J. Amer. Soc. Hort. Sci. 97(1):339-341. 1972.

Quality of 'Lula' Avocados Stored in Controlled Atmospheres with or without Ethylene[1]

T. T. Hatton, Jr.[2] and William F. Reeder[3]
Agricultural Research Service, U. S. Department of Agriculture, Orlando, Florida

ABSTRACT. Storage of 'Lula' avocados in controlled atmosphere (CA) of 2% oxygen (O2) and 10% carbon dioxide (CO_2) at 50°F for 30, 45, and 60 days resulted in more acceptable fruit than storage in air at this temp for similar durations. The removal of ethylene from the storage chambers increased the percentage of acceptable fruits, especially in the lots stored 60 days. CA-stored avocados, when placed in air at 70°F, softened more slowly than similar fruits that had been stored in air, and those stored without ethylene softened more slowly than those stored with ethylene. Anthracnose decay was the primary factor affecting acceptability, especially during the softening period at 70°F.

Ethylene long has been known to affect the physiology of various fruits in storage. Classic examples of the use of ethylene are its commercial application to ripen bananas and to de-green citrus fruits. Ethylene has been reported to increase disorders in citrus fruits, including pitting and decay (8, 17), and has been found to accumulate in apples during storage in quantities sufficient to injure the fruit (16). Storage in an atmosphere of 5% 02 + 10% CO_2, however, reduced ethylene production in apples (13). Eaks (7) found that neither a 6- nor 12-hr exposure to 100 ppm ethylene at 68°F was sufficient to initiate the ripening process of avocados, but a 24-hr exposure initiated ripening which was completed 3 or 4 days after the treatment was begun. Recently Gazit and Blumenfeld (9) found that avocados did not respond to ethylene treatments given immediately after harvest, but a softening response to treatment given 25 to 49 hr after harvest was observed at 17°C. They also found that avocados treated with either 10, 100, or 1,000 ppm ethylene softened at the same rate, which confirms the previous findings of Biale (3). A concentration of ethylene as low as 0.1 ppm was reported to initiate the ripening process of avocados (3, 4). Several investigations showed that the storage life of avocados was extended in a CA environment containing less CO_2 and more CO_2 than normal atmosphere (2, 10, 11, 15). Biale (1) reported that low concentrations of 0_2 reduced the respiratory activity during the pre-climacteric period and postponed the climacteric. Young et al. (18) showed that CO_2 delayed the onset of the respiratory rise in the avocado, reduced the rate of O_2 uptake at the climacteric peak, and extended storage life. In 1968, at the USDA Station in

[1] Received for publication October 15, 1971.
[2] Investigations Leader, Southeastern Citrus and Vegetable Investigations.
[3] Biological technician, Subtropical and Tropical Fruit Investigations, Miami, Florida. The authors wish to acknowledge the technical assistance of staff members of the Market Quality Research Division, Orlando, for monitoring the controlled-atmosphere equipment.

Miami and based on the results of previous tests (10, 11), a constant flow of an atmosphere containing 2% O_2 + 10% CO_2 was selected as promising for the storage of 'Lula' avocados (14). The previous tests conducted at Miami employed numerous combinations ofO_2 and CO_2 ranging from 1% to 5% and from 5% to 14%, respectively; a closed gas system was used in which ethylene presumably accumulated within the chambers. This investigation was initiated to compare the effects of storage in an atmosphere of 2% O_2 + 10% CO_2 with the ethylene removed from the system with similar storage during which the evolved ethylene was allowed to accumulate.

Materials and Methods

'Lula' avocados harvested on January 19, 1970, and packed in fiberboard cartons were obtained from a commercial packinghouse in the Homestead, Florida area. Three cartons containing 25 fruits each were stored at 50°F in chambers with atmosphere of 2% O2 + 10% CO_2 from which ethylene was removed; 3 similar cartons were stored at 50° in air, and an additional 3 cartons in 2% 0_2 + 10% $C0_2$ at 50° with ethylene allowed to accumulate. Chambers containing all fruit stored at 50°F, in both CA and air, were located in one controlled-temp room to eliminate the effects of temp differences in the various atmospheres. Chambers were identical in size and construction. One carton was placed directly at 70° in air. Relative humidity ranged from 75% to 95% in the 50° room and in storage chambers, and from 88% to 95% in the 70° room. One carton of avocados was removed from each of the 3 storage atmospheres after 30, 45, and 60 days' storage. Atmospheres within the CA chambers were adjusted to 2% O_2 + 10% CO_2 within 3 days and maintained within ±0.5% throughout the storage period. Atmospheres were maintained in gas tight chambers, and O_2 and CO_2 were monitored continuously and automatically by equipment that has previously been described (5). Atmospheres were circulated within the chambers and to the gas-analysis equipment with diaphragm pumps. Sequential analysis of separate atmospheres was controlled by time programming of solenoid valves to a gas chromatograph with a thermal conductivity detector. Return lines from the gas chromatograph provided a "closed system." $C0_2$ and 0_2 were added to the lines as needed with a flow meter to gauge proper levels. In the event CO_2 levels began to rise, metering valves were opened to a hydrated lime scrubber.

In half of the CA chambers the atmosphere was scrubbed to remove evolved ethylene. Canisters containing pellets of "Purafil"[4], activated alumina (Al_2O_3) impregnated with potassium permanganate ($KMnO_4$), were connected to the lines circulating the CA atmospheres to absorb evolved ethylene that was allowed to accumulate in the remaining chambers. Ethylene was measured daily by means of removing a 1-ml sample and injecting it into a flame ionization detector; the maximum sensitivity of the chromatographic equipment was 0.035 ppm per chart division.

After removal from storage, each fruit was examined for external appearance, and then held in the same room at 70°F in air until soft. When soft enough for eating, as

[4]Manufactured by Marbon Division, Borg-Wamer Corp., Washington, W.Va. Use of trade name and manufacturer's name is for identification purposes only and is not intended as a recommendation by the USDA of the article mentioned over similar articles by other manufacturers.

indicated by yielding under slight finger pressure, the fruit was examined for external and internal appearance. Palatability tests were made by taste panels with a minimum of 10 members.

Fruit was evaluated on freedom from decay and external discoloration. Avocados affected with any decay or having 25% or more of the surface area discolored were rated unacceptable; the remainder were rated acceptable. Statistical analyses of data were made by mean separation of the functional analyses of variance and multiple comparisons (6).

Results and Discussion

In chambers where ethylene was allowed to accumulate, 12, 18, and 29 ppm were present after 30, 45, and 60 days respectively. No ethylene was detected in those chambers in which $KMn0_4$ was used.

Table 1. Effect of ethylene on the acceptability[z] of 'Lula' avocados after storage at 50°F in controlled atmospheres and after the softening period in air at 70° (1970)[y].

Storage atmosphere	Immediately after storage for 30 days	45 days	60 days	After softening period following storage for 30 days	45 days	60 days
	%	%	%	%	%	%
Air	96a	12b	0b	84ab	4de	0e
2% O_2 + 10% CO_2 with ethylene[x]	100a	100a	100a	100a	76b	24d
2% O_2 + 10% CO_2 without ethylene	100a	100a	100a	100a	92ab	48c

[z]Data were based on 25 avocados per atmosphere after each storage period. Data in each section followed by different letters were significantly different at the 5% level (6).

[y]Avocados which exhibited less than 25% external discoloration and no decay. All acceptable fruit were palatable, and no internal discoloration was detected.

[x]Chambers contained 12, 18, and 29 ppm ethylene after 30, 45, and 60 days, respectively.

ACCEPTABILITY. When removed from CA storage, with or without ethylene, 100% of the avocados were acceptable (Table 1). From air storage only 12% were acceptable after 45 days. After 60 days in air all fruit was unacceptable because of anthracnose decay. The high percentage of unacceptable fruit after 45 and 60 days storage in air was comparable to previous studies (10, 11).

Significantly more avocados were acceptable after storage in CA without ethylene for 60 days and softened in air at 70°F than similar fruits stored with ethylene. No significant difference was observed in those stored 30 or 45 days, with or without ethylene (Table 1). Significantly more avocados stored in CA for 45 or 60 days, with or without ethylene, were acceptable than similar fruits stored in air; no significant differences were found after 30 days' storage. All fruit that was softened at 70° without storage was acceptable.

Most of the fruit that became unacceptable during the softening process had anthracnose decay. "Browning" of the skin, as previously described on 'Lula' avocados in CA storage (10), was not observed. The small amount of skin discoloration observed during the softening process on CA-stored fruit typified high temp spotting without darkening of the flesh, which has been described (12). No internal discoloration was detected on acceptable fruit, and all acceptable fruit was palatable.

DAYS TO SOFTEN. Avocados in CA storage with ethylene softened in significantly less time at all storage periods than those stored without ethylene (Table 2). Avocados from air storage softened in significantly less time than those from CA storage. Avocados which were not stored but softened directly at70°F required an average of 6.2 days to soften.

Table 2. Effect of ethylene on the time for 'Lula' avocados to soften in air at 70°F after storage at 50° in controlled atmospheres (1970)[z].

Storage atmosphere	Average time to soften after storage for 30	45	60	Total range
	Days	Days	Days	Days
Air	1.4e	0f	---	0-2
2% O_2 + 10% CO_2 with ethylene[y]	3.1d	3.6bc	3.5c	3-4
2% O_2 + 10% CO_2 without ethylene	3.5c	4.1a	3.7b	3-5

[z]Data were based on acceptable fruit only. Data followed by different letters were significantly different at the 5% level (6).

[y]Chambers contained 12, 18, and 29 ppm ethylene after 30, 45, and 60 days, respectively.

Conclusion

Removal of evolved ethylene from the storage atmosphere assists in maintaining market quality of avocados by reducing the rate of softening and increasing acceptability. The $KMnO_4$ used in this study appears satisfactory for removal of ethylene from the CA storage chambers.

Literature Cited

1. Biale, J. B. 1946. Effect of oxygen concentration on respiration of the Fuerte avocado fruit. *Amer. J. Bot.* 33:363-373.
2. _____. 1947. Control of vapors in storage essential for prolonging life of avocado. *Calif. voc. Soc. Yearb.* 1947:43.
3. _____. 1960. The post-harvest biochemistry of tropical and sub-tropical fruits. *Adv. Food Res.* 10:293-354.
4. Burg, S. P., and E. A. Burg. 1962. Role of ethylene in fruit ripening. *Plant Physiol.* 37:179-189.
5. Chace, W. G., Jr., P. L. Davis, and J. J. Smoot. 1969. Response of citrus fruits to controlled atmosphere storage. *Proc. XII Internatl. Congr. Refrigeration,* Madrid (1967), III:383-391.
6. Duncan, D. B. 1955. Multiple range and multiple F. tests. *Biometrics* 11:1-42.
7. Eaks, I. L. 1966. The effect of ethylene upon ripening and respiration rate of avocado fruit. *Calif. Avoc. Soc. Yearb.* 50:128-133.
8. Fawcett, H. S. 1936. Citrus diseases and their control. McGraw-Hill Book Co., New York. 656 p.
9. Gazit, S., and A. Blumenfeld. 1970. Response of mature avocado fruits to ethylene treatments before and after harvest. /. *Amer. Soc. Hon. Sci.* 95:229-231.
10. Hatton, T. T., and W. F. Reeder. 1970. Maintaining market quality of Florida avocados. *Proc. Trop. Products Inst. Conf.* London, England:277-280.
11. _____ and _____. Controlled atmosphere storage of Lula avocados-1965 *tests. Proc. Caribbean Region Amer. Soc. Hort. Sci.*9:152-159.

12. _____, _____, and C. W. Campbell. 1965. Ripening and storage of Florida avocados. *USDA Market. Res. Rept.* 697. 3 p.

13. Potter, N.A., and D. G. Griffiths. 1947. The effects of temperature and gas mixtures on the production of volatile substances by apples during storage. *J. Pomol. Hort. Sci.* 23:171-177.

14. Reeder, William F., and T. T. Hatton, Jr. 1971. Storage of Lula avocados in controlled atmosphere--1970 tests. *Proc. Fla. State Hort. Soc.* 83:403-405.

15. Salama, S. B., W. Grierson, and M. F. Oberbacher. 1966. Storage trials with limes, avocados, and lemons in modified atmospheres. *Proc. Fla. State Hort. Soc.* 78:353-358.

16. Smock, R. M. 1942. The influence of one lot of apple fruits on another. *Proc. Amer. Soc. Hort. Sci.* 40:187-192.

17. Winston, J. R., and C. L. Roberts. 1944. Effect of packing-house practices on decay, rind breakdown and juice quality in Florida oranges. *Proc. Fla. State Hort. Soc.* 57:140-144.

18. Young, R. E., R. J. Romani, and J. B. Biale. 1962. Carbon dioxide effects on fruit respiration. II. Response of avocados, bananas, and lemons in controlled atmospheres. *Plant Physiol.* 37:416-422.