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STORAGE TRIALS WITH LIMES, AVOCADOS, AND LEMONS IN MODIFIED ATMOSPHERES[1]

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ABSTRACT

The 'Bearss' strain of 'Sicilian' lemons was held in green, firm condition using controlled atmospheres with lowered oxygen down to 6%. Increasing carbon dioxide caused serious increase in decay. 'Booth 8' avocados responded well to controlled atmosphere storage both in terms of increased carbon dioxide and subnormal oxygen. However, samples were small, and results included inconsistencies that need further evaluation. Controlled atmospheres increased decay of 'Persian' limes. Dipping limes in 100 ppm 2,4-D and 300 ppm gibberellic acid before storage helped retard the green to yellow color change.

INTRODUCTION AND REVIEW OF LITERATURE

Although controlled atmosphere storage is a well established technique with deciduous fruits (11), comparatively little research has been devoted to its possibilities for tropical and subtropical fruits.

Lemons

Review of literature on controlled atmosphere storage of lemons and other pertinent papers is covered in another paper from this laboratory (10).

Limes

The importance of marketing bright, light green limes, reasonable free of various forms of peel injury, has been emphasized by Manley and Godwin (13). Post-harvest peel injuries can be divided into those initiated by rough handling (8), and those that are apparently physiological. Various chemicals have been reported as delaying undesirable color change or physiological breakdown. These include 2,4-D (9) sorbic acid, and gibberelic acid (6). No account of controlled atmosphere storage of limes was noted.

Avocados

Although it is generally accepted that avocados are subject to chilling injury, the literature gives a surprising range of "optimum" storage temperatures depending on race, variety, and locality where grown (2, 4, 7, 14, 15, 19, 21). At storage temperatures of 50° F or higher, softening is rapid, skin blemishes and fungal disorders develop quickly, and marketability is seriously affected (20).

A particularly pertinent account is that of Mustard (14) who reported storage life of Florida-grown 'Booth 8' avocados to be no more than 3 weeks in air storage and less at some temperatures.

Controlled atmosphere storage (also referred to as "modified air storage" (2) and "gas storage" (11) has been tried with varying degrees of success, benefit being reported both from raising CO_2, or lowering O_2 concentrations (1, 2, 3, 5, 19). Biale (3) reported good tolerance to CO_2, but oxygen levels below 2.5% caused internal fermentation and consequent off-flavors. This is in contrast to Lynch, reported by Ruehle (17) as finding CO_2 damage to Florida avocados by concentrations as low as 3%. It is possible, however, that this might be due to accumulation of organic volatiles (4).

Current work

This report summarizes a series of exploratory studies on the possible use of controlled atmosphere storage for extending the marketing period for lemons, limes, and avocados. In the experiments with limes, the use of controlled atmospheres was combined with the application of various post-harvest chemicals. The compounds used are known to have physiological effects, which might logically be beneficial in preserving green color or retarding stylar-end breakdown.

MATERIALS AND METHODS

Atmosphere Control

The simplest of all controlled atmosphere techniques was used for these exploratory studies. Fruit were enclosed in sealed 5-gallon glass jars with metal lids. The lids were pierced with a diffusion hole whose size varied from 1/32 to 1/8 of an inch. The jars within a given experiment were placed in a constant temperature room in a position of minimum air movement and disturbed as little as possible. Under such circumstances, respiratory activity lowers oxygen and raises carbon dioxide concentrations until the respiratory activity of the fruit is balanced by the diffusion of oxygen inward and carbon dioxide outward at the diffusion hole. At this point, equilibrium is established, and a reasonably constant controlled atmosphere condition results. If a carbon dioxide absorber is included in the jar ($Ca\ (OH)_2$, was used in some experiments), oxygen concentration decreases but carbon dioxide does not build up. The first trial used 10 grams of $Ca\ (OH)_2$, which did not prove adequate. Thereafter, half a pound of lime in a Kraft paper bag was used per 5-gallon jar.

In the avocado experiments, some jars had 10 grams of activated coconut shell carbon to absorb organic volátiles other than carbon dioxide and ethylene.

The atmospheres resulting from this simple, but convenient arrangement are exemplified in Figure 1. This is a graphical representation of the equilibrium atmospheres established using this technique with limes at 60° F and diffusion holes ranging from 1/32 to 1/8-inch. In all such experiments, control samples were held in ventilated fruit cartons adjacent to the diffusion jars.

Analyses of the atmospheres were made by using a hypodermic syringe to withdraw a 5-ml sample through the diffusion hole and analyzing this on a Fisher clinical gas partitioner, using H.M.P.A. and molecular sieve: Fisher No. 11134-45 matched set for CO_2 O_2 and N_2.

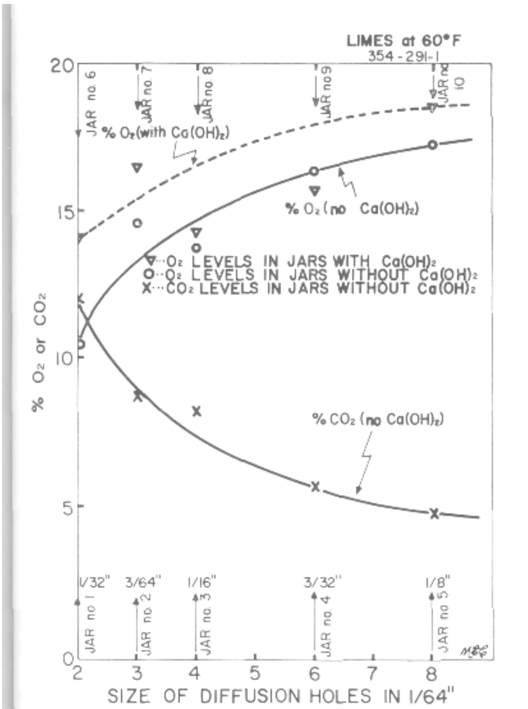

Figure 1.—Atmospheres established within 5-gallon jars filled with limes, equipped with diffusion holes of 1/32, 3/64, 1/16, 3/32, and 1/8 inch, respectively and held at a constant 60° F.

Prestorage dips

For the experiments with limes, the fruit were randomized into lots of 10. These were then dipped in the various solutions, dried, placed in Vexar (polyethylene net) bags, and put into the diffusion jars. Thus each atmosphere contained fruit treated with each of the various dip treatments. Dips used were:

Sorbic acid 0.1 and 1.0%

Maleic hydrazide 1,000 ppm

2,4-D 10 and 100 ppm

2,4,5-T 10 and 100 ppm

Gibberellic acid 100 and 300 ppm.

After the first experiment, the lower concentrations were discontinued, as was the 2,4,5-T dip.

Pressure tests

Pressure test measurements were made on avocados using a standard Magness-Taylor pressure tester (12) with a "Mechanical Thumb" attachment (18).

Color

Fruit color was read in terms of absorbance at 675 mμ, on a B & L Spectronic 20 (16).

Fruit

Lemons were the 'Bearss' strain of 'Sicilian' from groves in Dade and Highland Counties. 'Booth 8' avocados and 'Persian' limes were both obtained from Dade County.

RESULTS

Lemons

Typical data obtained with the diffusion jar technique are shown in Figure 2. This represents the findings on termination of this experiment at 56 days from the closing of the jars. Color change from green to yellow was increasingly retarded as carbon dioxide levels increased and oxygen levels decreased. Color change was virtually arrested for the full 56 days at 16% CO_2 and 5% O_2. The extent to which CO_2 is increased above normal, and oxygen decreased, affords an approximate basis for calculating respiratory quotient. Values above unity can indicate anaerobiosis. In this experiment, decay levels were so low that it is dubious whether much significance can be attached to the increase in decay as R.Q. values of unity are exceeded. However, it is of interest.

As a result of this and other exploratory experiments, a more complex study was set up. This clearly demonstrated that decay was increased in lemons by controlled atmospheres using raised CO_2 to delay maturation. Atmospheres in which the same effect was achieved by decreasing oxygen levels to 6% or less, did not cause increased decay (10).

Avocados

Two experiments were run at 50° F. Each included 9 treatments of 10 fruit each. These were a control (air-stored) sample, plus 2 series of 4 jars, each having 1/8and 1/16-inch diffusion holes respectively and the following sub treatments:

- No insert
- Activated charcoal at 1 gram per fruit
- Lime at 1 gram per fruit
- Both lime and activated charcoal.

Examination after 3 and 5 weeks at 50° F included pressure tests with a "Mechanical Thumb" device (18), external examination for pitting and fungal attack and, at the second examination, tasting.

Although the results were quite inconsistent, they were encouraging in that, although no air-stored fruit survived to the 3-week examination, some fruit in every controlled atmosphere treatment were marketable at 5 weeks. The 2 best results were: 80% marketable fruit at 5 weeks using an atmosphere of 5% oxygen and 13% carbon dioxide plus activated charcoal; and 70% marketable fruit from an atmosphere of 2% oxygen, 22% carbon dioxide and no insert. To some extent, the variability of the results probably reflects the small size of the individual samples, but it is apparent that further study is merited. For this, carbon dioxide concentrations of over 10%, oxygen concentrations below 10%, and activated charcoal in quantities greater than 1 gram per fruit are indicated.

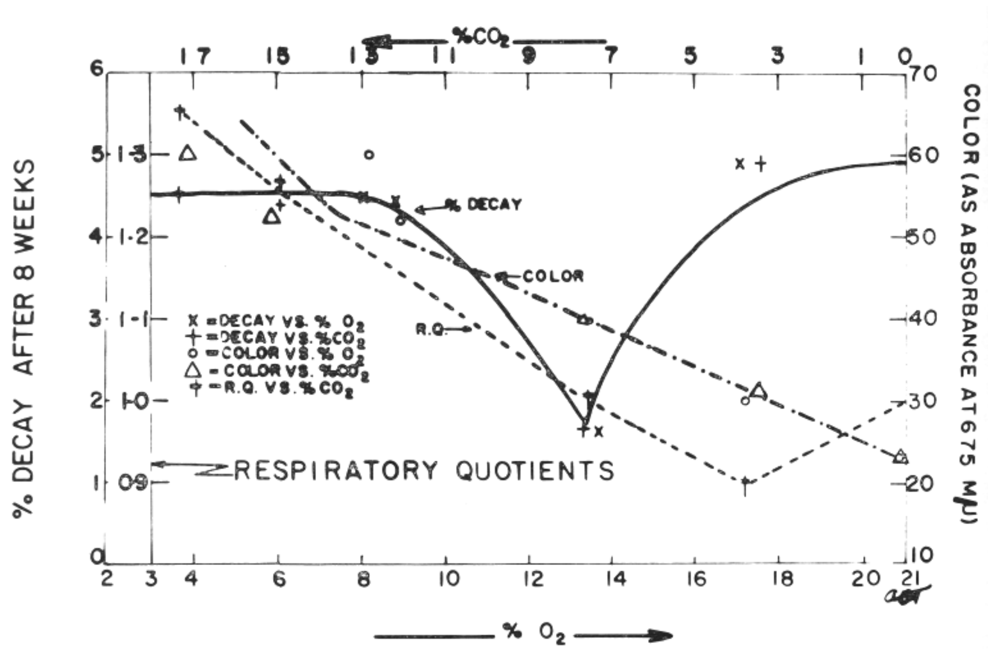

Figure 2.—Relationship between concentrations of carbon dioxide and oxygen, Respiratory Quotient, fruit color, and decay in Florida lemons in controlled atmospheres at 50° F.

Limes

Controlled atmosphere trials were disappointing. Four experiments were carried out using the variations in conditions tabulated in Table 1. All controlled atmosphere conditions caused substantial increases in decay. In the first experiment, losses at 4 weeks were 100% from *Penicillium* mold in the 2 most extreme controlled atmosphere conditions.

When such a decay problem was encountered with lemons, it was largely overcome by using controlled atmosphere with low oxygen levels, but without increasing carbon dioxide (10). With limes, complete removal of carbon dioxide by using 1/2 pound of lime per 5-gallon jar (containing about 75 limes) did not perceptibly change decay levels.

The green to yellow color change was slowed up or arrested by increased CO_2 levels, but decreased oxygen without increased CO_2 was comparatively ineffective. The most successful control of color change was in limes picked in late summer (18 August) and stored at 70° F in 4% O_2 + 30% CO_2. However, decay in the sub samples ranged from 20 to 80%, averaging 43%.

Prestorage dips affected color, but the effect was not always consistent. Gibberellin at 300 ppm was the most effective, and after that 2,4-D at 100 ppm. The use of 2,4-D consistently caused a reduction in decay of limes in controlled atmosphere storage, but not in the air-stored checks. This could well be explored further using larger samples, a wider range of concentrations, and prompter treatment after harvest.

DISCUSSION

Controlled atmosphere storage of Florida lemons began to look promising as soon as reliance was put upon decreasing oxygen concentration without increasing carbon dioxide above normal atmospheric levels. This work was then taken out of this "screening study" and pursued in parallel research in the same laboratory (10).

Avocados showed definite evidence of benefit from controlled atmosphere storage methods. Although the results with small samples and simple methods involved some inconsistencies, there was no evidence of damage due to oxygen levels as low as 3% or carbon dioxide levels as high as 22% during 5-weeks storage at 50° F. This is encouraging, but considerably more work would be necessary to determine optimum controlled atmosphere concentrations for the 'Booth 8' variety, and to explore interactions between atmospheres and temperatures for this and other varieties of Florida avocados. It is particularly encouraging to note that, apparently, high carbon dioxide levels can be used as well as decreased oxygen levels.

Any gain made in preserving the green color of limes by using controlled atmospheres was at the expense of greatly increased decay. Use of prestorage dips was more successful, 2,4-D and gibberellin both showing some promise for delaying color change in Florida limes. Attention is drawn to the fact that Food and Drug Administration approval is necessary for any such treatments. However, 2,4-D is already a standard treatment for preserving "green buttons" on California and Arizona lemons, and gibberellin is already in use for various preharvest uses (6).

Table 1. Controlled atmosphere experiments with limes: Dates and treatments.

Date started	Days duration	Atmospheres (limits as %) O_2	CO_2	Temperatures °F	Ca(OH)2 insert used?	Number of prestorage treatments
19 Oct/64	28	<4-15	8->30	60	No	9 + control
8 Dec/64	23	5-11	10-22	60	No	4 + control
	37			50	No	4 + control
20 July/65	15	6-18	0-24	60	No	4 + control
					Yes	4 + control
20 Aug/65	18	4-19	0-30	70	No	4 + control
					Yes	4 + control

Table 2. Effect of rough vs. gentle handling on stylar-end breakdown, decay, and color of 'Persian' limes.

Treatment	Days at 60° F	Stylar-end breakdown	Decay	Color*
Before handling	0	0	0	84.6
Gentle handling	14	1.3%	1.9%	73.1
Rough handling	14	14.9%	6.5%	56.9

*High readings indicate green, low readings yellowing.

No stylar-end breakdown was encountered. Eaks has stressed the importance of gentle handling in reducing physiological peel breakdown of California limes (8). In view of this, 4 additional cartons of limes were requested from our cooperators in Dade County. Immediately upon arrival at Lake Alfred, these were randomized into 2 treatments: "rough" in which the individual fruit were tossed into the carton, and "gentle" in which they were laid in carefully. The results are shown in Table 2, in which more than 10 times the amount of stylar-end breakdown occurred in the "rough" treatment as compared with gentle handling. Decay was increased threefold. What is of almost as much interest to lime growers is that the green to yellow color change was greatly accelerated by this much rough handling.

It would appear that the absence of stylar-end breakdown in the previous experiments may have been due to the care taken by our cooperators to deliver this fruit to us in good condition.

[1]Cooperative research by the Florida Citrus Experiment Station and the Florida Citrus Commission. Dr. Salama was on leave of absence at Lake Alfred.
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REFERENCES

1. Biale, J. B. 1941. The climacteric rise in respiration rate of the Fuerte avocado fruit. Proc. Am. Soc. Hort. Sci. 39: 137-142.
2. _______1942. Preliminary studies on modified air storage of the Fuerte avocado fruit. Proc. Am. Soc. Hort. Sci. 41: 113-118.
3. _______1946. Effect of oxygen concentration on respiration of the Fuerte avocado fruit. Am. J. Bot. 33(5): 363-373.
4. _______1947. Control of vapors essential for prolonging life of avocados. Yr. Bk. Calif. Avocado Soc. for 1947, p. 43.
5. Brooks, C., C. O. Brantley, and L. P. McCulloch. 1936. Transit and storage diseases of fruits and vegetables as affected by initial CO, treatments. U.S.D.A. Tech. Bull. 519.
6. Burns, R., D. O. Rosedale, J. E. Pehrson, Jr., and C. W. Coggins, Jr. 1964. Gibberellin sprays delay lime maturity. Calif. Agr. 18(7): 14-15.
7. Campbell, C. W., and T. T. Hatten, Jr. 1959. Chilling injury in Pollock avocados during cold storage. Proc. Fla. State Hort. Soc. 72: 337-338.
8. Eaks, I. L. 1955. The physiological breakdown of the rind of lime fruits after harvest. Proc. Am. Soc. Hort. Sci. 66: 141-145.
9. Gates, C. M. 1949. The possibilities of 2,4-D for the control of post-harvest decay in Florida limes. Proc. Fla. State Hort. Soc. 62: 220-222.
10. Grierson, W., H. M. Vines, M. F. Oberbacher, and S. V. Ting. 1965. Controlled atmosphere storage of Florida and California lemons. Presented to Ann. Mtg. Am. Soc. Hort. Sci. Aug. 1965. (In press).
11. Kidd, F., C. West, and M. N. Kidd. 1926. Gas storage of fruit. Special Rept. No. 30: 1-87, Food Investigation Board, Dept. Sci. & Ind. Res. (Gr. Brit.).
12. Magness, J. R., and G. F. Taylor. 1925. An improved type of pressure tester for determination of fruit maturity. U.S.D.A. Circ. 350, 8 pp.
13. Manley, W. T., and M. R. Godwin. 1962. Characteristics and potentialities of the consumer market for Florida limes. Fla. Agr. Expt. Sta. Bull. 1962.
14. Mustard, Margaret J. 1952. Effect of cold storage on some Florida avocados. Proc. Fla. State Hort. Soc. 65: 180-186.
15. _______, and A. L. Stahl. 1949. Packaging and storage of mangos and avocados. Proc. Fla. State Hort. Soc. 65: 226-232.

16. Oberbacher, M. F., and H. M. Vines. 1965. Use of B & L reflectance unit as a measure of chlorophyll disappearance. Proc. Assn. So. Agr. Workers Inc. 62: 243-244.
17. Ruehle, G. D. 1949. Avocado production in Florida. Fla. Agr. Expt. Sta. Bull. 141 p. 87. (Revision of Bull. 272 by H. S. Wolfe, L. R. Toy, and A. L. Stahl).
18. Schomer, H. A., and K. L. Olsen. The "mechanical thumb." Quoted in Agric. Mktg. 7(7): July, 1962.
19. _______, and E. R. Leonard. 1935. The storage of avocado pears. Low Temp. Res. Memoir No. 1, Imp. Coll. Trop. Agr. (Trinidad).
20. Williams, F. W., D. L. Brooke, and W. B. Riggan. 1962. The effect of price variation, skin blemish, and firmness on retail sale of Florida avocados. Fla. Agr. Expt. Sta. Bull. 645.
21. Wright, R. C., D. H. Rose, and T. M. Whiteman. 1954. The commercial storage of fruits, vegetables, and florist and nursery stocks. U. S. Dept. Agr., Agr. Handbook No. 66.

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