{-1}$ $CaCl_2$	65 b	–5.9 a	22 a
Wax	60 b	–9.5 b	28 ab
+ 0.14 $mol \cdot L^{-1}$ $CaCl_2$	70 bc	–10.0 b	28 ab
Shellac	66 b	–11.1 bc	31 b
+ 0.14 $mol \cdot L^{-1}$ $CaCl_2$	74 c	–12.6 c	34 b

[z]Measurements of color, firmness and titratable acidity were made at 7, 8, and 9 d, respectively, following removal of fruit from cold storage.

[y]Each value of firmness and color is the mean of 80 readings from 40 fruit while each value of titratable acidity is the mean of four 10-fruit replications. At harvest, firmness, peel color and titratable acidity expressed as malic acid were 85 N, –15.9 a value, and 38 $mmol \cdot L^{-1}$, respectively. Means in a column followed by the same letter are not significantly different by Tukey's multiple range test ($P \leq 0.05$).

Discussion

Sequential postharvest treatments with Ca, water (as a rinse) and a fruit coating can slow fruit ripening (Fig. 1 and Table 2), reduce respiration and ethylene production rates (Table 3) and modify the internal atmosphere of fruit (Table 4) as much or more than any of the treatments alone. The potential for creating modified atmosphere conditions may be one of the benefits of using fruit coatings and films (Banks et al., 1993; Smith et al., 1987). Calcium infiltration has also been shown to modify the internal atmosphere of apple fruit (Hewett and Thompson, 1992). Combining treatments is also an effective strategy for increasing the efficacy of Ca without increasing the risk of peel injury (Table 1).

Following the Ca treatments with a surface coating reduced peel injury in fruits treated with 0.24 or 0.34 $mol \cdot L^{-1}$ solutions of $CaCl_2$ and eliminated injury resulting from a 0.14 $mol \cdot L^{-1}$ Ca treatment (Table 1). Buffering the $CaCl_2$ solution and/or rinsing the fruit in water immediately following Ca infiltration is not enough to eliminate fruit surface injury (Meheriuk and Moyls, 1989; Yeun, 1994; Table 1). However, a water rinse is essential for removing the salt film that forms on the fruit surface and which interferes with coating performance (unpublished data). Buffering the Ca treatment solutions to reduce the potential for Ca-induced acidification in the cell wall region of fruit tissue by cation exchange reactions does not reduce peel injury (Beavers et al., 1994).

The mechanism(s) by which the surface coatings reduced or eliminated fruit surface injury is not clear. Calcium injury in apples can be reduced by increasing the moisture content of the air surrounding the fruit (Lidster et al., 1977). Surface coatings act as barriers both to water vapor and fresh mass losses and to noncondensible (CO_2, O_2 and ethylene) gases (Hagenmaier and Shaw, 1992; Fig. 1, Tables 3 and 4). The order of effectiveness of the coating and film treatments was correlated to the general permeability of coatings and films to water vapor (see Hagenmaier and Shaw, 1992), and was consistent with shrink-wrap films being more effective than fruit coatings in reducing water loss in other commodities (Paull and Chen, 1989). It is well established that desiccation increases the visual symptoms of many forms of injury associated with harvested fruits (Yuen et al., 1994). The osmotic potential of the 0.34 $mol \cdot L^{-1}$ (–2.2 MPa) solutions of $CaCl_2$ was lower than that of the tissue osmotic potential (mean ± SD = –1.8 MPa ± 0.2) of the fruit used in this study, but the 0.14 and 0.24 $mol \cdot L^{-1}$ (–0.9 and –1.5 MPa, respectively) solutions were generally higher (unpublished data). The higher concentrations of $CaCl_2$ may have induced plasmolysis and potentially immediate and irreversible membrane damage. Thus, the injury-mediating effects of the surface coatings were probably due more to their amelioration of water and salt stresses than to their impact on noncondensible gas exchange. Plastic films have been reported to extend shelf life of lemon and bell pepper fruits by alleviation of water stress (Ben-Yehoshua et al., 1983) and to delay ripening and reduce injury in mango resulting from Ca treatment (Yuen et al., 1994). Regardless of the mechanism(s) involved, sequential treatments with a 0.14 $mol \cdot L^{-1}$ solution of $CaCl_2$ and a surface coating eliminated peel injury resulting from Ca treatment in this study, thereby overcoming a major obstacle to the commercial application of postharvest Ca treatment. For the purpose of maintaining quality, apples are commercially stored in low O_2 established in a rapid controlled-atmosphere storage facility, when available, rather than to subject fruit to Ca and/or coating treatments prior to air storage (Lau et al., 1983; Lau, 1985; Lau and Meheriuk, 1994). However, sequential at-harvest treatments with 0.14 $mol \cdot L^{-1}$ Ca and relatively O_2-permeable fruit coatings provides an effective alternative means to maintain postharvest life in 'Golden Delicious' apples without injury. Higher flesh Ca content has the additional benefit of reducing decay in fruit caused by *Botrytis cinerea* Pers.:Fr. and *Penicillium expansum* Link (Conway et al., 1992; Saftner et al., 1997) and could reduce the apple industry's dependence on conventional synthetic fungicides.

The major disadvantages of applying a surface coating to fruit are the inhibition of CO_2 and O_2 exchange resulting in anaerobic respiration and uneven ripening (Banks et al., 1993; Hagenmaier and

Table 3. Evolved carbon dioxide and ethylene values of 'Golden Delicious' apples during a 7-d period at 20 °C immediately after 4 months of storage at 0 °C.

Treatment	CO_2[z] ($nmol \cdot kg^{-1} \cdot s^{-1}$)	C_2H_2[z] ($nmol \cdot kg^{-1} \cdot s^{-1}$)
Uncoated	106 a	1.70 a
+ 0.14 $mol \cdot L^{-1}$ $CaCl_2$	88 b	1.31 b
Shrink wrap	69 c	1.17 c
+ 0.14 $mol \cdot L^{-1}$ $CaCl_2$	67 c	0.66 d
Wax	43 d	0.18 e
+ 0.14 $mol \cdot L^{-1}$ $CaCl_2$	41 d	0.06 f
Shellac	37 e	0.05 f
+ 0.14 $mol \cdot L^{-1}$ $CaCl_2$	38 e	0.01 g

[z]Each value is the mean of 72 readings from three six-fruit replications. Means in a column followed by the same letter are not significantly different by Tukey's multiple range test ($P \leq 0.05$).

Table 4. Internal carbon dioxide, oxygen and ethylene values of 'Golden Delicious' apples after a 7-d period at 20 °C following 4 months of storage at 0 °C.[z]

Treatment	CO_2 (kPa)	O_2 (kPa)	C_2H_2 (Pa)
Uncoated	2.5 a	18.0 a	30.7 a
+ 0.14 mol·L^{-1} $CaCl_2$	4.6 b	16.5 a	15.6 b
Shrink wrap	3.0 ab	17.9 a	35.9 a
+ 0.14 mol·L^{-1} $CaCl_2$	6.1 c	15.0 b	19.4 ab
Wax	8.3 d	13.5 b	20.1 b
+ 0.14 mol·L^{-1} $CaCl_2$	10.6 e	10.1 c	9.0 bc
Shellac	12.0 ef	8.3 d	13.3 b
+0.14 mol·L^{-1} $CaCl_2$	14.4 f	6.7 e	2.4 c

[z]Each value is the mean of 10 three-fruit replications. Means in a column followed by the same letter are not significantly different by Tukey's multiple range test ($P \leq 0.05$).

Shaw, 1992). The surface coatings used in this study were selected for relatively high permeabilities for CO_2 and O_2 and low permeabilities for water vapor (see Hagenmaier and Shaw, 1992). Even when coated fruit used in this study were transferred to 20 °C, the internal O_2 level always remained well above levels that would result in anaerobic respiration. In addition, no uneven ripening in terms of uneven color development was observed.

To the contrary, the application of surface coatings alone or in combination with Ca treatments delayed fruit ripening as indicated by better retention of fresh mass, green peel color, titratable acidity and flesh firmness, and reduced respiration and ethylene production rates. In fact, the shellac-based coating delayed ripening as well as or better than Ca treatments (Tables 2 and 3). Except for better retention of fresh mass, shrink wrapping fruit was less effective than application of coatings at delaying ripening and maintaining quality (Fig. 1; Tables 2 and 3). More automated procedures for shrink wrapping than those used in this study may have allowed better film integrity and tightness around the fruit resulting in better efficacy of the film. Control of fruit ripening by application of surface coatings has been explained primarily as responses to the modification of concentrations of CO_2, O_2 and ethylene (Banks et al., 1993; Smith et al., 1987), although alleviation of water stress may be an additional factor (Ben-Yehoshua et al., 1983). Regardless of the mechanism(s) involved, sequential treatments with Ca and a fruit coating have significant potential as a postharvest strategy for the quality maintenance and shelf life extension of 'Golden Delicious' apples and perhaps other cultivars as well.

If $CaCl_2$ and surface coating treatments are to be used commercially for long-term storage, a systematic study of the optimal Ca concentration and surface coating treatment in a range of cultivars is needed to avoid risk of abnormal developments pre- and poststorage. Second, information is needed on the effects of Ca and surface coatings on biosynthesis, internal levels and permeation from treated fruit of flavor and antimicrobial compounds. Surfactant-assisted Ca infiltration to reduce risks of physical injury to fruit during treatment and ensure a more uniform distribution of Ca inside the fruit (Saftner et al., 1997) may improve the treatments in this research.

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