J. Amer. Soc. Hort. Sci. 110(3):398–402. 1985.

Relationship among Ventilation of Citrus Storage Room, Internal Fruit Atmosphere, and Fruit Quality

J. Waks, E. Chalutz, Mina Schiffmann-Nadel, and Ella Lomeniec

Division of Fruit and Vegetable Storage, Agricultural Research Organization, The Volcani Center, P.O. Box 6, Bet Dagan, 50250, Israel

Additional index words. grapefruit, orange, 'Shamouti', 'Valencia', carbon dioxide, oxygen, fresh air introduction

Abstract. **Changes in air composition of the citrus storage atmosphere and of the internal atmosphere of the fruit as affected by the ventilation rate were studied using 1 grapefruit and 2 orange cultivars. These changes were examined in relation to fruit weight loss, ethanol content of the juice, and rot development during storage periods of up to 5 months. Rates of ventilation affected the CO_2 concentrations more than the O_2 levels of both the external and internal atmospheres of the fruit. In small-scale tests, ventilation rates as low as 10%·hr^{-1} of the empty volume of the storage space did not cause major changes in the gas composition, nor did they effect fruit quality adversely. In commercial tests, however, an increased rate of ventilation (70% to 100%·hr^{-1}) was needed to reach similar results. On the basis of this information we recommend reducing the ventilation rate in commercial citrus storage rooms from 150% or 200%·hr^{-1}, the rate now commonly employed, to 100%·hr^{-1}. This reduced ventilation rate will help lower costs of refrigeration, while maintaining good fruit quality.**

Most citrus cultivars have a relatively long postharvest life. Consequently, these fruit are stored for periods of up to 7 months, making the fruit available to the consumer almost year around. Of the 3 primary environmental factors affecting fruit quality in storage (temperature, relative humidity, and composition of atmosphere) the first 2 have been studied extensively and optimized for storage of citrus fruit (3, 14). The composition of the atmosphere in storage, however, has received much less attention (3).

It has been recognized that ventilation of citrus storage rooms is necessary for successful storage or transport (3, 4, 10, 11, 13, 14, 21). In the absence of adequate ventilation, changes occur in the composition of both the storage atmosphere and the internal atmosphere of the fruit (2, 6, 7, 10, 11). However, unlike several other fruit and vegetables which clearly benefit from modified (or controlled) atmosphere storage (16), citrus fruit do not respond favorably to these conditions (9). Reduced O_2 levels often lead to a distinct off-flavor, and an accumulation of ethanol in the fruit (5, 6, 7, 15, 20, 21), whereas increased CO_2 concentrations do not reduce, and sometimes increase, the incidence of decay (2, 10, 25). Another possible undesirable change in the storage atmosphere is an increased concentration of C_2H_4. Although healthy citrus fruit produce very little of this gas after harvest (19, 23), fungal rots, particularly the green-mold rot caused by *Penicillium digitatum*, very markedly increase the rate of C_2H_4 production (10, 19). Removing or reducing C_2H_4 levels in the storage room has been shown to improve lemon (24) and grapefruit quality in storage, especially when the storage period is long and C_2H_4 concentrations are high (8, 10, 12, 15). Other volatile compounds also are produced by citrus fruit after harvest (17). The increased evolution of some of them, e.g., ethanol and acetaldehyde, has been associated with accelerated rot development (20) and fruit senescence (18).

To avoid these undesirable changes in the gas composition of the storage atmosphere, ventilation is provided during citrus storage by introducing outside air into the storage room at a rate of 150% to 300%·hr^{-1} (1½ to 3 exchanges·hr^{-1} of the empty volume of the storage room) and circulating the internal air. When external temperature is high, the introducton of fresh air increases the cost of refrigeration and also may make it more difficult to maintain the required storage temperature and relative humidity.

To the best of our knowledge, no comprehensive study has been undertaken to determine optimal ventilation requirements of the main citrus fruit cultivars during storage or shipment. Current recommendations are based on experience, which has shown that the introduction of fresh air at a rate of 150% to 300%·hr^{-1} usually is adequate. The high cost of energy and the need for energy conservation prompted us to study the effect of reduction of the ventilation rate on the quality of the fruit, by evaluating responses of the fruit to the gas composition of the storage room and to the internal atmosphere of the fruit.

Materials and Methods

The fruit used in all experiments was freshly harvested grapefruit (*Citrus paradisi* Macf.) 'Marsh' and oranges (*Citrus sinensis* Osbeck) 'Shamouti' and 'Valencia', commercially treated in the packing-house. The fruit either were placed in 3-liter glass jars or packed in cartons. For small-scale experiments, 4 to 6 fruit were placed in each glass jar. In other tests, 4 cartons (160 fruit) were placed in polyvinyl chloride (PVC) tents, leaving 10% to 15% of the tent volume unoccupied by the cartons. Fresh air was passed through the fruit in the jars or tents at rates of 100%, 50%, 25%, 10%, 5%, 2.5% or 0%·hr^{-1} of the empty volume of the jar or tent. Control fruit were packed in cartons and kept under ventilation conditions of 150% to 200%·hr^{-1}. The tents and jars were placed in refrigerated rooms at 11°C, and the relative humidity was kept high (90% to 92%) by passing the fresh air through water before introducing it to the fruit. To avoid excess humidity in the tents, the air was cooled to 11° and only then passed through water and to the fruit. Duration

Received for publication 27 Feb. 1984. Contribution from the Agr. Res. Org., The Volcani Center, Bet-Dagan, Israel. No. 963E 1984 Series. The technical assistance of S. Yavin and Y. Zutchi is acknowledged. We wish to thank A. Gisser and N. Kaplan of the Israel Citrus Marketing Board for their participation in the commercial tests. Supported in part by a grant from the Israel Citrus Marketing Board. 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.

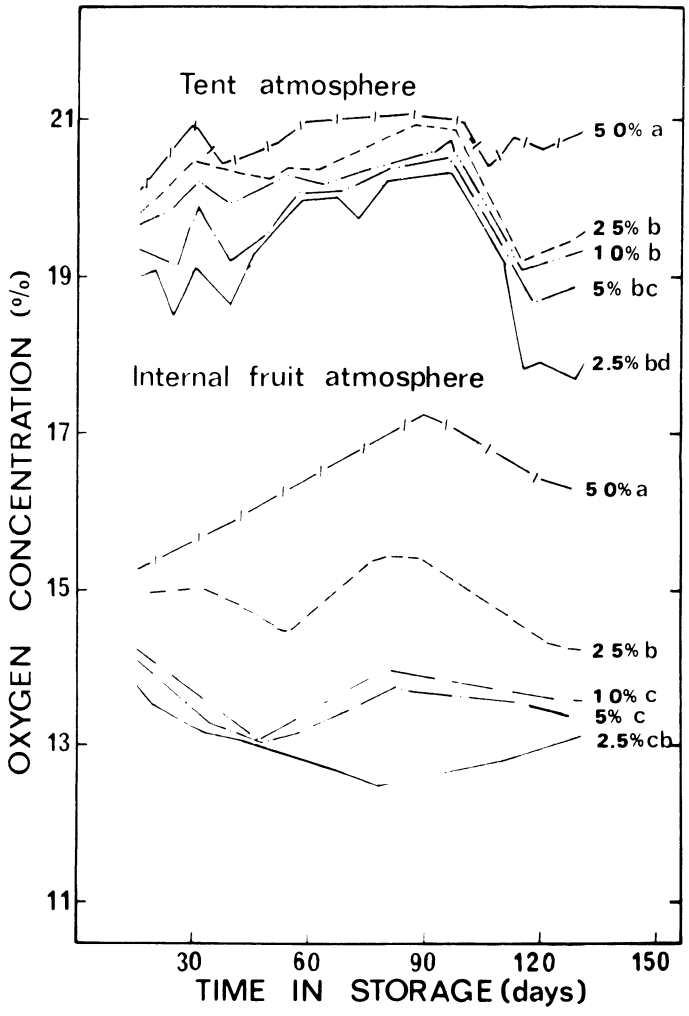

Fig. 1. Changes in O_2 concentration in the tent atmosphere and in the internal atmosphere of grapefruit. Packed fruit was stored in PVC tents and ventilated at rates of 50% to 2.5%·hr $^{-1}$ for periods up to 150 days. Ventilation rates followed by the same letter do not differ significantly at the 5% level using Duncan's multiple range test for differences between atmospheres.

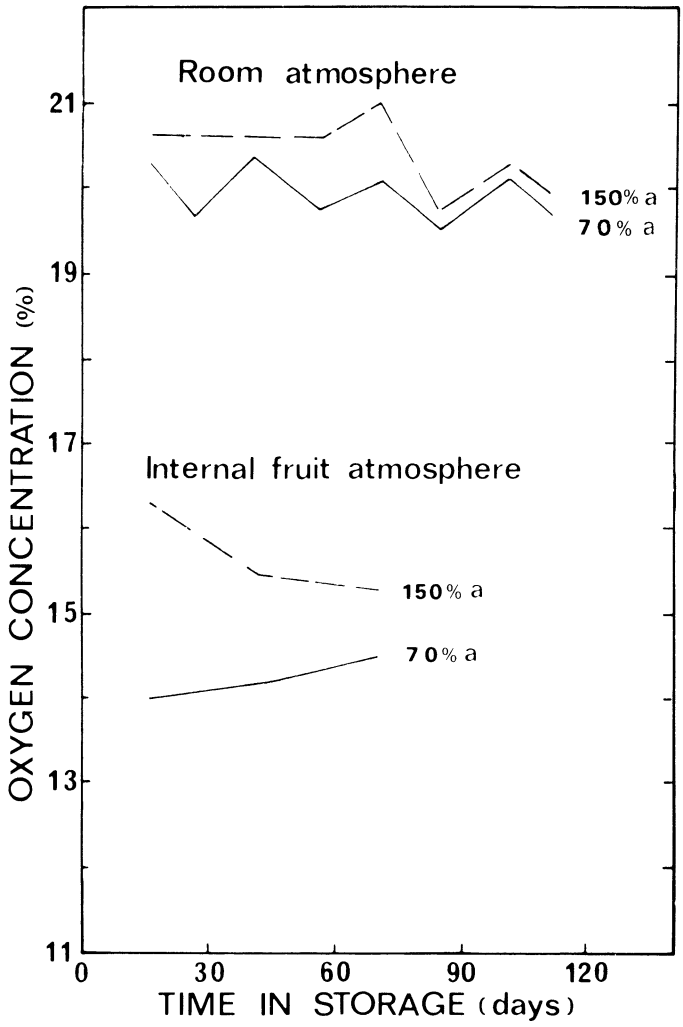

Fig. 2. Effect of ventilation rate in commercial storage rooms on O_2 concentration in grapefruit storage rooms and in the internal atmosphere of the fruit. Ventilation rates followed by the same letter do not differ significantly at the 5% level using Duncan's multiple range test for differences between atmospheres.

of storage was up to 16 weeks, with 2 additional weeks at 17° (150% to 200%·hr^{-1} of fresh air introduction) to simulate shelf life conditions. For large scale commercial trials which were carried out with grapefruit only, 100 MT storage rooms packed to 70% of their volume were used. Fresh air was introduced through an opening near the cooling coils and fans at rates of either 35% vs. 100% or 70% vs. 150%·hr^{-1}.

During cold storage and simulated shelf life conditions, several factors were analyzed in the storage container and inside the fruit. Periodically the composition of the atmosphere (O_2, CO_2, C_2H_4, and ethanol) near the fruit as well as in its internal atmosphere was analyzed by gas chromatography (8, 17, 19). Samples of the internal fruit atmosphere were obtained by submerging the fruit in water and withdrawing a 7-to 10-ml gas sample with an air-tight syringe from the central cavity (core) of the fruit. The combined volume of gas withdrawn from 3 fruit was used for each reading, with 3 replicates (a total of 9 fruit) per reading. Other parameters tested were weight loss of the fruit (20 fruit for each treatment), ethanol content of the juice (3 fruit for each treatment) (18), and the development of blemishes and rots (22). Two PVC tents, each containing 4 cartons (at least 160 fruit) were used for each ventilation treatment. For commercial trials two 100 MT rooms per treatment were used. The tests were carried out during 2 consecutive years.

Results and Discussion

In all experiments, both in small-scale tests with several fruit in jars and in tests with carton-packed fruit, the ventilation rate affected the composition of both the internal and the external atmosphere of fruit.

Oxygen. The concentration of O_2 in the atmosphere of the tents decreased only slightly and was kept at a level of 17.5% to 20% at ventilation levels of 50% to 2.5%·hr^{-1} during a storage period of 150 days at 11°C (Fig. 1). The O_2 levels in the internal atmosphere of this fruit, however, were reduced markedly as the ventilation rate was decreased reaching 12% to 13% at low ventilation rates (Fig. 1). Similar results were obtained also with fruit stored in glass jars. In tents without any ventilation, O_2 levels in the tent atmosphere were reduced to 12% and in the internal fruit atmosphere to 8% within 120 days of storage (data not shown). Tests in commercial storage rooms revealed that a decrease in the ventilation rate from 150% to

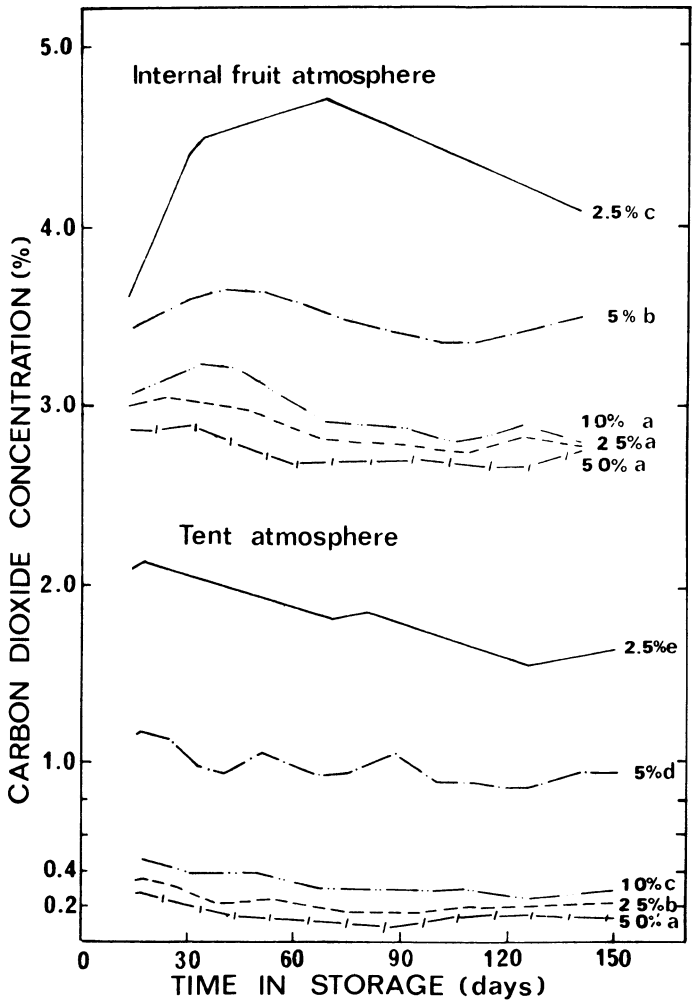

Fig. 3. Changes in CO_2 concentrations in the tent atmosphere and in the internal atmosphere of grapefruit as affected by the ventilation rate. Ventilation rates followed by the same letter do not differ significantly at the 5% level using Duncan's multiple range test for differences between atmospheres.

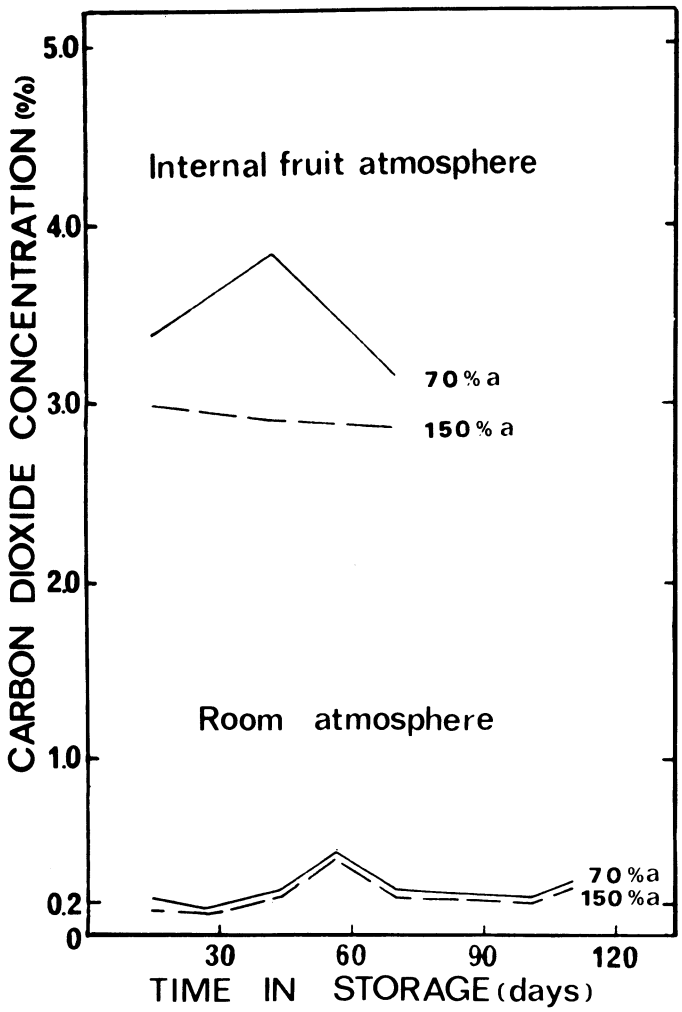

Fig. 4. Effect of ventilation rate in commercial storage on CO_2 concentration in grapefruit storage rooms and in the internal atmosphere of the fruit. Ventilation rates followed by the same letter do not differ significantly at the 5% level using Duncan's range test for differences between atmospheres.

70%·hr^{-1} affected the O_2 levels only slightly in the room atmosphere, whereas O_2 levels in the internal atmosphere of the fruit reached the level of 14% to 15% (Fig. 2).

Carbon dioxide. Different rates of ventilation affected the CO_2 content more than the O_2 level. CO_2 levels increased as the ventilation rate decreased both in the tent and in the internal fruit atmosphere (Fig. 3).

In commercial storage room (Fig. 4), CO_2 levels were very low, and internal fruit CO_2 levels were similar to those in tents for 5% to 10%·hr^{-1} ventilation (Fig. 4). With no ventilation, CO_2 levels in the tents reached 7% and, in the internal atmosphere, 12% after a storage period of 120 days (data not presented).

Different citrus fruit cultivars responded differently to the various rates of ventilations. The 'Shamouti' orange, which has a higher rate of respiration than the other cultivars (1), caused a change in the tent atmosphere that was more pronounced than that caused by the 'Valencia' and the grapefruit cultivars (Fig. 5). Thus, the rate of ventilation applied during storage of 'Shamouti' oranges should probably be slightly higher than that used for 'Valencia' or for grapefruit.

Ethanol content of the juice. The ethanol content of grapefruit, stored in tents at ventilation rates of between 50% to 2.5%·hr^{-1}, varied from 10 to 40 mg ethanol in 100 ml of juice. Within this range, the ethanol content increased at low ventilation rates. These levels had no clear effect on the visual appearance, flavor, or keeping quality of the fruit. Under no ventilation, however, ethanol content of the fruit reached 165 mg·100 ml^{-1} of juice resulting in off-flavor development. Similarly, in 'Shamouti' and 'Valencia' orange, the reduced ventilation rates had only a slight effect on the ethanol content, except under no ventilation treatment in which the ethanol content increased 6 times in 'Valencia' within 120 days and in 'Shamouti' within 40 days. This fruit also developed a distinct off-flavor. In the commercial storage rooms, the ethanol content of the juice after 2 months of grapefruit storage was 30 and 60 mg·100 ml^{-1} juice for fruit stored in rooms with ventilations rates of 150 and 70%·hr^{-1}, respectively.

Weight loss. Fruit weight loss corresponded directly to ventilation rates. For example, after 5 months of storage in tents at 11°C, weight loss of grapefruit was 5.6% at 50%·hr^{-1} ventilation while it was only 3.6% at a ventilation rate of 10%·hr^{-1} (Table 1).

Decay. The incidence of decay and blemishes of grapefruit

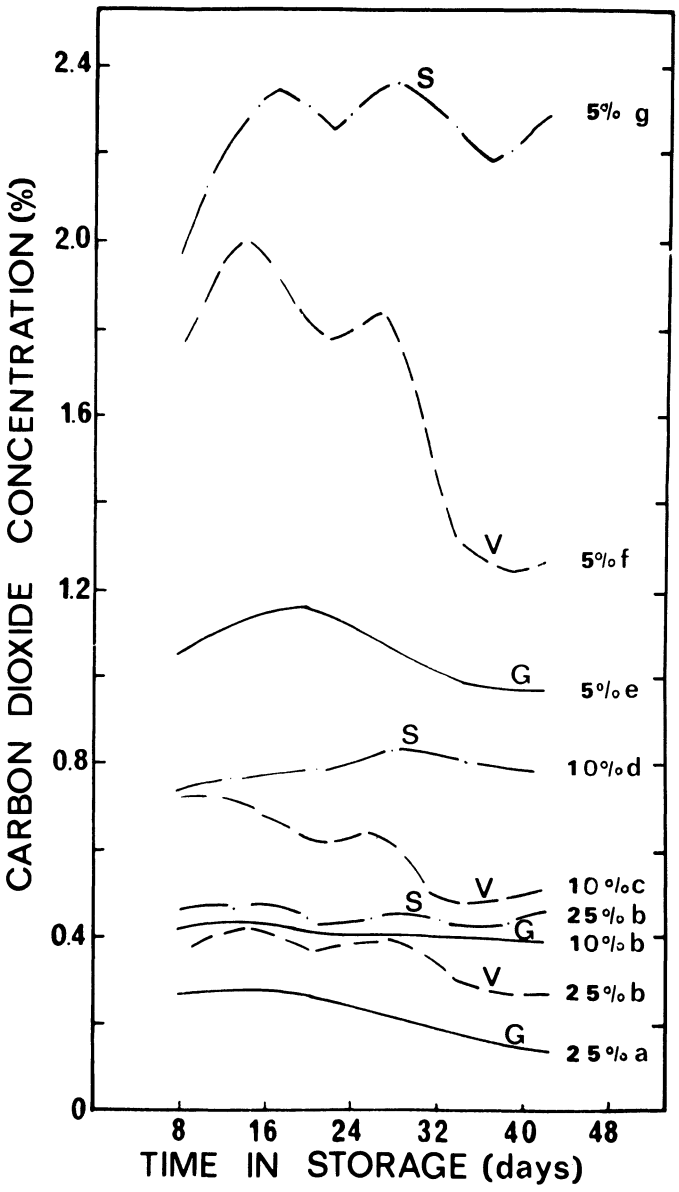

Fig. 5. Effect of ventilation rate during storage in PVC tents on CO_2 concentration in the atmosphere. 'Shamouti' (S) and 'Valencia' (V) oranges and grapefruit (G) were ventilated at rates of 5%, 10%, or 25%·hr^{-1}. Lines followed by the same letter do not differ significantly at $P = 0.05\%$ by Duncan's multiple range test.

Table 1. Effect of ventilation rate of grapefruit storage on total fresh weight loss (percentage of initial) from the fruit after 150 days of storage at 11°C (85% to 90% RH).

	Ventilation rate (%·hr^{-1})					
150[z]	50	25	10	5	2.5	0
7.0	5.6	4.2	3.6	3.2	3.0	2.8
0.4[y]	0.4	0.3	0.3	0.3	0.3	0.3

[z]Control.
[y]This row indicates SE.

stored in tents generally was low and was not affected by the various rates of ventilation. An exception was the case of no ventilation, in which fruit already showed severe deterioration after 6 weeks of storage at 11°C and a very marked increase in decay (Fig. 6).

Table 2. Incidence of decay developed during commercial cold storage of grapefruit[z] as affected by the rate of ventilation of the storage room.

Ventilation rate (%·hr^{-1})	Incidence of decay (%)	
	After cold storage	After shelf life
100	3.0 ± 1.0	3.6 ± 1.2
30	8.6 ± 2.3	10.2 ± 3.0

[z]The fruit were stored for 16 weeks at 11°C (85% to 90% RH) followed by a 2-week period at 17°C to simulate commercial shelf life conditions. At the end of the cold storage period, the internal concentration of CO_2 was 4.2% in fruit stored at the low rate of ventilation and 3.0% in the fruit stored at the higher rate.

Results obtained in this study indicate that the composition of the storage atmosphere, as well as that of the internal atmosphere of citrus fruit, is affected by the rate of ventilation. Although a change in the O_2 level may be critical for maintaining high fruit quality (6, 7, 10), different ventilation rates affected CO_2 more than O_2 levels, particularly in the storage atmosphere. The level of CO_2 in the storage atmosphere and/or in the internal atmosphere of the fruit, may serve as an indicator to help determine the actual, effective, and desirable rate of ventilation during storage of citrus fruit.

By comparing the results obtained in laboratory experiments with those obtained in commercial tents, it was found that at similar ventilation rates, levels of CO_2 were somewhat lower in the former than in the latter. This difference is because each fruit in laboratory tests was exposed more directly to the introduced air, and the entire volume of air could be exchanged more readily than in commercial tests in which the fruit were packed and stacked on pallets. Also, in commercial storage rooms, air circulation often is inadequate. The concentrations of CO_2 found in laboratory test at ventilation rate of 50% and 25%·hr^{-1} (Fig. 3) were similar to those found in the commercial test at 70% and 150%·hr^{-1} (Fig. 4), and were maintained at 0.2% to 0.3%. The CO_2 levels of the internal atmosphere also were somewhat higher in commercial than in laboratory tests: at the ventilation rate of 70%·hr^{-1}, the CO_2 level was 3.5% (Fig. 4) whereas in the laboratory tests it did not exceed 3.0% at 50%, 25%, and even 10%·hr^{-1}. These findings clearly indicate that the rate of ventilation under commercial conditions must be higher than in the laboratory test in order to reach equal air compositions.

Due to an unusually low incidence of decay, the results of the 1st commercial test did not show a clear effect of the reduced ventilation rate (70%·hr^{-1}) on the incidence of decay. However, in a subsequent commercial test, when decay was somewhat increased, fruit stored at a low ventilation rate (30%·hr^{-1}) developed greater rot than fruit stored at the high rate of 100%·hr^{-1} (Table 2). These data support earlier indications obtained from the ventilation experiments in tents suggesting a slightly increased incidence of decay under ventilation conditions which increased internal CO_2 concentration of the fruit.

The commonly used rate of ventilation of 150% to 300%·hr^{-1} indeed may be excessive. Results of both the laboratory and the commercial tests reported here show that a rate of 70% to 100%·hr^{-1} could be used for ventilating grapefruit storage. However, since air circulation of storage space often is inadequate, the concentration of CO_2 in the storage atmosphere and/or in the internal atmosphere of the fruit should be analyzed in order to ensure that the reduced rate of ventilation does not cause excessive CO_2 concentration under the specific commercial conditions.

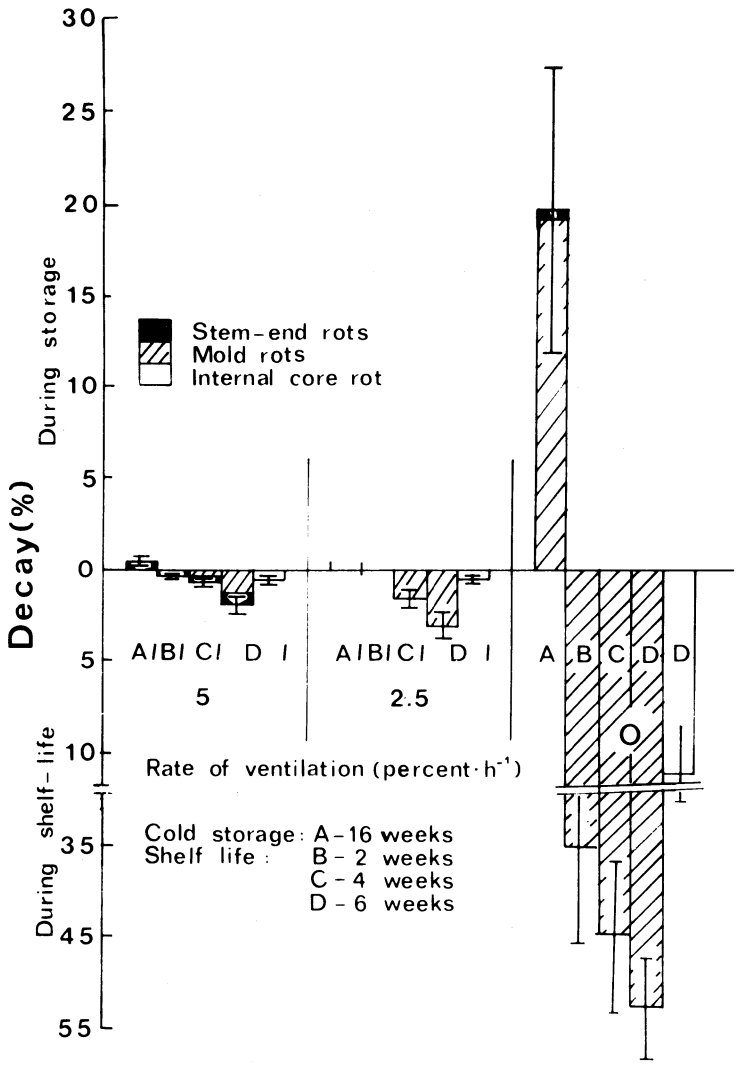

Fig. 6. Incidence of decay developed during storage of grapefruit as affected by the ventilation rate of the storage space. Decay in control fruit as well as in fruit kept at ventilation rates of 25% or 10%·hr^{-1}, was similar to that of fruit kept at 5%·hr^{-1} ventilation rate. Bars indicate SE.

Literature Cited

1. Aharoni, Y. 1968. Respiration of orange and grapefruit harvested at different stages of development. Plant Physiol. 43:99–102.
2. Aharoni, Y. and F.S. Lattar. 1972. The effect of various storage atmospheres on the occurrence of rots and blemishes on Shamouti oranges. Phytopath. Z. 73:371–374.
3. ASHRAE Guide and Data Book, Application for 1966 and 1967. (1966) New York.
4. Baier, W.E. 1945. How the citrus industry measures it: IV. Lemon storage ventilation. Calif. Citrogr. 30(4):306–318.
5. Biale, J.B. and R.E. Young. 1947. Critical oxygen concentrations for the respiration of lemons. Amer. J. Bot. 34:301–309.
6. Chace, W.G. 1969. Controlled atmosphere storage of Florida citrus fruit. Proc. 1st Intl. Citrus Symp. 3:1365–1373.
7. Chace, W.G., P.L. Davis, and J.J. Smoot. 1967. Response of citrus fruit to controlled atmosphere storage. Proc. 12th Intl. Congr. Refrig. (Madrid) III: 383–391.
8. Davis, P.L. 1974. Biochemical changes in grapefruit stored in air containing ethylene. Proc. Fla. State Hort. Soc. 87:222–227.
9. Davis, P.L., B. Roe, and J.H. Bruemmer. 1973. Biochemical changes in citrus fruits during controlled-atmosphere storage. J. Food Sci. 38:225–229.
10. Grierson, W. and T.T. Hatton. 1977. Factors involved in storage of citrus fruits: a new evaluation. Proc. Intl. Soc. Citriculture 1: 227–231.
11. Grierson, W., H.M. Vines, M.F. Oberbacher, S.K. Ting, and G.J. Edwards. 1966. Controlled atmosphere storage of Florida and California lemons. Proc. Amer. Soc. Hort. Sci. 88:311–318.
12. Hatton, T.T. and R.H. Cubbedge. 1975. Disorders caused by ethylene in stored 'Marsh' grapefruit harvested during autumn, winter and spring. Proc. 14th Intl. Congr. Refrig. (Moscow) C-2, 95.
13. Harvey, E.M. 1946. Changes in lemons during storage as affected by air circulation and ventilation. USDA Tech. Bul. 908.
14. Hinds, R.H., Jr. 1970. Transporting fresh fruits and vegetables overseas. USDA, ARS. 52–39.
15. Ichiro, K. and I. Masatoshi. 1972. Effects of gas concentrations on fruits. IV. Effect of oxygen concentrations on Natsudaidai fruit (*Citrus natsudaidai* Hayata). J. Japan Soc. Hort. Sci. 41:98–106.
16. Lipton, W.J. 1975. Controlled atmospheres for fresh vegetables and fruits: why and when, p. 130–143. In: N.F. Haard and D.K. Salunkhe (eds.). Postharvest biology and handling of fruits and vegetables. AVI Pub.
17. Norman, S.M. 1977. The role of volatiles in storage of citrus fruits. Proc. Intl. Soc. Citriculture 1:238–242.
18. Norman, S.M. and C.C. Craft. 1971. Production of ethanol, acetaldehyde and methanol by intact oranges during and after nitrogen storage. J. Amer. Soc. Hort. Sci. 96(4):464–467.
19. Schiffmann-Nadel, Mina. 1975. Relation between fungal attack and postharvest fruit maturation. Colloq. CNRS No. 238. Paris. Facteurs et regulation de la maturation des fruits.
20. Schiffmann-Nadel, Mina. 1977. Chemical and physiological changes in citrus fruit during storage and their relation to fungal infection. Proc. Intl. Soc. Citriculture 1:311–317.
21. Schiffmann-Nadel, Mina and E. Cohen. 1973. Factors affecting keeping quality of lemons in storage. Proc. 1st Intl. Congr. Citriculture III:353–358.
22. Schiffmann-Nadel, Mina, F.S. Lattar, and J. Waks. 1971. The response of grapefruit to different storage temperatures. J. Amer. Soc. Hort. Sci. 96(1):87–90.
23. Vines, H.M., W. Grierson, and G.J. Edwards. 1968. Respiration, internal atmosphere and ethylene evolution of citrus fruits. Proc. Amer. Soc. Hort. Sci. 92:227–234.
24. Wild, B.L., W.B. McGlasson, and T.H. Lee. 1976. Effect of reduced ethylene levels in storage atmospheres on lemon keeping quality. HortScience 11(2):114–115.
25. Young, R.E. and J.B. Biale. 1968. Carbon dioxide effects on fruits. Planta 81:253–263.