

The Effect of Calcium on the Ripening of Avocado (*Persea americana* Mill.) Fruits¹

P. O. Tingwa and R. E. Young²
University of California, Riverside

ABSTRACT. Treatment with calcium (0.1 M CaSO₄, 0.1 M CaCl₂) depressed respiration of avocado fruits during preclimacteric and climacteric phases. Na₂SO₄ was ineffective. Calcium not only inhibited respiration but delayed the onset of the climacteric and depressed the peak of ethylene production at the climacteric rise. Determinations of endogenous Ca confirmed that higher levels were positively correlated to delay in ripening and negatively correlated to peak of CO₂ and ethylene production. It is inferred that this difference in Ca level is one of the factors causing lack of uniformity in ripening.

The Ca ion is known to be involved in many fundamental physiological plant processes involving cell walls, membranes, chromosomes, and enzyme activation (9). In post harvest physiology, disorders such as bitter pit in apples have been directly linked to low Ca content of the fruits (5, 11, 16, 18). It has been suggested that such disorders result from increased respiration rate (6) following membrane permeability changes (15). Higher Ca levels in the flesh (2, 6) depressed preclimacteric, climacteric, and post climacteric respiration of apples. The same inhibitory effect was observed on respiration of apple mitochondria (16).

Despite careful selection, one of the problems commonly encountered with the avocado is lack of uniformity in time of arrival at the climacteric (1). Since Ca has such a profound effect on the post harvest respiration of apples, we decided to consider its possible involvement in this phenomenon. In experimental work with avocado wherein a sample may comprise a few fruits, anomalous behavior by one fruit may greatly influence the interpretation of the results.

Our results suggest that differences in Ca content of avocado fruits cause differences in the rate of respiration, and that higher levels not only depress respiration, but may be one of the causes of variability in the ripening of avocado fruits.

Materials and Methods

Early season (Nov.) 'Fuerte' fruits were obtained from a single tree at the University of California South Coast Field Station. Fruits were selected for uniformity of size, shape, and wt and divided into 3 lots. The first lot was dipped in water; the second, in 0.1 M

¹Received for publication March 19, 1974. We thank J. B. Biale and L. C. Erickson for valuable suggestions. Technical assistance of Cameron Duncan is gratefully acknowledged. This paper represents part of the Ph.D. dissertation of the senior author.

²Graduate Student and Plant Physiologist, respectively. Department of Plant Sciences.

CaSO₄, each for 10 min, fruits of the third lot were sliced longitudinally into equal halves and the embryos and seed coats removed. One half of each fruit was dipped in water and the other in 0.1 M CaSO₄ for 10 min. Respiration of each intact fruit and segment was determined with a Model 215 Beckman infrared CO₂ gas analyzer at 20°C. Ethylene was not determined.

The same experiment was repeated on 'Hass'. Treatments were: dipping and vacuum infiltrating the fruits with water (control), 0.1 M CaSO₄, 0.1 M CaCl₂, and 0.1 M Na₂SO₄. Infiltration was carried out by reducing the pressure over the fruits to 260 mm Hg for 6 min. Total respiration and C₂H₄ production were determined through a system which automatically sampled each of 24 samples every 4 hr. Carbon dioxide was monitored by a recording infrared gas analyzer.

Samples for C₂H₄ determination were automatically injected into the gas chromatograph and recorded on a digital integrator. For endogenous Ca content, samples were obtained from 24 uniform 'Hass' fruits whose respiration and C₂H₄ production had been followed. Fruits were analyzed after they had passed the climacteric peak. One half g of the dried flesh was ashed and Ca determined by atomic absorption.

Results and Discussion

Respiration of intact 'Fuerte' fruit, dipped in Ca solutions, was inhibited in the preclimacteric stage but not in the climacteric rise, and the time to ripen (postclimacteric stage) was not greatly influenced (Fig. 1). Ca-treated halves of the same fruit always showed a depressed rate of respiration in both preclimacteric and climacteric stages. A similar observation has been reported for apples (2). Some of the Ca-treated halves were not as soft as untreated segments, a characteristic which has been attributed to rigidity of the cell wall due to super optimal concentration of Ca (17).

Infiltration has been used successfully to improve penetration of substances into intact fruits (7) and slices (10, 12). Increases in wt of up to 10% have been reported for banana slices (12). We obtained an increase of only 1-2% for intact fruits and 2% for segments indicating that the avocado has little intercellular space.

In studies on 'Hass' fruit, results of dip treatments in Ca were omitted since

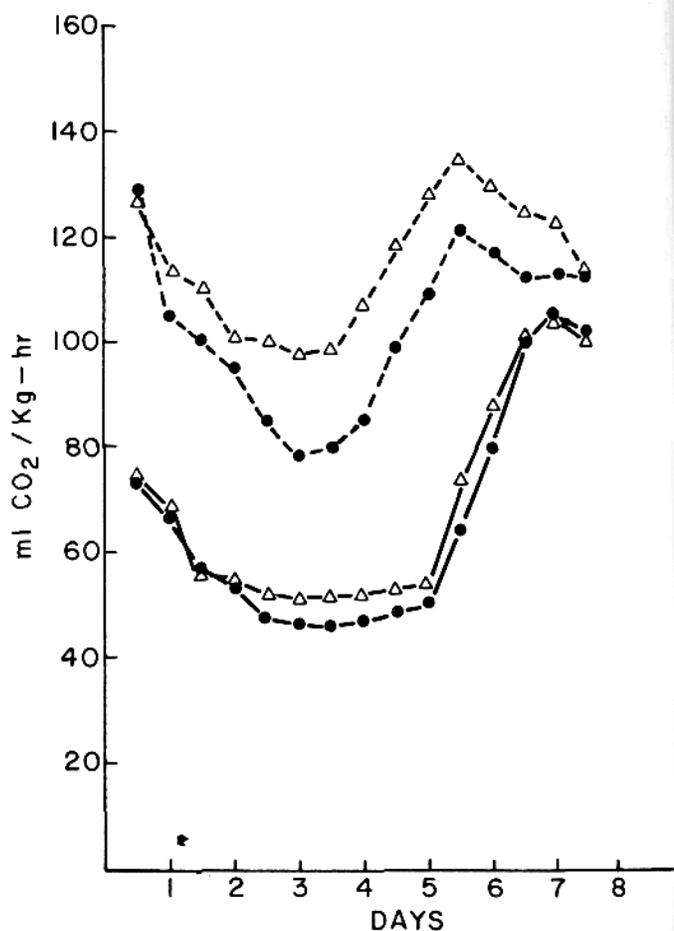


Fig. 1. Respiration pattern of 'Fuerte' avocado fruits treated with: 0.1 M CaSO₂ (●), and water (△) at 20°C. Half fruits are shown in broken lines, and each point represents the average of 4 fruits.

better penetration of Ca following infiltration

increased inhibition. Calcium sulphate and CaCl_2 inhibited the rate of respiration in both intact fruits (Fig. 2a) and half fruits (Fig. 3b and c). As in the case of 'Fuerte', the effect was present in preclimacteric and climacteric periods. The ineffectiveness of Na_2SO_4 suggests that Ca is the responsible ion; however the possibility exists that other divalent ions may cause the same effect. The onset of the climacteric is taken to be the time when the fruits started to produce ethylene, and this was delayed by 48 hr in Ca-infiltrated, intact fruits as compared to the water-infiltrated controls (Fig. 2b). In every fruit cut into 2 parts, the Ca-infiltrated half always ripened at least 10 hr later than the other, water-infiltrated half (Fig. 3b and c). This is in contrast to fruits in which $\frac{1}{2}$ was infiltrated with water and the other $\frac{1}{2}$ with Na_2SO_4 . In these fruits respiration pattern, C_2H_4 production and time to the climacteric rise were the same for both halves (Fig. 3a).

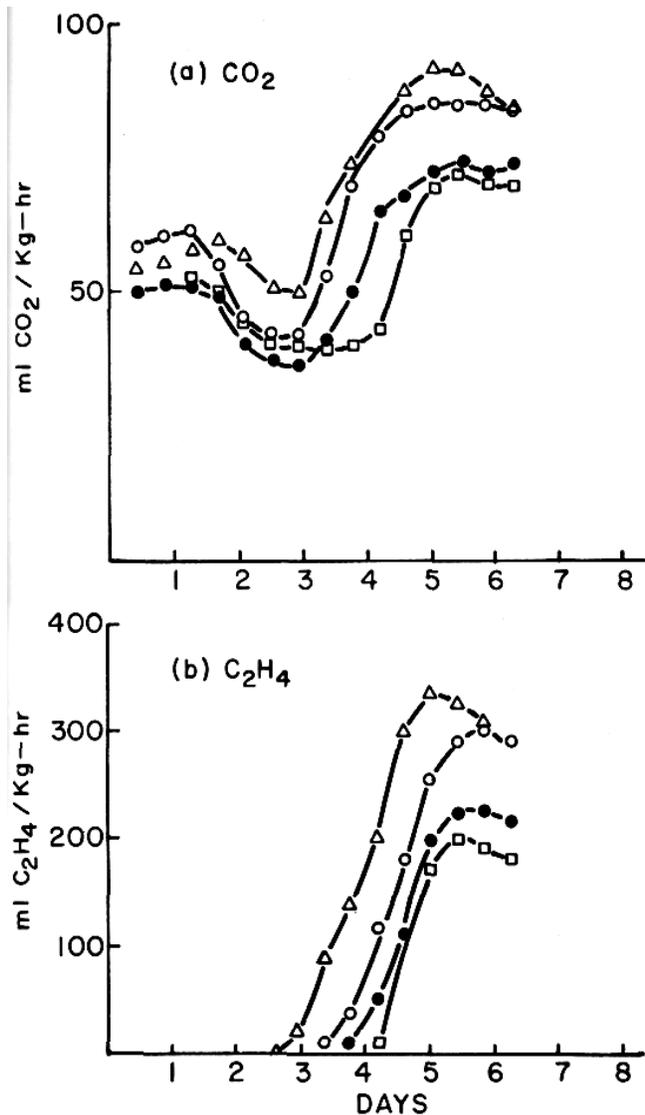


Fig. 2. Respiration pattern (a) and ethylene production (b) at 20°C of intact 'Hass' avocado fruits infiltrated with: water (Δ); 0.1 M Na_2SO_4 (\circ); 0.1 M CaSO_4 (\bullet); and 0.1 M CaCl_2 (\square) at 20°C. Each point represents an average of 4 fruits.

A most striking feature is that Ca depressed the peak of ethylene production (Fig. 2b) in intact fruits and to some extent in half fruits (Fig. 3b and c). This observation is supported by the results of the experiment on analysis for Ca levels (Fig. 4). The Ca levels of the fruits, expressed as % dry wt, were higher in fruits that ripened late. A positive and highly significant correlation existed between lateness in ripening and high Ca levels. Poovaiah and Leopold (13) have reported a similar delay in the ripening of bananas due to Ca. On the other hand, Bramlage et al. (2) found no such influence of Ca content on the time occurrence of the climacteric in apples. Avocados containing high Ca were always late in ripening and produced less CO_2 and C_2H_4 at the climacteric. The negative correlation coefficient between Ca content and peak C_2H_4 production was significant ($P = 0.05$), but the relationship with peak CO_2 production was not significant. This is consistent with observation in bananas where Ca depressed respiratory rise and other characteristics of ripening (13). The senescence delaying influence of Ca is well documented, being reported in explants of bean petiole (14) and in leaf discs of corn and Rumex where its effect is additive to those of cytokinins and gibberellins (13).

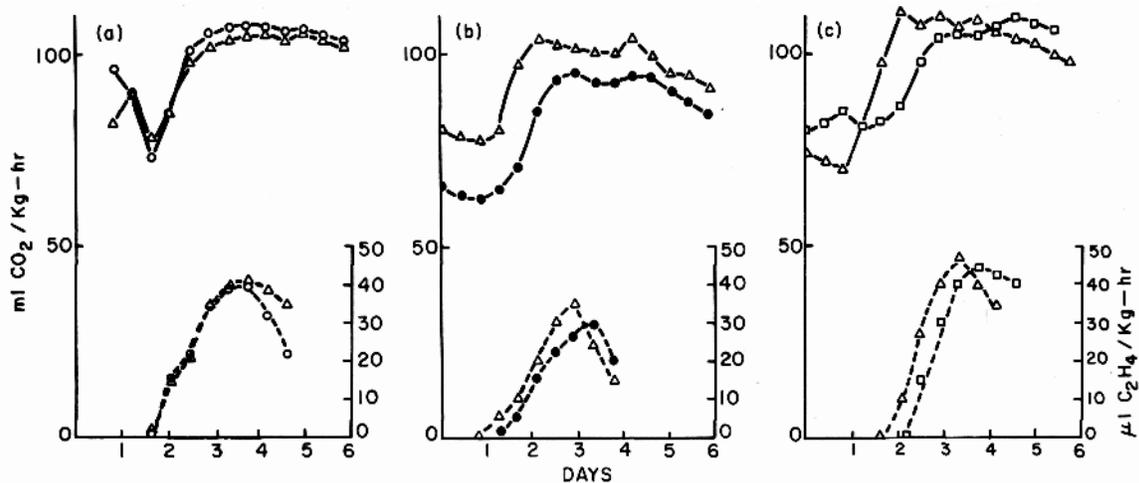


Fig. 3. Respiration pattern and ethylene production of 'Hass' avocado half fruits infiltrated with: (a) 0.1 M Na_2SO_4 (\circ); (b) 0.1 M CaSO_4 (\bullet); and (c) 0.1 M CaCl_2 (\square). In each graph, the other half of the same fruit infiltrated with water is shown as (Δ).

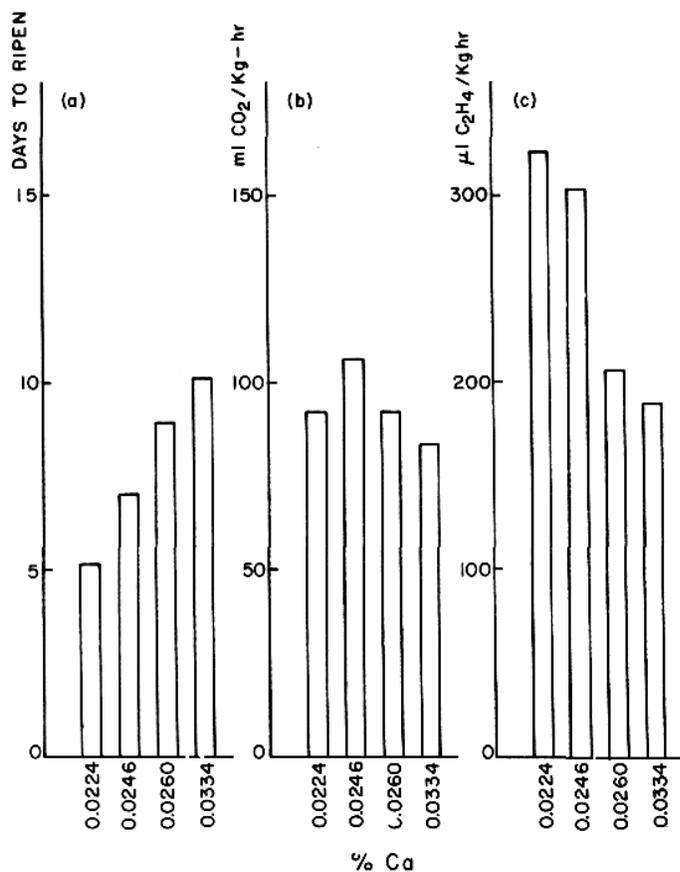


Fig. 4. Relationship between Ca content of the flesh of 'Hass' fruits to: days to ripen (a) $r = 0.57^*$; peak CO_2 production (b) $r = -0.54$; and peak ethylene production (c) $r = 0.67^*$. (*Significant at $P = 0.05$).

Calcium has been considered as one of the metabolic regulators (6, 9) and its role in membrane structure and function is well established (4). Its ability to delay senescence is considered to follow indirectly from its role in maintaining membrane integrity (13) and thus cellular compartmentalization (15). While the above results confirm the observation that high levels of Ca inhibit respiration (26), they add the new dimension that Ca may also be implicated in the regulation of C_2H_4 production. The close relationship between C_2H_4 production and IAA and the IAA oxidase system (7, 8) on one hand, and Ca and IAA transport (11) and responses (17) on the other, would suggest the possible link between Ca and C_2H_4 production. In view of the fact that Ca is relatively immobile and is not readily translocated from older to newer tissue, individual fruits on the same tree can have different Ca levels.

This in turn, as our results indicate, would influence post harvest respiration and, consequently, the variability in the onset of the climacteric as well.

Literature Cited

1. Biale, J. B., and R. E. Young. 1971. The avocado pear. *In* The Biochemistry of fruits and their products. Ed. Hulme, A. C. Acad. Press, p. 30.
2. Bramlage, W. J., M. Drake, and J. H. Barker. 1973. Influence of calcium content on the post harvest behavior of 'Baldwin' apples. *HortScience* 8:255.
3. déla Fuente, R. K., and A. C. Leopold. 1973. A role for calcium in auxin transport. *Plant Physiol.* 51:845-847.
4. Epstein, E. 1973. Mineral nutrition of plants: Principles and Perspectives. John Wiley Inc., NY. 412 p.
5. Faust, M., and C. B. Shear. 1968. Corking disorders of apples: A physiological and biochemical review. *Bot. Rev.* 34:411-469.
6. _____ and _____. 1972. The effect of calcium on the respiration of apples. *J. Amer. Soc. Hort. Sci.* 97:437-439.
7. Frenkel, C., and R. Dyck. 1972. Auxin inhibition of ripening in Bartlett pears. *Plant Physiol* 51:6-9.
8. Hall, W. C., and P. W. Morgan. 1964. Auxin-ethylene interrelationships. *In* J. P. Nitsch, ed. *Regulateurs Naturels de la croissance Vegetale*. Centre National de la Recherche Scientifique. p. 727-745.
9. Jones, R. G., and O. R. Lunt. 1970. The function of calcium in plants. *Bot. Rev.* 35:407-426.
10. Lee, T. H., W. B. McGlasson, and R. A. Edwards. 1970. Physiology of disks of irradiated tomato fruit. I. Influence of cutting and infiltration on respiration and ethylene production and ripening. *Rad. Bot.* 10:521-529.
11. Oberly, G. H. 1973. Effect of 2,3,5 triiodobenzoic acid on bitter pit and calcium accumulation on 'Northern Spy' apples. *J. Amer. Soc. Hort. Sci.* 98:269-272.
12. Palmer, J. K., and W. B. McGlasson. 1969. Respiration of banana fruit slices. *Austr. J. Biol. Sci.* 22:87-99.
13. Poovaiah, B. W., and A. C. Leopold. 1973. Deferral of senescence and ripening with calcium. *Plant Physiol.* 51:(Suppl)18.
14. _____ and _____. 1973. Inhibition of abscission by calcium. *Plant Physiol.* 51:848-851.
15. Rousseau, G. G., F. J. Hassbroek, and C. J. Visser. 1972. Bitter pit in apples: the effect of calcium on permeability changes in apple fruit tissue. *Agroplanta* 4:73-80.
16. Snay, E. R., and W. J. Bramlage. 1973. Effect of calcium on the apple mitochondria. *HortScience* 8:273.
17. Uhström, I. 1969. The time effect of auxin and calcium on growth and elastic modulus in hypocotyls. *Physiol. Plantarum* 22:271-287.
18. Wills, R. B. H. 1972. Effect of calcium on the production of volatiles by apples. *J. Fd. Agr.* 23:1131-1134.