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Effect of Calcium on Ripening, Respiratory Rate, Ethylene Production, and Quality of Avocado Fruit

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Abstract. **The effect of Ca between 0.05 and 5.0 M on days to ripen, respiratory rates, rates of ethylene evolution, and external and internal quality of 'Fuerte' and 'Hass' avocado fruit at 20°C when placed directly at 20° or at 20° after 1, 3, and 5 weeks storage at 0° and 5° was determined. Dipping fruit in Ca solutions had no significant effect on these responses. The results discussed are for vacuum-infiltrated fruit. Days to ripen was increased and respiratory rates and rates of ethylene evolution were reduced as the Ca concentration increased. At 0.4 and 0.5 M Ca, no detectable climacteric occurred, essentially no ethylene was produced and the fruit failed to ripen. Exogenous ethylene or propylene exposure for 2 days resulted in typical stimulation of respiratory rates, ethylene production, and ripening of untreated fruit. Treatment with Ca reduced each response. Storage experiments indicated that Ca reduced internal chilling injury symptoms and increased external symptoms. Commercial Ca treatment of avocados to delay ripening and reduce chilling injury symptoms does not seem practical, because of the necessity to vacuum-infiltrate the Ca solution into the fruit and the adverse effect on external quality when ripened after storage.**

The physiology of plants is influenced profoundly by the level of Ca during growth and development (5, 8). Increasing the Ca content of apples has been reported to retard senescence and to reduce physiological disorders during storage (1, 6, 9, 10, 12), and to reduce the respiratory rate and the ethylene production (1, 4, 7, 11). Low levels of Ca in avocados have been associated with chilling injury susceptibility (2), and avocados with low levels of Ca ripen more rapidly than avocados with higher levels of Ca (13, 14). Vacuum-infiltration of 0.1 M Ca solutions into avocados reduced the preclimacteric and climacteric respiratory rates and the peak rate of ethylene production (13). Dipping avocado fruit for 10 min in 0.1 M Ca slightly suppressed the preclimacteric respiratory rate compared with fruit dipped in water, but had no effect on the climacteric peak respiratory rates. When halves of avocados were dipped in 0.1 M Ca or water, however, Ca inhibited both the preclimacteric and climacteric respiratory rates compared to the halves dipped in water (14).

Reported here are the results of experiments with 'Fuerte' and 'Hass' avocado fruit evaluating the effect of a range of Ca concentrations between 0.05 and 0.5 M on ripening, respiratory rate, ethylene production, and internal and external quality at 20°C, when placed directly at 20° and at 20° after various storage periods at 0° and 5°.

Materials and Methods

'Fuerte' and 'Hass' avocado fruit were obtained from a commercial avocado packinghouse. Uniform, 1st grade fruit (weight range 210 to 250 g) were selected, weighed, and treated. Fruit then were set-up for evaluations on respiratory rate, ethylene production rate, ripening, and quality at 20°C or placed in storage about 24 hr after picking. Treatments consisted of control (no treatment), water, and 0.05, 0.2, 0.2, 0.3, 0.4, and 0.5 M Ca ($CaCl_2$). Fruit were dipped for 15 min or vacuum-infiltrated at 50 mm Hg for 1 min. Under vacuum-infiltration, the avocado fruit absorbed about 1.1 g solution per 100 g of fruit weight. Fruit from the above treatments were placed at 20° for respiratory rate, ethylene production rate determinations, and for evaluation of rate of ripening and quality.

Avocados were vacuum-infiltrated with 0.1 and 0.3 M Ca, placed in respiratory chambers, and exposed to air and 10 ppm ethylene or 1000 ppm propylene in air (10) for 2 days. Then the avocados were exposed to air at 20°C. Storage experiments to evaluate the effect of Ca on chilling injury susceptibility consisted of control fruit and fruit vacuum-infiltrated with 0.2 M Ca. Samples were placed directly at 20° and others were held at 0° and 5° for 1, 3, and 5 weeks. They were then transferred to 20° for determination of the respiratory rate, rate of ethylene production, rate of ripening, and external and internal quality.

Respiratory rate and rate of ethylene production were determined on 6 individual fruit of each treatment. Ripening and quality evaluations were made on 10 individual fruit for each treatment which were held in paper bags during storage and in open flats when transferred to 20°C after the designated storage exposure. Fruit on which respiratory rate and rate of ethylene production were determined were placed in respiratory chambers at 20°. The air flow through the chambers, metered by calibrated capillaries at 8–10 liters/hr, was freed of ethylene by passing it through a 5 × 50 cm glass tube. Purafil ($KMnO_4$) on alumina pellets) was contained in the glass tube, and freed of CO_2 by bubbling it through a gas-dispersion tube in 2 N NaOH and then through water.

The CO_2 production of each fruit was determined by a Beckman infrared analyzer connected to a Leeds and Northrup recorder. A switching system sequentially directed the air stream from each respiratory chamber to the analyzer. Readings were taken from the chart every 12 hr, converted to μl/liter from a table of standardized values and the respiratory rate calculated as ml CO_2/kg/hr. Ethylene production was determined twice daily, at 0800 and 1600 during the week and at 0800 on weekends, on 1 ml samples taken from the outlet of each respiratory chamber, using a Varian Aerograph gas chromatograph Model 1440 with hydrogen flame ionization detector (detection limit about 0.004 μl/liter). The instrument was calibrated at each

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sampling with 1 ml samples from a cylinder containing a standardized ethylene-nitrogen mixture. The data were calculated as μl C_2H_4/kg/hr.

Each fruit for ripening and external and internal quality evaluations was evaluated initially for external quality when transferred from storage to 20°C and when ripe. Internal quality was evaluated when the fruit was ripe. Four categories were used to evaluate the external and internal disorders, consisting primarily of discoloration and breakdown of the surface of flesh, as follows: none = 1; slight = 2; moderate = 3; and severe = 4. Fruit rated "none" and "slight" would be acceptable in the market, whereas fruit rated "moderate" and "severe" would be discriminated against in the market. Ripening was evaluated subjectively by applying gentle pressure to the fruit held in the palm of the hand.

Results and Discussion

Dipping 'Fuerte' or 'Hass' avocado fruit in a range of Ca concentrations between 0.05 and 0.5 M had no significant influence on respiratory rate, rate of ethylene evolution, or ripening rate at 20°C compared with untreated fruit or fruit dipped in water. These results for intact fruit are consistent with a previous report using 0.1 M Ca (14).

The respiratory rates of mid-season 'Hass' avocado fruit at 20°C, following vacuum infiltration with water and 0.05, 0.1, 0.2, and 0.3 M Ca solutions and a control (untreated), are shown in Fig. 1. Fruit vacuum-infiltrated with water, 0.05, 0.1, and 0.2 M Ca reached the climacteric peak on the 9th day compared to the 10th day for the control fruit. The 0.3 M Ca-treated fruit showed a small climacteric-like peak on the 10th day. The climacteric peak heights essentially were the same for the control and the water treatment, whereas the peak heights decreased as the Ca concentration increased. The patterns of ethylene production (Fig. 2) were similar to the respiratory rate patterns, except that the peak rates occurred one day earlier than the climacteric peaks. The control, water and 0.05 M Ca-treated fruit ripened on the 11th day, whereas the 0.1 and 0.2 M Ca-treated fruit ripened on the 12th and 13th day, respectively. Fruit treated with 0.3 M Ca began to soften after about 14 days but did not attain acceptable eating quality. Avocado fruit vacuum-infiltrated with 0.4 and 0.5 M Ca displayed no climacteric,

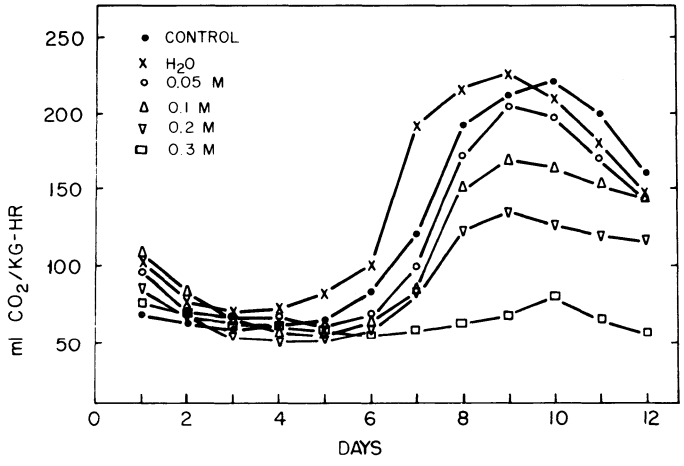

Fig. 1. Respiratory rate of 'Hass' avocados at 20°C. Treatments were control (untreated) and vacuum-infiltrated with water and 0.05, 0.1, 0.2, and 0.3 M Ca.

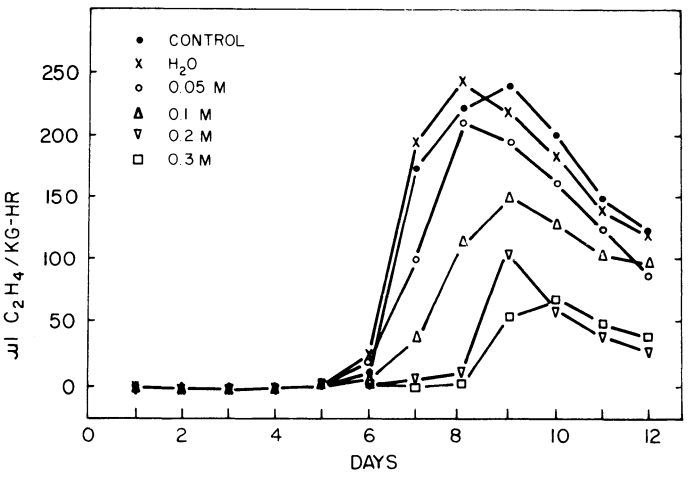

Fig. 2. Ethylene production of 'Hass' avocados at 20°C. Treatments were control (untreated) and vacuum infiltrated with water and 0.05, 0.1, 0.2, and 0.3 M Ca.

produced essentially no ethylene (less than 5μl/kg/hr) and failed to ripen. The results of the same treatments with early- and late-season 'Hass' avocados and a range of maturities with 'Fuerte' avocados were similar in relative response to those presented for mid-season 'Hass' avocados when the responses were compared to the respective untreated avocados.

Vacuum-infiltration of 'Fuerte' avocados with 0.1 M Ca under 260 mm Hg for 6 min suppressed the climacteric peak and peak rate of ethylene production at 20°C, with the peak rates occurring within a day of the peak rates for water infiltrated fruit, but data were not given for days to ripen (14). In Australia, vacuum-infiltration of 'Fuerte' avocados under 375 mm Hg and 'Hass' avocados under 250 mm Hg, with 1%, 2%, and 4% Ca (1.1, 2.2, and 4.4 M Ca, respectively), reduced the respiratory climacteric peak and peak rate of ethylene evolution compared with fruit vacuum-infiltrated with water, and delayed ripening from 10 days for the water infiltrated fruit to more than 16 days for the 4% Ca treatment (13). All fruit ripened to acceptable eating quality. However, fruit vacuum-infiltrated with 8% Ca (8.8 M Ca) solution failed to ripen by 16 days, developed decay and was discarded. The results presented here indicate similar responses of 'Fuerte' and 'Hass' avocados but at reduced concentrations of Ca. The difference can be attributed to the lower pressure (50 mm Hg) used to vacuum-infiltrate the fruit.

Avocados were vacuum-infiltrated with 0.1 and 0.3 M Ca and then exposed to 10 μl/liter ethylene or 1000 μl/liter propylene for 2 days, beginning immediately after treatment. At these concentrations, propylene elicits the same physiological responses as ethylene and permits ethylene production determinations during the exposure. Therefore, data are presented for the propylene treatment. Untreated and 0.1 and 0.3 M Ca-treated 'Hass' avocados not exposed to propylene reached the climacteric peaks after 8, 9, and 10 days, respectively (Fig. 3), and the peak heights were similar to those presented in Fig. 1 for the respective treatments. Calcium treatment at 0.1 M reduced the respiratory response to propylene compared with the control, and both reached maximum rates after 2 days. Fruit treated with 0.3 M Ca and propylene maintained a respiratory rate near the initial rate, which was above the rate for fruit not exposed to propylene but considerably suppressed compared to the propylene-treated control. Ethylene production of untreated and 0.1

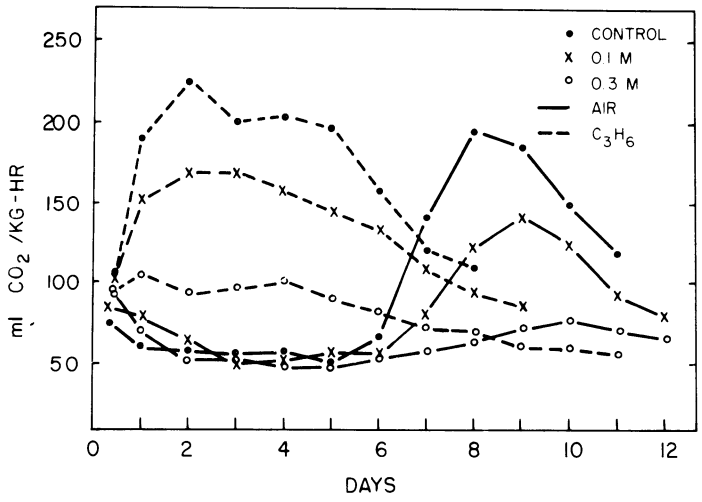

Fig. 3. Respiratory rate of 'Hass' avocados at 20°C. Treatments were control (untreated), vacuum-infiltrated with 0.1 and 0.3 M Ca and 2 days exposure to 1000 ppm propylene.

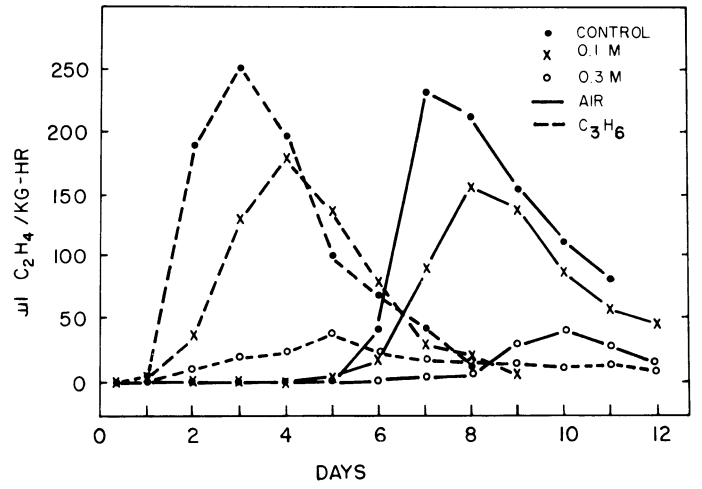

Fig. 4. Ethylene production of 'Hass' avocados at 20°C. Treatments were control (untreated), vacuum-infiltrated with 0.1 and 0.3 M Ca and 2 days exposure to 1000 ppm propylene.

and 0.3 M Ca-treated fruit not exposed to propylene reached the peak rate of production after 7, 8, and 10 days, respectively (Fig. 4), and the peak rates for the respective treatments were comparable with those presented in Fig. 2. The peak rates of ethylene evolution for the control and 0.1 and 0.3 M Ca exposed to propylene occurred after 3, 4, and 5 days, respectively. The Ca treatment reduced the peak rate of ethylene production when exposed to propylene, with the 0.3 M Ca treatment reducing the peak rate of ethylene production to about one-fifth that of the untreated fruit.

The days to ripen of fruit not exposed to propylene (control) and the 0.1 M Ca treatment were 9 and 10 days, respectively, whereas those exposed to propylene ripened on the 4th and 5th day, respectively. Fruit treated with 0.3 M Ca and not exposed to propylene softened slightly after 12 days, and those exposed to propylene softened slightly after 8 days. Neither attained good eating quality. 'Fuerte' avocados responded to the respective treatments of Ca or propylene in a fashion similar to those presented for 'Hass' avocados. Avocados exposed to ethylene (10 µl/liter) for 2 days had similar respiratory rate and ripening patterns as those exposed to propylene for 2 days. Also, the rates of ethylene evolution following the ethylene exposure were comparable with those of avocados exposed to propylene for the respective treatments and times after treatment. The results indicate that exposure to ethylene or propylene does not overcome the suppression of respiratory rates, rates of ethylene evolution, ripening rate or inhibition of normal ripening of the 0.3 M Ca treatment.

The effect of 0.2 M Ca vacuum-infiltrated into avocado fruit on external and internal quality, days to ripen, respiratory rate and ethylene evolution at 20°C after 1, 3, and 5 weeks storage at 0° and 5° was determined to evaluate the influence of Ca on the susceptibility to chilling injury. The use of 0.2 M Ca for the storage experiments was because this concentration had the greatest effect in delaying ripening and reducing respiratory rates and rates of ethylene evolution without interfering with normal ripening. The respiratory rates for the untreated 'Fuerte' avocado fruit placed directly at 20° and at 20° after storage at 5° (Fig. 5) are similar to those reported previously (3). The Ca treatment reduced the respiratory rates for the respective treatments.

The rates of ethylene production for untreated 'Fuerte' avocado fruit placed directly at 20°C and at 20° following storage at 5° (Fig. 6) are typical of the results reported previously (3). The rates of ethylene production were reduced by Ca for the respective treatments. 'Hass' avocado fruit displayed similar respiratory rate and rate of ethylene evolution patterns as those presented for 'Fuerte' avocado fruit. Untreated 'Fuerte' and 'Hass' avocado fruit stored at 0° and transferred to 20° had respiratory rates and rates of ethylene production similar to those previously reported (3), and the Ca treatment lowered the respective respiratory rates and rates of ethylene production at 20°.

Vacuum-infiltration of 'Fuerte' and 'Hass' avocado fruit with 0.2 M Ca delayed ripening for fruit placed directly at 20°C and at 20° following various storage periods at 0° and 5° (Table 1, 2). The external quality of the ripe fruit was reduced by the Ca treatment, and the internal quality was improved, compared with untreated fruit in cases where the storage treatment caused chilling injury symptoms. Internal symptoms of chilling injury have been reported to be reduced when avocados vacuum-infiltrated (250 mm Hg for 30 sec) with 1%, 5%, and 7.5% Ca (1, 5.5, and 8.2 M Ca, respectively) were ripened at 20° following 3 weeks storage at 5° (2). The higher the Ca concentration, the

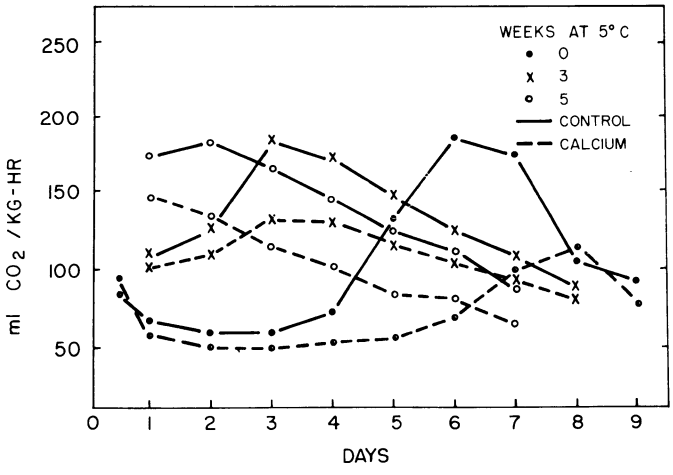

Fig. 5. Respiratory rate of 'Fuerte' avocados at 20°C. Treatments were control (untreated) and vacuum-infiltrated with 0.2 M Ca and 1, 3, and 5 weeks storage at 5°.

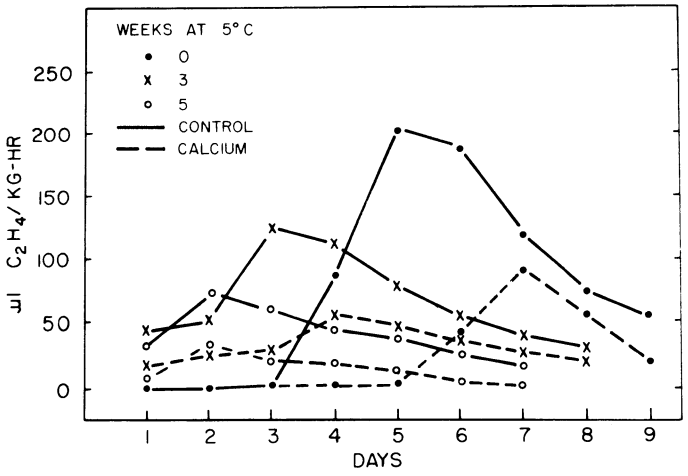

Fig. 6. Ethylene production of 'Fuerte' avocados at 20°C. Treatments were control (untreated) and vacuum-infiltrated with 0.2 M Ca and 1, 3, and 5 weeks storage at 5°.

Table 1. Effect of Ca (0.2 M $CaCl_2$ vacuum infiltrated) on external and internal quality and days to ripen at 20°C after 3 and 5 weeks storage at 0° and 5° on 'Fuerte' avocado fruit.

Treatment			Quality[z]				
			External			Internal	
Storage period (weeks)	Storage temp. °C	Ca	Initial	Transfer	Ripe	Ripe	Days to ripen
0	–	–	2.0	–	2.0 a[y]	1.0 a[y]	5.7 c[y]
0	–	+	2.0	–	2.5 b	1.0 a	6.9 e
3	5	–	2.0	2.0	2.6 b	2.0 b	5.1 b
3	5	+	2.0	2.0	2.9 c	1.7 b	6.0 d
3	0	–	2.0	2.0	3.1 c	2.7 cd	5.2 b
3	0	+	2.0	2.0	3.3 d	2.2 bc	6.1 d
5	5	–	2.0	2.0	3.3 d	2.9 d	4.2 a
5	5	+	2.0	2.0	3.8 e	2.3 c	5.6 c
5	0	–	2.0	2.3	3.6 e	3.4 e	5.2 b
5	0	+	2.0	2.8	4.0 e	2.6 c	7.0 e

[z]External and internal quality rated as follows: 1 = none; 2 = slight; 3 = moderate; and 4 = severe damage or discoloration.
[y]Means separated in columns by Duncan's multiple range test, 5% level.

greater the reduction in internal symptoms. However, no mention was made of the external quality of the avocados. Under the conditions used in the experiments reported here, vacuum infiltration of Ca into avocados delayed ripening, reduced internal chilling injury symptoms, and reduced external fruit quality. Commercial application of Ca to avocados to delay ripening and reduce chilling injury symptoms does not appear practical because of the necessity to vacuum-infiltrate the Ca solutions into the fruit and the adverse effect on external appearance of the fruit when ripened after storage.

Table 2. Effect of Ca (0.2 M $CaCl_2$ vacuum infiltrated) on external and internal quality and days to ripen at 20°C after 1, 3, and 5 weeks at 0° and 5° on 'Hass' avocado fruit.

Treatment			Quality[z]				
			External			Internal	
Storage period (weeks)	Storage temp. °C	Ca	Initial	Transfer	Ripe	Ripe	Days to ripen
0	–	–	1.0	–	1.0 a[y]	1.0 a[y]	6.4 d
0	–	+	1.0	–	1.0 a	1.0 a	8.1 f
1	5	–	1.0	1.0	1.0 a	1.0 a	6.3 d
1	5	+	1.0	1.0	1.0 a	1.0 a	7.0 e
1	0	–	1.0	1.0	1.0 a	1.0 a	6.3 d
1	0	+	1.0	1.0	1.0 a	1.0 a	7.1 e
3	5	–	1.0	2.0	2.5 c	1.0 a	4.6 a
3	5	+	1.0	2.9	3.1 d	1.0 a	5.1 b
3	0	–	1.0	1.0	1.7 b	1.0 a	4.7 a
3	0	+	1.0	1.6	2.6 c	1.0 a	5.2 b
5	5	–	1.0	2.6	2.7 c	2.2 bc	5.8 c
5	5	+	1.0	3.0	3.5 b	1.8 b	6.2 d
5	0	–	1.0	2.2	2.5 c	2.5 c	5.6 c
5	0	+	1.0	2.5	3.1 b	2.0 b	6.4 d

[z]External and internal quality rated at follows: 1 = none; 2 = slight; 3 = moderate; and 4 = severe damage or discoloration.
[y]Means separated in columns by Duncan's multiple range test, 5% level.

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