thesis and/or the operation of these enzymes is dependent upon the operation of the respiratory enzyme cytochrome oxidase (9).

Visual external anaerobic injury symptoms have been described for 'Delicious' (1) and 'McIntosh' (15). Anderson (1) reports only 51% of the fruit developed external disorders after 6 months of storage in 0.0% O_2 with 0.0% CO_2 followed by 1 week in air. In this study, 75% of the fruit showed no external injury, even after 14 weeks of anoxia if they were observed immediately upon removal from storage, but 100% of the fruit developed necrotic patches during the following week in air.

In anaerobic studies with other tissues, the toxicity of ethanol is suspected to be very low (7), especially in a flow-through system (2) as used in this study.

In conclusion, the 'Delicious' apples in this study were very tolerant of anaerobic stress. No external injury was seen until 8 weeks of anoxia followed by 1 week in ambient air. Only one incidence of internal injury developed. The injury symptoms finally displayed were not related by a specific threshold ethanol level. Some fruit with high ethanol concentrations did not develop injury at the 8- and 10-week analysis. Some fruit developed injury while in the 0.0% O_2 environment, while others possessing greater ethanol quantities did not. Ethanol levels decreased during a week in air at 20°C following 14 weeks in 0.0% O_2, while injury increased from 25% to 100%. This work does not suggest the injury to be a direct result of ethanol accumulation alone. Physiological age is an important variable in successful low-O_2 storage as shown by increased ethanol accumulation and the earlier development of external injury in the late harvested fruit. No benefits in fruit quality were found by storing 'Delicious' apples in O_2 levels $<1.5\%$ for 12 or 14 weeks.

Literature Cited

1. Anderson, R.E. 1967. Experimental storage of eastern-grown 'Delicious' apples in various controlled atmospheres. Proc. Amer. Soc. Hort. Sci. 91:810–820.
2. Crawford, R.M.M. and Z.M. Zochowski. 1984. Tolerance of anoxia and ethanol toxicity in chickpea seedlings (*Cicer arietinum* L.). J. Expt. Bot. 35(159):1472–1480.
3. Davies, D.D., S. Grego, and P. Kenworthy. 1974. The control of the production of lactate and ethanol by higher plants. Planta 118:297–310.
4. Fidler, J.C. 1968. The metabolism of acetaldehyde by plant tissue. J. Expt. Bot. 19(58):41–51.
5. Fidler, J.C. and C.J. North. 1971. The effect of conditions of storage on the respiration of apples: VII. The carbon and oxygen balance. J. Hort. Sci. 46:245–250.
6. Fidler, J.C., B.G. Wilkinson, K.L. Edney, and R.O. Sharples. 1973. The biology of apple and pear storage. Commonwealth Agr. Bur., Slough, U.K.
7. Jackson, M.B., B. Herman, and A. Goodenough. 1982. An examination of the importance of ethanol in causing injury to flooded plants. Plant, Cell & Env. 5:163–172.
8. Kimmerer, T.W. and T.T. Kozlowski. 1982. Ethylene, ethane, acetaldehyde and ethanol production by plants under stress. Plant Physiol. 69:840–847.
9. Knee, M. 1982. Fruit softening: III. Requirement for oxygen and pH effects. J. Expt. Bot. 33:1263–1269.
10. Lidster, P.D., H.J. Lightfoot, and K.B. McRae. 1983. Production and regeneration of principal volatiles in apples stored in modified atmospheres and air. J. Food Sci. 48(2):400–402.
11. Neal, G.E. and A.C. Hulme. 1958. The organic acid metabolism of 'Bramley's Seedling' apple peel. J. Expt. Bot. 9:142–157.
12. North, C.J. and J.T. Cockburn. 1976. The tolerance of 'Cox's Orange Pippin' apples to low levels of oxygen. Rpt. East Malling Res. Sta. 1975:76.
13. Nursten, H.E. 1970. Volatile compounds: the aroma of fruits, p. 239–268. In: A.C. Hulme (ed.). The biochemistry of fruits and their products. Academic, New York.
14. Olsen, K.L. 1980. Rapid Ca and low oxygen storage of apples. A new concept for long storage of 'Golden Delicious' apples and more effective storage of red 'Delicious' apples. Proc. Wash. State Hort. Assn. p. 121–125.
15. Smock, R.M. 1958. Controlled-atmosphere storage of apples. N.Y. (Cornell) Ext. Bul. 759(rev.):1–36.
16. Thomas, M. and J.C. Fidler. 1933. Studies to zymasis: IV. Zymasis by apples in relation to oxygen concentration. Biochem. J. 27:1629–1642.
17. Topping, A.J. 1981. A recording laboratory penetrometer for fruit. J. Agr. Eng. Res. 26:179–183.
18. Washington State Apple Maturity Handbook. 1984. Washington State Apple Maturity Program. Wenatchee, Wash.

HortScience 22(1):92–94. 1987.

Effect of Postharvest Heat Treatments for Insect Control on the Quality and Market Life of Avocados

Eduardo L. Kerbel, F. Gordon Mitchell, and Gene Mayer
Department of Pomology, University of California, Davis, CA 95616

Additional index words. *Persea americana*, surface browning, bruising, respiration, ethylene production

Abstract. **The tolerance of avocado (*Persea americana* Mill. cv. Fuerte) to different heat treatments, using hot air at 43°C, was evaluated. The heat-treated avocados did not soften or ripen normally and exhibited severe surface browning after a 14-day simulated transit period at 7° followed by a 4-day simulated marketing period at 20°. Heat treatments also increased rate of weight loss, susceptibility to vibration injury, and loss of fresh avocado flavor.**

The avocado is an important fruit grown in California and is listed as one of the Mediterranean fruit fly [*Ceratitis capitata* (Wied.)] host commodities (4). Only fumigation, cold treatments, and heat treatments have been accepted as disinfestation procedures by quarantine authorities in importing countries (6). However, fumigants are difficult to use because of their extreme toxicity to humans, and cold treatments (10 days at ≤0°C to 16 days at ≤2° for the Mediterranean fruit fly) are of limited use for chilling-sensitive commodities like avocado.

The vapor heat treatment approved by the quarantine authorities for certain commodities consists of gradually raising the fruit temperature by exposure to saturated water vapor at 43°C until the center of the fruit reaches that temperature, then keeping the fruit at 43° for at least 8 hr (6).

Nothing has been reported on heat treatment of avocado since 1955, when Sinclair and Lindgren (5), working with 'Fuerte' and 'Dickenson' cultivars, found that this fruit would not tolerate a 16-hr treatment in a saturated atmosphere at 43°C.

The purpose of this study was to investigate the tolerance of 'Fuerte' avocado fruits to different heat treatments using hot air at 43°C, and a procedure to cool the fruit rapidly.

'Fuerte' avocados were obtained from the Ventura coastal area of California on 1 Mar. 1982. Fruit were selected for uniformity of size, maturity, and freedom from defects. One initial sample of 15 fruit was evaluated for flesh color and firmness, skin color, and oil content. Flesh and skin color were recorded using the Rd, a, and b modes of a Gardner Color Difference Meter (CDM Model XL-23) calibrated to a white reference plate

Received for publication 25 Apr. 1985. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

Table 1. Effect of heat treatments on weight loss, flesh firmness, internal appearance, and external appearance of 'Fuerte' avocado fruit[z] (n = 15) after 14 days of storage at 7°C + 4 days ripening at 20°.

Treatment	Hr of exposure to 43°C air	Wt loss (%)	Flesh firmness (N)	Internal appearance[y] (score)	External appearance[y] (score)
1 Control (7°)	0	5.5 ab[w]	5.8 a	0.1 a	0.6 a
2 Preheated only[v]	0	5.1 a	7.6 a	0.2 a	1.1 a
3 Preheated + air at 43°	3.5	6.3 bc	23.1 a	0.4 ab	4.1 b
4 Preheated + air at 43°	4	6.7 c	23.1 a	0.6 ab	4.3 b
5 Preheated + air at 43°	5	6.8 c	24.0 a	0.8 abc	4.4 b
6 Preheated + air at 43°	7	6.4 bc	41.4 a	1.0 abc	4.7 b
7 Preheated + air at 43°	11	7.0 c	161.5 b	1.4 bc	4.7 b
8 Air at 43° only	12	6.5 bc	170.0 b	1.7 c	4.3 b

[z]Fruit characteristics (mean ± SD) at harvest: flesh firmness (N) = 214 ± 2.1, flesh color ("a" value) = −14.9 ± 3.2, skin color ("a" value) = −10.1 ± 1.9, oil content = 24% ± 1%.
[y]Browning of flesh based on a scale of 0–5 (0 = none, 5 = extreme).
[x]Browning of surface based on a scale of 0–5 (0 = none, 5 = extreme).
[w]Mean separation within columns by least significant difference at the 1% level. Statistical analysis was made on data transformed using the arcsin transformation.
[v]Preheated at 35° for 6¼ hr.

(X = 81.7, Y = 84.1 and Z = 97.9). For this test, one cheek, with a 2- to 3-cm-diameter portion of skin removed, was placed in a watchglass over the large aperature of the colorimeter. Firmness measurements were taken on opposite cheeks of each fruit after skin removal using a UC Fruit Firmness Tester (1) fitted with an 8-mm plunger. Oil content was determined using the relation of dry weight to oil content reported by Lee et al. (2). In this relationship, dry weight is always 10% higher than percentage of oil content. For dry weight and oil analyses, the avocados were quartered longitudinally, peeled, and pitted. A potato peeler was used to take thin slices of tissue from one cut surface of each quarter. Ten grams of tissue were put into a tared petri dish. These dishes were weighed and set uncovered in a microwave oven (Amana model RR-10). The avocado slices were dried to constant weight (about 15 min at high power), after which dry weight was calculated as percentage of fresh weight. Oil content was calculated from dry weight values.

After sorting and randomizing, the fruit (240 ± 5 fruit per treatment) were distributed to the 8 treatments (Table 1). The fruit were placed into 45 × 45 × 90 cm (1½ × 1½ × 3 ft) open wooden bins with 5% vented bottoms. The bins were placed on top of fan boxes in rooms adjusted to the treatment temperature. In order to achieve 43°C quickly when transferred, and therefore to reduce possible injury at 43° by long exposure to this temperature, fruit from Treatments 2, 3, 4, 5, 6, and 7 (Table 1) were conditioned (preheated) for 6¼ hr in air at 35° and then kept in air at 43° for the designated times. About 2¼ hr were required for the center of the fruit to achieve 35°, and thereafter about 1 hr more to achieve 43°. Treatment 8 fruit (no conditioning) were kept in air at 43° for 12 hr, in this instance it took about 3½ hr for the center of the fruit to achieve 43°. In all instances, forced-air heating [0.06 $m^3 \cdot min^{-1} \cdot kg^{-1}$ (1 $ft^3 \cdot min^{-1} \cdot lb^{-1}$)] was used until the specified temperatures were achieved in the center of the fruit (as checked with thermocouple probes). After heating, the fruit were moved to 0° where they were forced-air cooled for 2 to 3 hr and then stored in vented corrugated boxes and covered with plastic film (to reduce water loss) for 14 days at 7° (simulated transit conditions). After storage, the fruit were ripened at 20° for 4 days (simulated marketing conditions). Relative humidities at 0°, 7°, 20°, 35°, and 43° were 94% ± 1%, 90% ± 1%, 83% ± 1%, 62% ± 2%, and 68% ± 2%, respectively.

Flesh firmness and color, skin color, and internal and external appearance were evaluated on 15 individual fruit per treatment, at time of transfer to 20°C and at the end of the 4-day ripening period. External and internal appearance were evaluated subjectively by scoring for browning of skin and flesh on the following scale: 0 = none, 1 = very slight, 2 = slight, 3 = moderate, 4 = severe, and 5 = extreme. Weight loss was determined on a composite sample by difference in weight before treatment and after storage and ripening. Carbon dioxide and C_2H_4 production were monitored on six individual fruit per treatment kept in individual 500-ml glass jars that were ventilated with a continuous air flow at 100 $ml \cdot min^{-1}$. Gas samples (10 ml) were withdrawn with disposable syringes and used for CO_2 and C_2H_4 analyses using Carle Model 111 thermal conductivity and Model 211 flame-ionization gas chromatographs, respectively. Measurements were made every 3 days during storage at 7° and every day during ripening at 20°.

Vibration injury and impact bruising tests were conducted on sets of 15 fruit per treatment 48 hr after treatment and following storage. For vibration injury, fruit were placed in smooth-surface open boxes and vibrated at 1.1× *g* acceleration for 10 min. For impact bruising, each fruit was impacted once on each cheek from a standard 91.4-cm (3-ft) height with a 2.5-cm (1-inch) steel ball dropped through a vertical column. The results of both tests were recorded 48 hr after the test.

A panel of 10 judges participated in the sensory evaluation of avocado flavor. Panelists were selected for their taste perception and were trained for 4 days on the use of the scoring system and the definitions of the flavor characteristics of avocados. Judges scored the samples for "cooked flavor", "sourness", and "fresh avocado flavor." Evaluations were replicated 3 times and the flavor characteristics were evaluated by the least significant difference multiple comparison test (3), using analyses of variance to test for significance.

Skin color and impact bruising did not differ significantly among treatments (data not included). Only fruit from Treatments 4, 5, and 7 lost more weight than control fruit. Relative to control fruit, only fruit from Treatments 7 and 8 developed more severe flesh browning, had lower flesh color "a" values, and softened less after 4 days ripening at 20°C (Tables 1 and 2). When fruit from Treatments 5, 6, 7, and 8 were peeled, there were many black spots (0.5 to 4.0 mm in diameter) in the flesh.

In contrast with control fruit, surface browning was more severe on fruit from all treatments except Treatment 2 (Table 1). These results suggest that surface browning

Table 2. Effect of heat treatments on flesh color and vibration injury (n = 15) after 14 days of storage at 7°C, and 'fresh avocado flavor' (n = 10) after 14 days of storage at 7° + 4 days ripening at 20°, of 'Fuerte' avocado fruits.

Treatment	Hr of exposure to 43°C air	Flesh color (CDM "a")	Vibration injury[z] (score)	Fresh avocado flavor (score)
1 Control (7°)	0	−13.5 c[x]	1.2 a	4.6 b
2 Preheated only[w]	0	−13.2 c	1.2 a	4.6 b
3 Preheated + air at 43°	3.5	−13.2 c	1.4 a	4.6 b
4 Preheated + air at 43°	4	−13.6 c	1.7 b	4.5 b
5 preheated + air at 43°	5	−11.6 c	2.0 b	4.4 b
6 Preheated + air at 43°	7	−11.1 bc	2.6 c	3.2 a
7 Preheated + air at 43°	11	− 8.1 a	4.9 e	3.3 a
8 Air at 43° only	12	− 8.3 ab	3.2 d	3.3 a

[z]Based on a scale of 0–5 (0 = none, 5 = extreme).
[y]Based on a scale of 0–5 (0 = lowest, 10 = highest).
[x]Mean separation within columns by least significant difference at the 1% level. Statistical analysis was made on data transformed using the arcsin transformation.
[w]Preheated at 35° for 6¼ hr.

was caused by the 43°C air treatment.

The heat treatments increased fruit susceptibility to vibration injury on all fruit that were exposed to 43°C air for 4 hr or more (Table 2). The judges scored fruit from Treatments 6, 7, and 8 as lacking fresh avocado flavor compared to control fruit.

Fruit from Treatments 2, 3, and 4 showed slightly lower CO_2 production rates than control fruit but reached their climacteric peak at the same time (i.e., after 2 days at 20°C). Fruit from Treatments 5, 6, 7, and 8 had not reach their climacteric peak after 4 days at 20° (data not shown). Ethylene production by control fruit and fruit from Treatment 2 reached the climacteric peak after 2 days at 20°. In fruit from all other treatments, C_2H_4 production rates continued to increase during the 4 days at 20°, which may have been due to heat stress injury, since it did not parallel changes in fruit softening.

We should mention that we were not able to achieve "saturated water vapor" conditions (100% RH) at 43°C in our laboratory. Therefore, the low relative humidity that was maintained during the experiments could have had an effect in the development of the observed heat injury symptoms.

The remarkable retention of firmness by the long exposures to 43°C (Treatments 7 and 8; Table 1) indicates inhibition of softening (which accompanies normal ripening) by heat stress. Presumably the enzymic degradation of polysaccharides that brings about softening was impaired.

Based on the extent of fruit injury, particularly surface browning and susceptibility to vibration injury, we conclude that these heat treatments were sufficiently injurious to be eliminated as potential quarantine procedures.

Literature Cited

1. Claypool, L.L. and R.B. Fridley. 1966. Precision in a pressure tester. Western Fruit Grower 20(7):18–19.
2. Lee, S.K., R.E. Young, P.M. Schiffman, and C.W. Coggins, Jr. 1983. Maturity studies of avocado fruit based on picking dates and dry weight. J. Amer. Soc. Hort. Sci. 108:390–394.
3. Little, T.M. and F.J. Hills. 1978. Agricultural experimentation, design and analysis, 1st ed. Wiley, New York.
4. Mitchell, F.G. 1981. Medfly host commodities. Perishables handling. Univ. of California Coop. Ext. 47(4):6–7.
5. Sinclair, W.B. and D.L. Lindgren. 1955. Vapor heat sterilization of California citrus and avocado fruits against fruit fly insects. J. Econ. Ent. 48(2):133–141.
6. United States Department of Agriculture, Animal and Plant Health Inspection Service. 1976. Plant Protection and Quarantine Treatment Manual.

HortScience 22(1):94–96. 1987.

Sugar and Organic Acid Content of Cherry Tomato Fruit at Different Ripening Stages

David H. Picha

Department of Horticulture, Louisiana Agricultural Experiment Station, Louisiana State University Agricultural Center, Baton Rouge, LA 70803

Additional index words. composition, fruit quality, *Lycopersicon esculentum*

Abstract. **Sugar and organic acid concentrations in fruit of two cherry tomato (*Lycopersicon esculentum* var. *cerasiforme* Alef.) cultivars ('Large Red Cherry' and 'Small Fry') were determined at five stages of ripening. Fructose and glucose concentration increased in both cultivars from the immature-green to table-ripe stage, with fructose being the primary sugar. Sucrose, present in low concentration, was higher in the immature-green than table-ripe stage. Citric acid was the primary organic acid and it increased in concentration from the immature-green to mature-green stage (and to the light-red stage in 'Small Fry'), but no further change occurred from the light-red to table-ripe stage. Malic acid decreased in concentration from the mature-green to table-ripe stage. 'Large Red Cherry' fruit contained more fructose, glucose, and malic acid, but less citric acid than 'Small Fry' fruit. The pattern of sugar and organic acid change during cherry tomato fruit ripening was similar to the pattern of change previously reported for large-fruited types.**

Sugars and organic acids comprise the majority of the total dry matter content of tomato fruit. Compositional changes in large-fruited *Lycopersicon esculentum* Mill. cultivars during ripening have been well-characterized, with total sugars found to increase progressively from the mature-green to table-ripe stage (1, 8, 13). Titratable acidity increased to its maximum at the breaker stage, usually followed by a decrease in the more advanced ripening stages (1, 8, 10, 13). Both citric and malic acid concentrations were greater at the breaker stage than table-ripe stage (2, 9). To my knowledge, no published information is available on the individual sugar and organic acid content in cherry tomato fruit during the different stages of ripening. Cherry tomato fruit had more total reducing sugars, titratable acidity, and citric acid than large-fruited cultivars when compared at the table-ripe stage (6, 7, 11, 12).

Physiological studies of tomato fruit are easy to perform on cherry-type fruit, which are usually uniform in size, small, and can be produced in abundance. It is not known if cherry tomato fruit follow a similar pattern of sugar and acid change during ripening as do large-fruited types. If the pattern is similar, metabolic studies involving the major sugars and organic acids during tomato ripening may be facilitated by using cherry-type fruit. The objective of this study was to determine the sugar and organic acid composition during different ripening stages in two widely grown cherry tomato cultivars.

'Large Red Cherry' (LRC) and 'Small Fry' (SF) cherry tomatoes were grown following commercially recommended cultural practices at the LSU Hill Farm, Baton Rouge, La., during Spring 1984. Sugar and organic acid contents were determined in fruit picked 22 June at five ripening stages (immature-green, mature-green, pink, light-red, and table-ripe). Five replications of 10 fruit were analyzed. All fruit within each cultivar were of comparable size, except that the immature-green stage fruit were slightly smaller. The 10 whole fruit from each replication were

Table 1.—Sugar content of 'Large Red Cherry' (LRC) and 'Small Fry' (SF) cherry tomatoes at different ripening stages.

	Sugar (% fresh wt)					
	Fructose		Glucose		Sucrose	
Stage	LRC	SF	LRC	SF	LRC	SF
Immature-green	1.26 e	1.08 e	0.97 e	0.85 d	0.05 a	0.05 a
Mature-green	1.31 d	1.25 d	1.02 d	0.88 c	0.05 a	0.04 b
Pink	1.67 c	1.33 c	1.32 c	0.95 b	0.05 a	0.03 c
Light-red	1.89 b	1.45 b	1.50 b	0.96 b	0.05 a	0.03 c
Table-ripe	2.00 a	1.77 a	1.67 a	1.40 a	0.03 b	0.03 c

[z]Mean separation within columns by Duncan's multiple range test, 5% level.

Received for publication 18 Apr. 1986. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.