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# Fresh-cut cantaloupe: effects of $\text{CaCl}_2$ dips and heat treatments on firmness and metabolic activity

Irene Luna-Guzmán<sup>a,\*</sup>, Marita Cantwell<sup>b</sup>, Diane M. Barrett<sup>a</sup>

<sup>a</sup> Department of Food Science and Technology, University of California, Davis, CA 95616, USA

<sup>b</sup> Department of Vegetable Crops, University of California, Davis, CA 95616, USA

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## Abstract

Calcium chloride (1–5%) dips were applied to melon cylinders taken from commercially ripe (3/4 to full slip) cantaloupe melons for 1–5 min. A wound response was observed after cutting, and  $\text{CO}_2$  production was higher in untreated samples than in calcium treated and intact fruit. Dip time did not significantly effect respiration rate. Application of calcium dips at any temperature resulted in unchanged ethylene production throughout storage, and inhibited respiration. Calcium chloride dips improved firmness of fresh-cut cantaloupe during storage at 5°C, with 1 min dips showing the same effect as 5 min dips. When dipped for 1 min in 2.5% calcium chloride solutions at 20, 40 or 60°C, firmness was maintained or improved, especially at higher dip temperatures while total calcium concentration in the melon tissue was increased on average by 300%. © 1999 Elsevier Science B.V. All rights reserved.

**Keywords:** Calcium; Melon; Postharvest physiology; Fresh-cut; Firmness

## 1. Introduction

Muskmelons (*Cucumis melo* L. var. *reticulatus*) are climacteric fruits (Lyons et al., 1962) and the main factors affecting their eating quality are texture, flavor and sweetness (Rosa, 1928; Yamaguchi et al., 1977). Fresh-cut products are a rapidly growing segment of the retail and food service horticultural industry, with an estimated retail market of \$11 billion by the year 2000 (Anon., 1998). According to the 'Fresh Trends'

report (Vance Research Services and Market Facts, Inc., 1990), between 21 and 36% of all consumers have purchased some kind of tray-wrapped fresh-cut melons. The most commonly marketed fresh-cut melon products are: balls, chunks, and slices with or without rind (Schlimme, 1995). Although fresh-cut products have met the consumers' desire for convenience (Bruhn, 1995), product freshness and shelf life in particular are still important challenges for fresh-cut fruit. Operations involved in preparing fresh-cut melons may affect their shelf life, eating quality and acceptance by the consumer (Anon., 1995). A suitable method for shelf life extension, which avoids detrimental effects on quality of

\* Corresponding author. Tel.: +1-530-752-2585; fax: +1-530-752-4759.

E-mail address: ilguzman@ucdavis.edu (I. Luna-Guzmán)

fresh-cut products, would be beneficial for both the consumer and the producer.

Postharvest treatments that have been applied to fruit slices or pieces have targeted mainly improvement of post-processing quality rather than shelf life extension of the fresh-cut product. Calcium dips have been used as firming agents to extend postharvest shelf life in apples (Abbott et al., 1989; Lurie and Klein, 1992; Mir et al., 1993; Sams et al., 1993), strawberries (García et al., 1996), sliced pears and sliced strawberries (Rosen and Kader, 1989) and zucchini slices (Izumi and Watada, 1995); and to improve post-processing quality in blueberries (Camire et al., 1994), peaches (Postlmayr et al., 1956), fermented cucumbers (Hudson and Buescher, 1985), tomatoes (Floros et al., 1992), and sliced strawberries (Main et al., 1986). Heat treatments are another postharvest treatment that has been used to control postharvest decay and/or improve the storage quality of intact apples (Klein and Lurie, 1990, 1992) and to improve post-processing quality of potatoes (Aguilar et al., 1997). A combination of heat treatment followed by calcium dip has also been applied for the primary purpose of controlling postharvest pests and/or diseases and has been found to have very good results in maintaining or improving the texture of potatoes (Hoff and Bartolome, 1972), hot peppers (Mohammed et al., 1991) and apples (Lurie and Klein, 1992; Sams et al., 1993; Shalom et al., 1993; Conway et al., 1994). The effects of postharvest heat treatments on fruit physiology have been reviewed by Paull (1990).

Firming and resistance to softening resulting from addition of  $\text{Ca}^{2+}$  have been attributed to the stabilization of membrane systems and the formation of Ca-pectates, which increase rigidity of the middle lamella and cell wall (Grant et al., 1973; Poovaiah, 1986; Bourne, 1989; Jackman and Stanley, 1995) to increased resistance to polygalacturonase attack (or inhibition of degradation) on the pectic substances of the middle lamella and cell wall (Buescher and Hobson, 1982) and to improved turgor pressure (Mignani et al., 1995).

The beneficial effects obtained with heat treatments have generally been explained in terms of pectin esterase (PE) activation, which is known to occur in the temperature range of 55–70°C (Hoff and Bartolome, 1972). PE is the enzyme responsible for cleaving the methoxyl groups from methylated galacturonic acid residues in pectin, generating free pectic acids (Belitz and Grosch, 1986) which contain newly available carboxyl groups. Endogenous and added  $\text{Ca}^{2+}$  can firm plant tissue by complexing with the pectic carboxyl groups that have been generated through the action of PE (Stanley et al., 1995).

The objectives of this study were to determine the effects of postharvest calcium chloride dips on the physiological responses and firmness of fresh-cut cantaloupe melon, and the combined effects of calcium chloride dips and heat treatments on the firmness, calcium concentration and distribution, and postharvest biology of fresh-cut cantaloupe.

## 2. Materials and methods

### 2.1. Sample preparation

Cantaloupe melons were harvested ripe (3/4 to full slip) and stored for no more than 3 days at 2.5 or 7.5°C and 80–90% relative humidity (RH) before samples were prepared. Fruits were selected for uniform size and maturity based on physical appearance, e.g. external color (75% yellow), net development (full) and stem abscission (3/4 to full slip). Knife, cork borer and cutting board were washed with soap and water and rinsed with 1000 ppm sodium hypochlorite solution prior to use. Fruits were washed in soap and water and one or two rings were cut from the equatorial region of the fruit. Cylinders were obtained from melon rings using a 1.8 cm diameter cork borer. Cylinders were dipped in a 50 ppm sodium hypochlorite solution (commercial bleach-5.25% sodium hypochlorite w/w), drained, and placed on a plastic tray covered with cheesecloth which had been dampened with 1000 ppm chlorinated water.

## 2.2. Sampling design and treatment application

### 2.2.1. Physiological responses

One ring of approximately 3.5 cm in width was obtained from each of the 18 fruit following the above sample preparation steps. An average of 12 melon cylinders were obtained per ring and all 216 cylinders (18 fruit  $\times$  12 cylinders/fruit) were combined. Two replicates of six cylinders were randomly taken for each of the three storage times (0, 6 and 12 days), and dipped into 0, 1, or 5% calcium chloride ( $\text{CaCl}_2$  dihydrate, USP/FCC, Fisher Scientific, New Jersey, USA) solutions for 1 or 5 min at room temperature (2 replicates  $\times$  6 cylinders/replicate  $\times$  3 times/treatment  $\times$  3 calcium chloride levels  $\times$  2 dip times = 216 cylinders). After being treated, melon cylinders were drained and stored as described below. Four additional intact fruit were put into containers and transferred to the same storage conditions as the melon cylinders. Respiration and ethylene production rates were determined from gas samples taken from containers holding either intact fruit or melon cylinders every 12 h during the first 4 days of storage and every 24 h for the remainder of the storage period. Tissue firmness was evaluated on fruit cylinders using a UC Firmness Tester on days 0, 6, and 12 after samples were removed from storage jars and equilibrated to room temperature.

### 2.2.2. Effect of calcium chloride dips on firmness

Two 4 cm central rings were cut from the equatorial region of each fruit. Each of these rings was cut horizontally in half to produce four 2 cm rings per fruit. In total 12 cylinders were obtained per ring by cutting around in opposite directions (clockwise and counter-clockwise). Each cylinder was tagged using a paper tag covered with transparent tape anchored with a sewing pin so that its replicate was facing it in the other ring. A total of 48 cylinders (4 rings  $\times$  12 cylinders) were obtained from each melon. Each treatment was applied to 108 cylinders (2 replicates  $\times$  3 evaluation days  $\times$  18 melons). The treatments applied were 0, 1, 2.5 and 5% calcium chloride for 1 min; 0, 1, and 2.5% calcium chloride for 2.5 min, and 2.5% calcium chloride for 5 min. After being treated, samples

were drained and stored as described below. Flesh firmness was evaluated with the Texture Analyzer at 0, 10, and 19 days after samples were removed from storage and equilibrated to 20°C. Respiration and ethylene production rates were also determined during storage.

### 2.2.3. Effects of calcium chloride dips and heat treatments

From each fruit, four rings of approximately 2 cm in width were obtained following the sample preparation steps described previously. Eight 2 cm high melon cylinders per ring were obtained using a 1.8 cm diameter stainless steel cork borer. These were tagged using paper tags covered with transparent tape and sewing pins before being dipped in a 50 ppm sodium hypochlorite solution (commercial bleach-5.25% sodium hypochlorite w/w). A total of 32 cylinders (4 rings  $\times$  8 cylinders/ring) were obtained from each melon, therefore there were 224 total cylinders available (32 cylinders/melon  $\times$  7 melons). Each of the four treatments was applied to 56 cylinders (7 melons  $\times$  2 replicates  $\times$  4 storage times) in two batches, with new calcium solutions prepared for each batch. All treatments, replicates, and evaluation times were applied to tagged melon cylinders coming from the same melon. Samples for replicates and storage times came from adjacent cylinders on the same ring, while samples for different treatments came from adjacent rings. This sampling procedure was used based on previous results (Luna-Guzmán and Barrett, unpublished) that indicated that inherent variability of the melon firmness is lower along the longitudinal axis than along the equatorial axis (i.e. from stem end to blossom end).

Control samples were dipped in the 50 ppm sodium hypochlorite solution. Calcium treatments consisted of dipping the melon pieces for 1 min in 2.5% calcium chloride (w/w) at 20, 40, or 60°C maintained with a temperature controlled water bath. After being treated, melon cylinders were drained and cooled (if heat treated) to approximately 20°C in a  $-20^\circ\text{C}$  freezer for less than 5 min while monitoring temperature and stored as described below. Respiration and ethylene production rates were determined every 12 h as de-

scribed below by measuring samples stored longest, while tissue firmness was evaluated using the Texture Analyzer on days 0, 4, 8, and 12. After evaluating firmness, samples were placed in plastic freezer bags with reclosable openings and stored for about 5 months in a  $-10^{\circ}\text{C}$  freezer before being analyzed for calcium concentration.

### 2.3. Storage

After being treated, melon cylinders were drained, put into clean glass containers, and transferred to  $5^{\circ}\text{C}$ . Glass jars, lids and connecting tubing were rinsed with 1000 ppm sodium hypochlorite solution prior to use. All containers were connected to a humidified air-flow system (95% RH), and air flow rates were selected so that the maximum accumulation of  $\text{CO}_2$  was 0.5%.

### 2.4. Gas analysis

Gas samples were taken with a hypodermic syringe from the outlet tubing of each jar connected to a flow-through system.  $\text{CO}_2$  concentrations were measured by injecting a 1 ml gas sample into an infrared gas analyzer (model PIR-2000, Horiba Ltd., Japan) using  $\text{N}_2$  as the carrier gas. Ethylene concentrations were determined by injecting a 1 ml gas sample into a gas chromatograph (model 8000, Carle Instruments, Inc., Fullerton, CA) equipped with a NaCl modified Alumina F1 60/80 mesh column and a flame ionization detector interfaced with an integrator (model SP4270, Spectra-Physics, San Jose, CA). The ethylene volumetric production rate is given with respect to 101 kPa total pressure and  $21 \pm 1^{\circ}\text{C}$ .

### 2.5. Texture evaluation using the UC firmness tester

Tissue cylinders were held in an 18 mm diameter glass tube and punctured using a 6 mm diameter flat-head stainless steel cylindrical probe attached to a manual UC Firmness Tester (Western Industrial Supply, CA) as developed by Madrid (1993). Firmness was recorded as the force of penetration indicated by the 5 kg spring-

gauge on the Firmness Tester. This system was only used for the physiological responses experiment.

### 2.6. Texture evaluation using the texture analyzer

A puncture test was performed on the flat side of each cylinder at the end closest to the blossom end of the melon using the TA.XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) with a 25 kg load cell. During the puncture test, a 5 mm diameter flat-head stainless steel cylindrical probe travelled 30% of the height of the cylinder at  $1 \text{ mm s}^{-1}$ . Firmness measurements were taken as the first peak force value obtained during the test.

### 2.7. Calcium analysis

Duplicate melon cylinders from three of the seven fruits that had been treated and evaluated for firmness were taken out of frozen storage. A 10 mm diameter cork borer was used to obtain an internal cylinder from each 1.8 cm diameter cylinder. Calcium analysis was performed on both external and internal cylinders using a modification of the method of Suwwan and Poovaiah (1978). External or internal cylinders were cut into very small pieces using a sharp stainless steel knife. In total 500 mg of tissue were weighed into a centrifuge tube, 5 ml of distilled deionized water were added and homogenized for 30 s at high speed with a Polytron Homogenizer (PT3000, Kinematica AG, Switzerland). The 5 ml water used to rinse the Polytron was added to the homogenate. After stirring for 1 h at low speed, samples were centrifuged at 13 000 rpm ( $20\,000 \times g$ ) and  $4^{\circ}\text{C} \pm 2$  for 1 h using an RC5C Sorvall centrifuge (DuPont Company, Wilmington, DE). Samples and the 5 ml water rinse used for the centrifuge tube were filtered through Whatman 541 ashless filter paper. In total 5 ml of the filtrate were used to determine free calcium levels after addition of 5 ml of 10% HCl. The insoluble material retained on the Whatman filter paper was ashed at  $550^{\circ}\text{C}$  for 4 h and resuspended in 5 ml of 5% HCl. Lanthanum chloride (0.5% w/w) was added to all final solutions to control ioniza-

tion interferences (Perkin Elmer Corp., 1982).  $\text{Ca}^{2+}$  concentration was determined at 422.7 nm using an atomic absorption spectrophotometer (Perkin Elmer Corp., Norwalk, CT) with an air-acetylene flame. Results are reported on a fresh weight basis.

### 2.8. Statistics

Analysis of variance was performed using the GLM procedure from SAS (SAS Institute Inc., 1989), except for firmness results from the physiological response experiment where the ANOVA procedure was used. Means were compared using Fisher's LSD test ( $\alpha = 0.05$ ).

## 3. Results

### 3.1. Physiological responses

A wound response was detected in fresh-cut samples in comparison to intact fruit (Fig. 1), indicated by an increase in  $\text{CO}_2$  production immediately after cutting. Calcium treated samples dipped for 1 min and intact fruit showed no difference in respiration rates throughout most of the storage period, but untreated (0% calcium chloride) samples had higher  $\text{CO}_2$  production at all storage times. The respiratory patterns of samples dipped for 5 min were similar to samples dipped for 1 min until approximately day 6, when the pieces from the 1% treatment had a greater increase in respiration rate.

Untreated melon cylinders had lower ethylene production rates than calcium treated and intact fruit (Fig. 2). Calcium treated samples showed an increase in ethylene production rate towards the end of the storage period, similar to that observed in untreated samples. Intact fruit showed an increase in ethylene production rate at day 7. Similar  $\text{C}_2\text{H}_4$  production rates were observed for the 1 and 5 min calcium treated samples.

### 3.2. Effect of calcium chloride dips on firmness

Application of calcium treatments generally resulted in increased firmness of the melon samples

(Table 1), as previously observed in the physiological responses experiment (data not shown). The higher the calcium concentration applied, the greater the improvement in firmness (Fig. 3, Table 1). Highest firmness values were obtained with 5% calcium chloride for 1 min. Treatment with 2.5% calcium chloride for 1, 2.5 or 5 min provided the same improvement in firmness. Firmness of 1% calcium chloride treated pieces was not different from untreated samples. Samples treated with 2.5% calcium chloride seemed to hold firmness better than other treatments over 10 days of storage. No data are reported for day 19 (Fig. 3) due to microbial spoilage of the samples.

### 3.3. Effects of calcium chloride dips and heat treatments

A general wound response was observed for all treatments (2.5% calcium chloride/1 min at 20, 40 or 60°C) and control samples (data not shown);

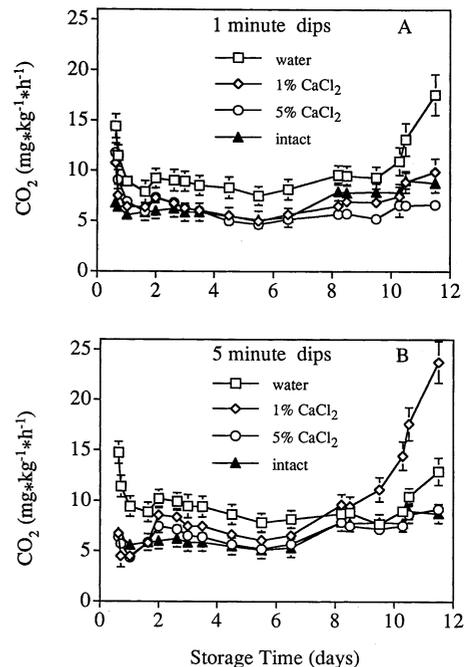


Fig. 1. Respiration rates of fresh-cut cantaloupe melon cylinders stored in air at 5°C and 95% RH. Cylinders were treated with 0, 1 or 5% calcium chloride dips for 1 (A) or 5 (B) min. Each data point is the average of three determinations  $\pm$  SE.

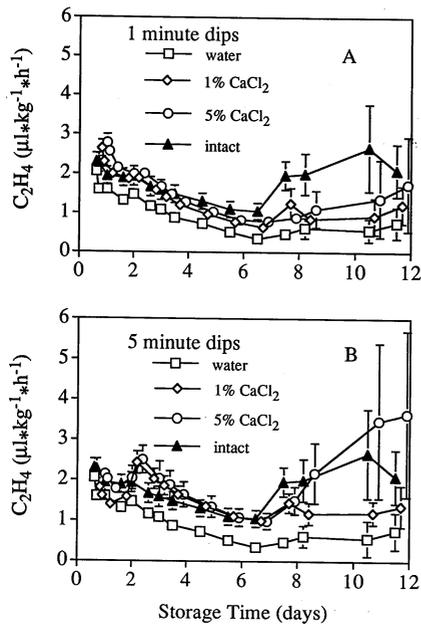


Fig. 2. Ethylene production rates of fresh-cut cantaloupe melon cylinders stored in air at 5°C and 95% RH. Cylinders were treated with 0, 1 or 5% calcium chloride dips for 1 (A) or 5 (B) min. Each data point is the average of three determinations  $\pm$  SE.

$CO_2$  production increased immediately after cutting, and declined to a steady level within one day at 5°C. An increase in respiration was observed only in the control sample after about day 4. The respiratory behavior of calcium treated samples was similar at all temperatures, and  $CO_2$  production was slightly lower as dip temperature increased (data not shown).

No wound ethylene response was observed

Table 1

Average firmness (N) of fresh-cut cantaloupe stored for 10 days at 5°C and 95% RH measured with the TA.XT2

Dip time (min)	$CaCl_2$ (%)			
	0	1	2.5	5
1	8.5d <sup>a</sup>	8.8cd	9.4b	9.8a
2.5	8.7d	8.6d	9.2b	–
5	–	–	9.1bc	–

<sup>a</sup> Means with the same letter are not significantly different at  $P < 0.05$ .

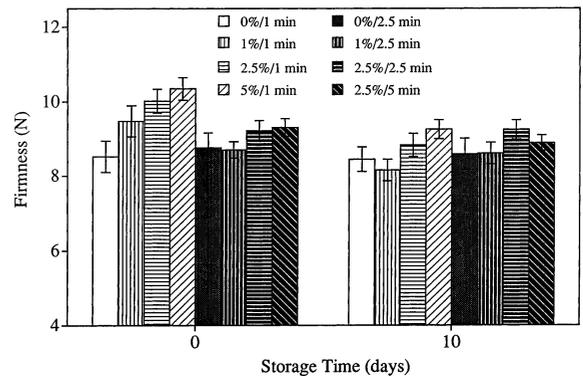


Fig. 3. Firmness of fresh-cut cantaloupe melon cylinders dipped in various calcium chloride solutions and stored in air at 5°C and 95% RH. Measurements were made with the Texture Analyzer after equilibrating to 20°C. Each data point is the average of 36 determinations  $\pm$  SE.

(data not shown) for either treatment or the control. Ethylene production was very low immediately after cutting in all samples ( $< 1 \text{ ml kg}^{-1} \text{ h}^{-1}$ ) and slowly declined throughout storage. There were no significant differences in ethylene production between calcium dipped and control samples.

Calcium treated samples were significantly ( $P < 0.05$ ) firmer than control melon cylinders (Fig. 4). Similar effects were obtained in the 40 and 20°C treatments, but the 60°C calcium-treated samples were significantly firmer ( $P < 0.05$ ) than samples from any other treatment.

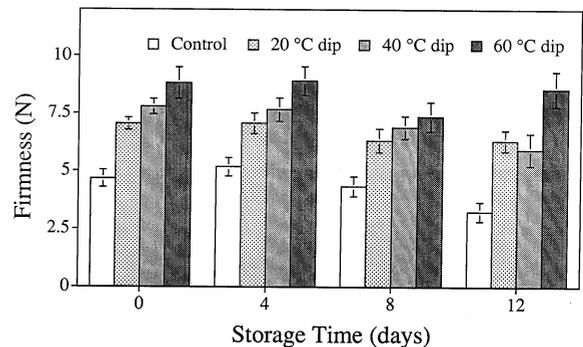


Fig. 4. Firmness of fresh-cut cantaloupe during storage at 5°C and 95% RH for 12 days after being dipped in 2.5% calcium chloride for 1 min at different temperatures. Each data point is the average of 14 determinations  $\pm$  SE.

Table 2

Average bound, free and total calcium concentrations ( $\text{mg g}^{-1}$  fresh tissue) of external and internal sections of fresh-cut cantaloupe dipped in 2.5%  $\text{CaCl}_2$  for 1 min at different temperatures

Dip temperature ( $^{\circ}\text{C}$ )	External			Internal		
	Bound	Free	Total	Bound	Free	Total
Control	0.13c <sup>a</sup> A <sup>b</sup>	0.07cB	0.20c	0.08cA	0.04cB	0.12c
20	0.32aA	0.36bA	0.68ab	0.23aA	0.16bB	0.39a
40	0.21bB	0.40bA	0.61b	0.12bcB	0.16bA	0.28b
60	0.26abB	0.49aA	0.75a	0.13bB	0.21aA	0.33ab

<sup>a</sup> Means followed by same lowercase letter are not significantly different at  $P < 0.05$  for each column.

<sup>b</sup> For each section, means followed by same uppercase letter are not significantly different at  $P < 0.05$  for each row.

Firmness was improved by 45 and 58% following the 20 and 40 $^{\circ}\text{C}$  dips, respectively, while a 60 $^{\circ}\text{C}$  dip provided a 77% improvement in firmness throughout storage compared with control samples.

The calcium concentration determined in our control samples was between 0.08 and 0.27  $\text{mg g}^{-1}$  of edible portion of cantaloupe falling within the range of values previously reported by Watt and Merrill (1950). As expected, calcium concentration was higher in calcium treated samples than in just cut (control) samples (Table 2). In control samples, external calcium concentration was higher than internal concentration. Both external and internal calcium concentrations increased in treated samples in comparison with the control.

Bound calcium concentration was lower than free calcium in the 40 and 60 $^{\circ}\text{C}$  treatments, but was higher in the just cut control sample and the same as 20 $^{\circ}\text{C}$  treated samples (Table 2). There was no difference in internal free calcium concentration in the 20 and 40 $^{\circ}\text{C}$  dipped samples, but the 60 $^{\circ}\text{C}$  treatment had a significantly higher internal and external free calcium concentration. Although more internal and external bound calcium was found in the treated samples as compared to control samples, those treated at 60 and 20 $^{\circ}\text{C}$  showed the highest external bound calcium concentration.

## 4. Discussion

### 4.1. Physiological responses

Respiration rates determined in our study were relatively low and comparable to those obtained for fresh-cut melons by Madrid (1993) and Watada et al. (1996), as well as to those of intact fruits. This may be due to the relatively large piece size. Respiration rates of fresh-cut cantaloupes held at 5 and 15 $^{\circ}\text{C}$  (Madrid, 1993), or at 5, 10 or 15 $^{\circ}\text{C}$  (Watada et al., 1996) did not differ from those of intact melons. The size of the cylinders used by Madrid (1993) was similar to that used in our study. In addition, commercially mature cantaloupes (3/4 to full slip stage) are generally considered postclimacteric (Pratt, 1971) and the constant low temperature during storage would minimize differences between cut and intact melons. The increase in respiration rates observed after day 6 could be due to microbial spoilage, although macroscopic decay was not visible on calcium treated samples. Similarly, the increased ethylene production observed at about day 8 could be an indication of either continued ripening or microbial spoilage. The large degree of variability observed in ethylene production rates could also be possibly due to maturity differences in the melons which were selected at the commercially

mature or ripe stage (3/4 to full slip) on the basis of physical appearance. In general, calcium treated fresh-cut cantaloupes had lower respiration rates but higher ethylene production rates than untreated samples. A similar response has been observed in intact fruit, such as apples (Bangerth et al., 1972; Faust and Shear, 1972; Bramlage et al., 1974) and avocado (Tingwa and Young, 1974). However, calcium treatment inhibited ethylene synthesis and ripening of green tomatoes (Wills and Tirmazi, 1979).

Fresh-cut products generally have higher respiration rates and ethylene production rates than intact products (Rosen and Kader, 1989; Madrid, 1993; Brecht, 1995; Watada et al., 1996). Zagory (1995) indicated that this is probably due to both the increased surface area exposed to the atmosphere after cutting (which allows oxygen to diffuse into the interior cells more rapidly) and to the increased metabolic activity of injured cells. McGlasson and Pratt (1964) reported that cutting fruit into 2 mm discs caused an immediate increase in respiration of fresh cantaloupe slices compared with intact fruits. In addition, cutting increased the ethylene production rate ten-fold. In general, the higher the extent of processing and wounding, the greater the increase in respiration rate (Rolle and Chism, 1987; Brecht, 1995). Wound ethylene is usually greater in preclimacteric and climacteric than postclimacteric tissues (Abeles et al., 1992), and whereas wound ethylene has no effect on ripening of non-climacteric fruit, it may advance ripening of climacteric fruit. The increased respiration in wounded plant tissues is thought to be a consequence of ethylene action (Brecht, 1995).

The possible role of  $\text{Ca}^{2+}$  in retardation of ripening has been discussed by Mignani et al. (1995) in terms of PG expression or activity and production of pectic oligomers, which induce ripening. On the other hand, Ferguson (1984) postulated that the calcium ion interacts with sites in the membrane phospholipid and cell wall pectins, thus preventing or delaying changes that are important to ripening. Lester (1996) postulated that calcium applications can delay or hasten (depending on  $\text{Ca}^{2+}$  concentration used) senescence-related changes by having a direct ef-

fect on plasma membrane leakiness (microporosity). Although ethylene production rates were higher for calcium treated samples than untreated melon pieces, metabolic activity appeared to be reduced based on the lowered respiration rates.

#### 4.2. *Effect of calcium chloride dips on firmness*

Firmness measurements from the physiological responses experiment were highly variable (data not shown). The sampling were carried out by randomly selecting cylinders from different melons and firmness measurements were made with the UC Firmness Tester. Although it was possible to observe a trend of increasing firmness values with increasing calcium concentrations, no significant differences could be detected between treatments. To reduce such high inherent variability, a different sampling system was used as well as a different firmness measurement instrument. The sampling procedure consisted of tagging melon cylinders to keep track of their original location and orientation (Luna-Guzmán et al., unpublished). Firmness was measured using the TA.XT2 Texture Analyzer instead of the UC Firmness Tester, since the tester is manually operated, and firmness measurements may be affected by operator-dependent parameters such as speed and force of penetration.

In subsequent experiments it was possible to confirm that the higher the calcium concentration applied, the greater the improvement in firmness (Fig. 3, Table 1). However, no differences were found between dip times for the same calcium concentration (Table 1) and it is possible that calcium uptake may be limited by rates of mass transfer.

The firming effect of calcium chloride has been shown for numerous fresh products. Silva et al. (1987) reported that 0.125% calcium chloride dips maintained melon pieces with a 'crispier' texture during storage at 2°C. Calcium chloride dips (0.5% calcium chloride) have had a beneficial effect on retaining or improving the texture of zucchini slices stored at 0 and 10°C (Izumi and Watada, 1995). Izumi and Watada (1994) reported that use of either a 0.5 or 1% calcium chloride treatment for 2 min maintained firmness

of shredded carrot when stored at 0, 5 or 10°C. Treatments increased calcium content slightly in sticks and slices and substantially in shreds (two and three times that of sticks and slices, respectively) and had no effect on storage quality of sticks or slices. Tissue firming has been attributed to the crosslinking between the carboxyl groups of adjacent polyuronide chains and divalent calcium ions (Barnes and Panchet, 1976; Van-Buren, 1979) creating the so-called 'egg-box model' (Grant et al., 1973). The beneficial effect of calcium treatments on greater turgor pressure and firmness of tomato pericarp discs has also been reported (Mignani et al., 1995).

#### 4.3. Effects of calcium chloride dips and heat treatments

The CO<sub>2</sub> production rates of calcium treated samples was slightly lower as dip temperatures increased, and an increase in respiration was observed only in the control sample after about day 4. This could indicate that calcium dips may have effectively retarded the ripening process and/or microbial contamination. The lack of wound ethylene response observed (data not shown) for either treatment or the control, coincides with results obtained by Madrid (1993) using fresh-cut cantaloupe cylinders obtained following very similar procedures and stored under air at 5°C. Fresh-cut products are living respiring tissues (Rolle and Chism, 1987) and can exhibit all of the changes typically used to characterize ripening of intact fruits as observed by Greve and Labavitch (1991) on discs cut from the outer pericarp of mature-green tomatoes. Ripening processes did not seem to have had an effect on calcium dipped melon cylinders, but could have in the control, since it showed an increase in respiration compared with calcium treated samples. Since the ethylene production observed in our experiment was not affected by the calcium chloride dips or dip temperature, firmness throughout storage did not seem to have been affected by ripening or tissue injury.

Although no reports on the use of hot water dips on quality of fresh-cut melons are available, data on whole melons can be used as an indicator

of possible effects of hot dip treatments on fresh-cut melons. Dunlap et al. (1990) found that cantaloupe melons heated at 45°C for 3 h had ethylene production rates 130% of those determined before treatments, but rates declined during refrigerated storage. This elevated level of ethylene production in response to heat treatment was thought to be due to the effect of physical injury to fruit tissue. Couey (1989) stated that cantaloupes are heat sensitive fruits. Teitel et al. (1989) controlled decay from *Alternaria*, *Fusarium*, *Rhizopus* and *Mucor* species with 52°C water dips for 2 min without causing external heat injury on 'Galia' melons. However, a 55°C hot water dip for longer than 2 min resulted in heat injury characterized by well defined pitted, necrotic spots (Teitel et al., 1991). On the other hand, Barkai-Golan et al. (1993) observed that 'Galia' melons dipped in 52 or 55°C water for 2 or 5 min had the same firmness and significantly reduced fungal decay. Cantwell and Nie (1992) reported longer hot water treatments at lower temperatures (40°C/90 min or 45°C/30 min versus 60°C/3 min) to be more efficient in controlling the development of stem end during storage in polyethylene bags at 10°C.

The fact that neither respiration rate nor ethylene production rate was affected by the heat treatments applied in the present study indicates that such heat treatments were not long enough to produce damage equivalent to that observed in heated apples (Klein and Lurie, 1992). These authors heated intact 'Granny Smith' apples at 46°C for 24 h or 42°C for 48 h, and observed heat damage, characterized by flesh and skin browning, after 3 months of storage in air at 0°C. The level of CO<sub>2</sub> and C<sub>2</sub>H<sub>4</sub> production observed in our experiments were also comparable to those obtained in previous experiments on unheated melon cylinders (see Section 3.1) and Madrid (1993).

The firming effects observed in calcium and heat treated samples indicate that it is possible that the higher temperature treatments may have activated PE, thus allowing more calcium complexing following PE-activated demethylation of pectins in the cell wall and middle lamella. In our study, heat treated samples were cooled immediately to 20°C and then, to stop the reaction,

placed in a  $-20^{\circ}\text{C}$  freezer; this could have caused volume reduction of the air spaces and infusion of the residual surface calcium solution.

Although we did not evaluate electrolyte leakage or membrane damage, we consider that the calcium chloride dips were probably not hot enough to provoke an alteration of membrane function as observed by Greve et al. (1994), or long enough to provoke electrolyte leakage as observed by Simon (1977). Greve et al. (1994) observed that carrot discs lost firmness after 3 min of cooking in boiling water as a consequence of membrane disruption which eliminated the turgor component of texture. Simon (1977) observed that leakage from melon tissue placed in water at room temperature was as rapid and extensive as that from apples, which lost 90% of their electrolytes and soluble carbohydrates in 2–3 h. Our conditions were mild compared with those used by Greve et al. (1994) and Simon (1977).

The combined use of heat treatments and minimal processing has been reported by Kim et al. (1993, 1994). Heating whole apples at  $45^{\circ}\text{C}$  every 30 min for a 2 h period before slicing improved the texture of apple slices as compared to non-treated apples, but this improvement depended upon cultivar. Lidster et al. (1979) obtained firmer apple slices when Spartan apples were heated to  $38^{\circ}\text{C}$  for 6 days immediately after harvest, and sliced and dipped in  $\text{Ca}^{2+}$  after 6 months of cold storage. The firming effects of the heat treatments were explained on the basis of PE activation.

Calcium treated samples contained almost twice as much external as internal calcium, indicating that calcium uptake and/or diffusion during the 1 min dip may be limited to the external area of the melon cylinder even if a higher dip temperature is used. Although increasing the temperature of dipping solutions is known to enhance diffusion rates, very little information exists on the effects of dipping time and temperature on actual calcium concentration in tissue. The fact that the  $60^{\circ}\text{C}$  treatment had a significantly higher internal and external free calcium concentration suggests possible enhanced diffusion at higher temperatures. However, Porreta et al. (1995) found that calcium concentration of the dipping solution was the most important factor of calcium uptake on

diced tomatoes, while temperature effects were not as important. We observed that  $60^{\circ}\text{C}$  treated samples had a greater total external concentration than samples treated at  $40^{\circ}\text{C}$ , but were no different than samples treated at  $20^{\circ}\text{C}$ . These seeming differences in temperature response may be due to biological variability of the melon tissue, or perhaps to the activation of different physiological phenomena at the temperatures evaluated.

The firmness results suggest a possible activation of PE by heat treatment, however the fact that the amount of bound calcium in the samples dipped at  $60^{\circ}\text{C}$  was not significantly different than that of the 40 or  $20^{\circ}\text{C}$  dipped samples may indicate that the combined effect of calcium and heat treatment on firmness could be a membrane or turgor pressure effect rather than PE activation. The increase in calcium concentration and subsequent firmness could then be due to enhanced diffusion of calcium ions into the tissue at higher dip temperatures. Diffusion is most likely to be through the porous apoplasm (Harker et al., 1989). It may be that calcium ions, although already diffused into the tissue, do not immediately bind to the middle lamella. This would explain why the increase in bound calcium concentration is similar or lower in magnitude to that of free calcium concentration. Another possibility is that the rate of diffusion into damaged external cell layers was faster since they had lost integrity. However, it could be slower once beyond the external cell layers due to a more tortuous diffusion path, the electrostatic interactions with the negative charges of the pore walls (Grignon and Sentenac, 1991), or smaller calcium concentration gradient.

Even though no sensory evaluation was performed, the visual quality (tissue integrity, mushiness, and watery appearance) of the calcium treated samples at all dip temperatures appeared to decline at a slower rate than control samples during storage.

## 5. Conclusions

Calcium dips retarded metabolism as indicated by the lower respiration rates of calcium treated

samples. However, dip temperature did not affect metabolism. Calcium chloride dips improved the firmness of fresh-cut cantaloupe. This improvement was greater with higher calcium chloride concentrations but not with longer dip times.

The firming effect provided by dipping fresh-cut cantaloupe melons in 2.5% calcium chloride was improved when combined with higher dip temperatures. Calcium concentration of treated samples was significantly greater ( $P < 0.05$ ) than the control, but the observed increase appeared to be due to temperature-induced diffusion rather than PE activation.

For fresh-cut melons, a 10-day shelf life is desirable in the distribution chain (Anon., 1996), but retail stores get an average shelf life of only 3 days. Further studies are necessary to determine the sensory profile and the microbiological stability throughout the potential 12 day shelf life obtained when combining calcium chloride dips and heat treatments on fresh-cut cantaloupe melons.

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