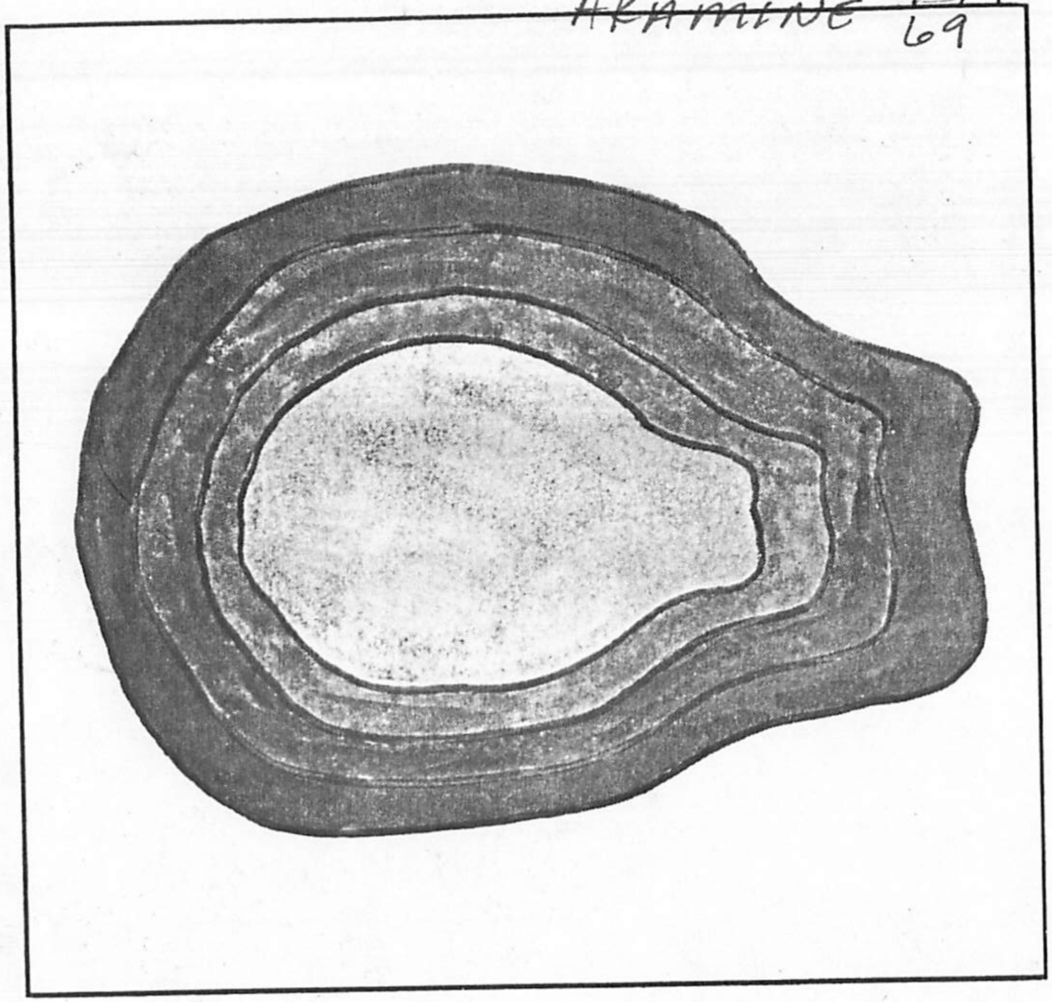
Akamine 69

STABY



9Ø8AR

Effects of Controlled Atmosphere Storage of Fresh Papayas (*Carica papaya* L., var. Solo) with Special Reference to Shelf-life Extension of Fumigated Fruits

Ernest K. Akamine and Theodore Goo

Research Bulletin No. 144
Hawaii Agricultural Experiment Station
University of Hawaii

THE AUTHORS

ERNEST K. AKAMINE is Plant Physiologist, Hawaii Agricultural Experiment Station, and Professor of Plant Physiology, University of Hawaii.

THEODORE GOO is Research Associate, Hawaii Agricultural Experiment Station.

CONTENTS

Effects of Controlled Atmosphere Storage of Fresh Papayas (*Carica papaya* L., var. Solo) with Special Reference to Shelf-life Extension of Fumigated Fruits*

ERNEST K. AKAMINE AND THEODORE GOO

INTRODUCTION

Schomer (*9*) has traced the historical development of the use of modified or controlled atmosphere (CA) storage for extending the shelf life of fresh commodities. Shelf-life extension may occur if modification or control of the storage atmosphere reduces the rate of respiration under refrigeration without damaging the commodity. This effect may be achieved by reducing the oxygen concentration or increasing the carbon dioxide concentration of normal atmosphere or by combining both conditions. Atmospheric modification may occur naturally as a result of the respiration of plant tissues in storage or may be produced artificially. Specific concentrations of the gases in the atmosphere may be maintained by removing or adding oxygen or carbon dioxide to a storage chamber or by adding an inert gas such as nitrogen. A particular atmosphere may also be maintained by a continuous purging of the storage chamber with a gas mixture.

The effect of CA storage on the shelf life of temperate zone and semitropical fruits has extensively been studied elsewhere (*4, 5, 8, 11*). A list of selected references to research on CA storage of these fruits has been compiled by Hardenburg (*6*). However, the commercial application of this principle on these fruits is rather limited in scope. Only in the storage of apples in the eastern United States is CA storage used commercially to any great extent (*10*). Except for a limited amount of work done on papayas and mangoes (*1, 7*), virtually no research has been done on CA storage of tropical fruits.

*The work reported here was supported by a grant from Oxytrol, Division of Occidental Petroleum Corporation, and the United States Atomic Energy Commission, Contract No. AT(04-3)-235, Project Agreement No. 5. The laboratory of the Hawaiian Fruit Flies Investigations, U.S. Department of Agriculture, fumigated the papayas used in this investigation.

Because some species of fruit fly infest fresh Hawaiian commodities, almost all such commodities must be subjected to one of the disinfestation treatments approved by the U. S. Department of Agriculture before export to the mainland U. S. Fumigation and vapor heat (2) are the two approved disinfestation treatments for export papayas. Ethylene dibromide is used in the fumigation treatment and heat with 100-percent relative humidity is employed in the vapor heat treatment. Currently most of the papayas exported to the mainland United States are fumigated; a small percentage is vapor-heat treated. All commercial shipments are carried by air freight.

The aims of this investigation were (1) to study the effect of CA storage on extending the shelf life of papayas and (2) to study the feasibility of CA storage for shipping fumigated papayas by refrigerated marine and rail transportation.

MATERIALS AND METHODS

Freshly harvested fruits for these studies were obtained from a papaya orchard at the Waimanalo Experimental Farm of the Hawaii Agricultural Experiment Station. Fifteen to 30 fruits matched on the basis of surface color development, *i.e.*, from 0 percent yellow (mature-green fruit) to 100 percent yellow (full-color fruit), were used for each treatment.

For decay control, fruits were hot-water dipped at 120°F for 20 minutes (*2, 3*). After cooling in running tap water for 20 minutes, fruits were fumigated with ethylene dibromide at a dose of ½ pound per 1,000 cubic feet chamber space for 2 hours at ambient temperature and atmospheric pressure.

Fruits were then stored at 55°F or other temperatures as indicated later, under varying levels of oxygen maintained by mixing proportionate volumes of compressed nitrogen from cylinders and air from a compressor. The required proportions of the gases were maintained through a system of flowmeters. Each storage chamber consisted of a rectangular, watertight fish aquarium (10 x 20 x 12 inches) inverted over a plastic fiberglass tray with a groove into which the edge of the open end of the aquarium fitted. The chamber was sealed with water placed into the groove. The tray was also fitted with outlets for incoming and outgoing gas. In order to minimize the occurrence of dead spots in circulation within the chamber, the incoming gas was released into the top area of one end of the chamber and removed from the bottom at the other end. The fruits were placed on the elevated portion of the tray. Since the storage chambers were water sealed, relative humidities close to 90 percent (measured with Abbeon Relative Humidity and Temperature Indicator) were maintained in the chambers. The chambers were continuously purged with gas mixture at a

flow rate of approximately 500 ml per minute, which was sufficient to prevent the accumulation of respiratory carbon dioxide and ethylene in the storage chamber and excessive weight loss of the fruits. This flow rate probably eliminated circulation dead spots. The oxygen concentration in the effluent stream was determined daily using a portable Johnson-Williams oxygen indicator. The CA storage period was either 6 days, to simulate the surface shipping period under refrigeration from Hawaii to the West Coast, or 12 days, to simulate the shipping period under refrigeration from Hawaii to the East Coast by ship and rail.

After initial storage under CA, fruits were removed to room temperature (75 to 85°F) and atmosphere conditions to simulate retail conditions. Daily observations were then made on the following parameters: percent surface color development, percent ripe fruits, percent overripe fruits, percent decayed fruits, and percent weight loss. Fruits were observed until they were overripe. Surface color development was estimated as percent of surface area with yellow pigmentation. Fruits were considered ripe when they were judged to be slightly soft to touch and approximately 87 to 100 percent yellowed. Fruits were judged to be overripe when they were very soft to touch. Fruits with any visible lesions were considered decayed, regardless of the extent of the lesions. However, fruits with superficial surface molds were not placed in the category of decayed fruits. The mean percent weight loss was calculated from decreases in weight of the fruits from their original weight. Fruits were considered unmarketable when decayed or overripe, and the percent unmarketable fruits was calculated from the number of these fruits. The daily number of unmarketable fruits was used to calculate the average number of marketable days. Data were subjected to statistical treatment of variance analysis wherever feasible. Deviations from this general procedure are described in appropriate sections of the text.

RESULTS

Initial experiments were conducted to determine the effects of CA storage on untreated papayas. These were followed successively by experiments on fruits hot-water treated, fumigated, and both hot-water treated and fumigated. Subsequent experiments dealt with the effects of oxygen concentration and temperature during CA storage and degree of initial ripeness of fruit entering treatment. The effect of CA storage on fruit quality was next studied. Finally experiments were conducted to simulate shipping and retail conditions.

Effect of CA Storage on Untreated Fruits

In four experiments, untreated papayas of various stages of ripeness (0 to 100 percent yellow) were stored under 1 percent oxygen and 21 percent oxygen (air) at 55°F for 6 days followed by storage at room conditions. In general, the lower oxygen level delayed the incidence of decay at room temperature. However, the rate of ripening and overripening was the same for fruits held in 1 percent oxygen as in air. Thus, some extension of shelf life due to low oxygen level was observed, but statistical significance could not be established. Data in figures 1*a*, 1*b*, and 1*c* are from one experiment that demonstrates this relationship.

Effect of CA Storage on Hot-Water Treated Fruits

The effects of hot-water dip on fruits stored under CA were investigated. In a typical experiment, 15 fruits (6 to 25 percent yellow) were hot-water treated, cooled, then placed in 1.5 percent oxygen at 55°F for 6 days followed by storage under room temperature conditions. Controls were not given the hot-water treatment. The results collected during storage at room temperature are shown in figures 2*a*, 2*b*, 2*c*, 2*d*, 2*e*, and 2*f*.

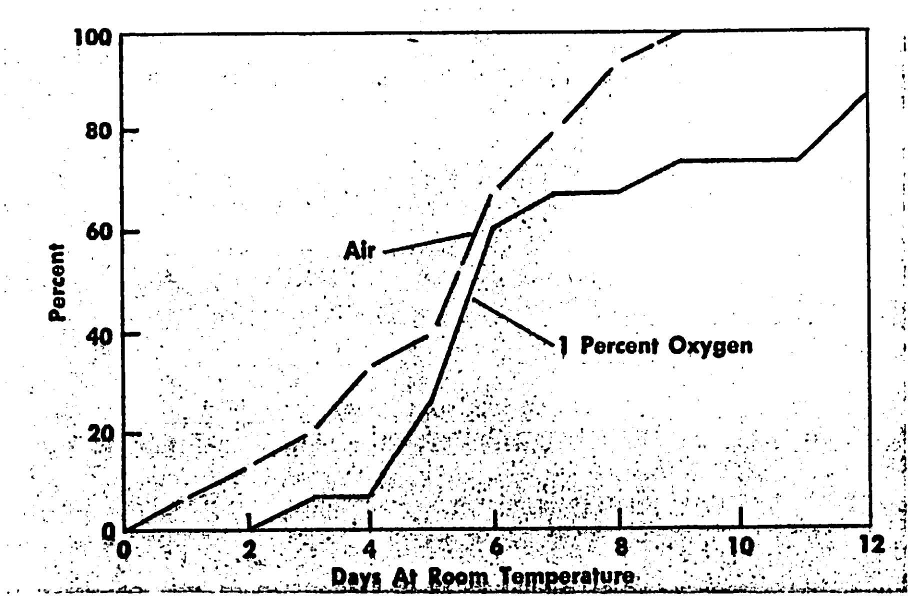


FIGURE 1*a*. The effect of initial storage under 1 percent oxygen and air at 55°F for 6 days on incidence of decay in papayas subsequently stored at room temperature (0 to 25 percent yellow fruits, 20 per treatment).

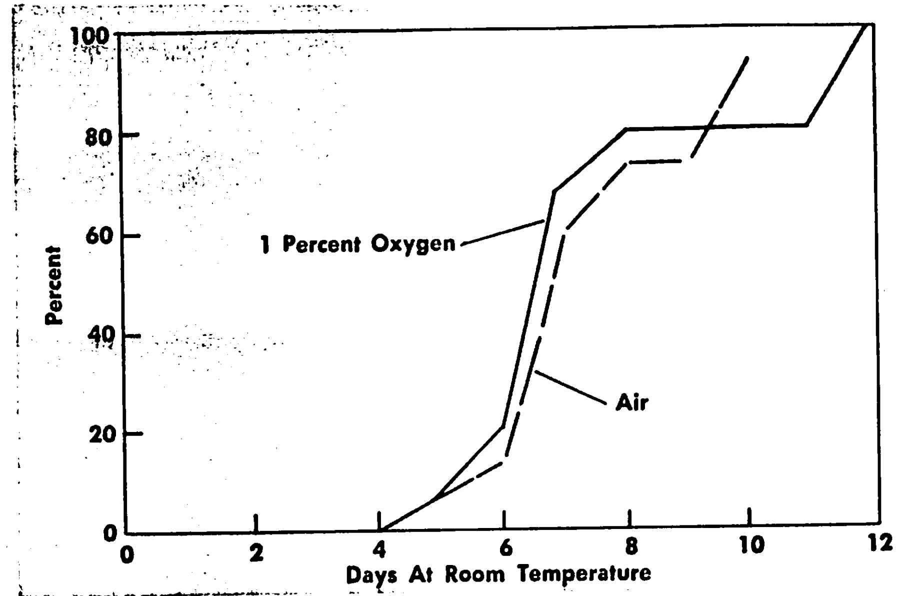


FIGURE 1*b*. The effect of initial storage under 1 percent oxygen and air at 55°F for 6 days on the rate of overripening in papayas subsequently stored at room temperature (0 to 25 percent yellow fruits, 20 per treatment).

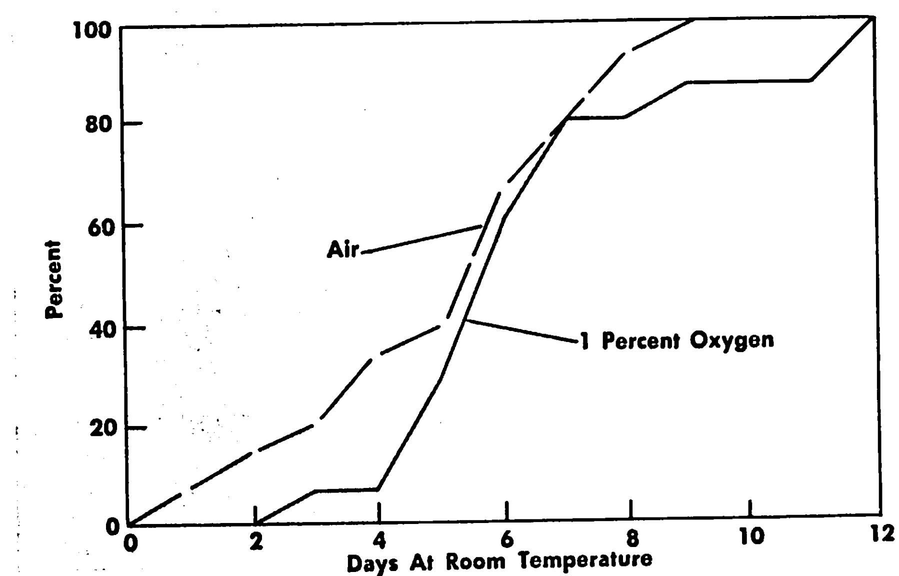


FIGURE 1*c*. The effect of initial storage under 1 percent oxygen and air at 55°F for 6 days on the incidence of unsalable fruits (decayed and/or overripe) in papayas subsequently stored at room temperature (0 to 25 percent yellow fruits, 20 per treatment).

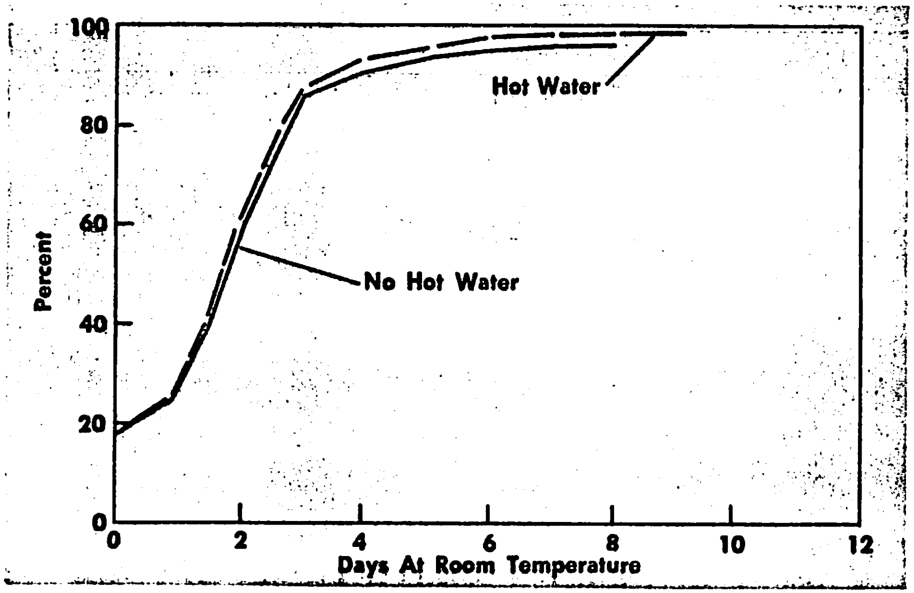


Figure *2a.* The effect of initial storage under 1.5 percent oxygen at 55°F for 6 days on the rate of coloring in hot-water treated and untreated papayas subsbequently stored at room temperature (6 to 25 percent yellow fruits, 15 per treatment).

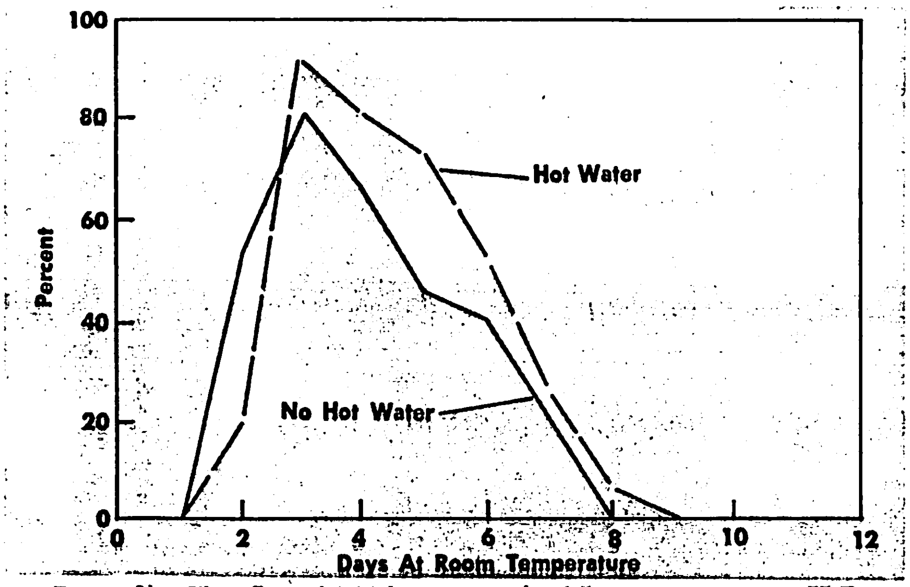


Figure *2b.* The effect of initial storage under 1.5 percent oxygen at 55°F for 6 days on the percentage of edible ripe fruits in hot-water treated and untreated papayas subsequently stored at room temperature (6 to 25 percent yellow fruits, 15 per treatment).

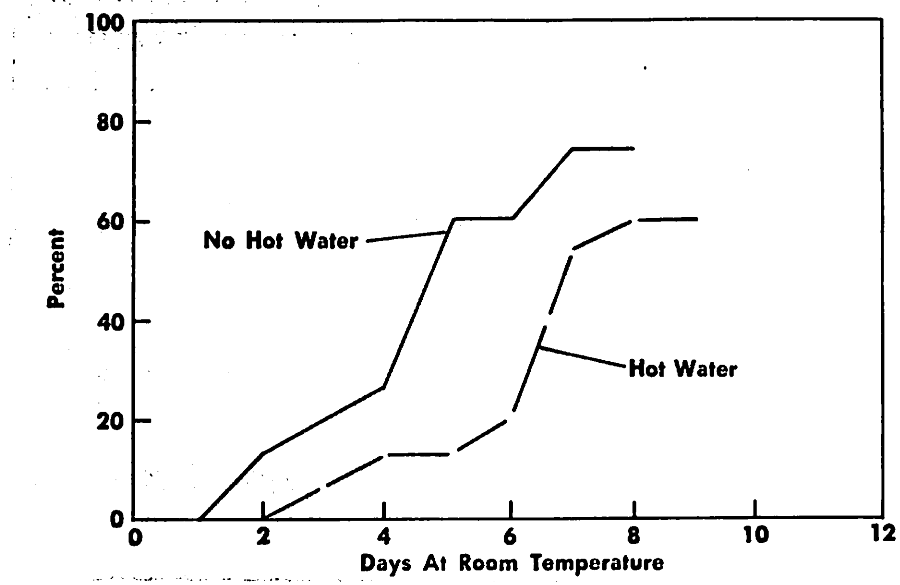


Figure *2c.* The effect of initial storage under 1.5 percent oxygen at 55°F for 6 days on the incidence of decay in hot-water treated and untreated papayas subsequently stored at room temperature (6 to 25 percent yellow fruits, 15 per treatment).

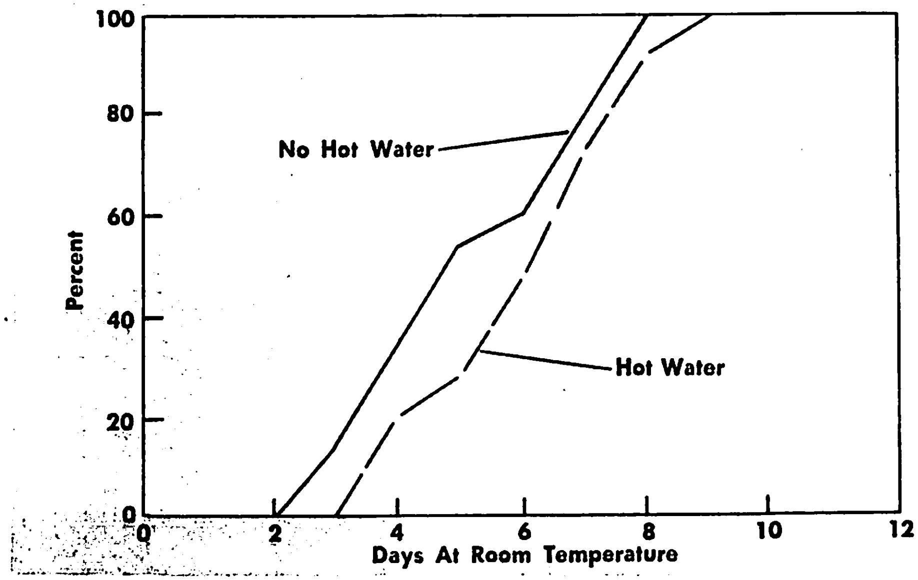


Figure *2d.* The effect of initial storage under 1.5 percent oxygen at 55°F for 6 days on the rate of overripening in hot-water treated and untreated papayas subsequently stored at room temperature (6 to 25 percent yellow fruits, 15 per treatment).

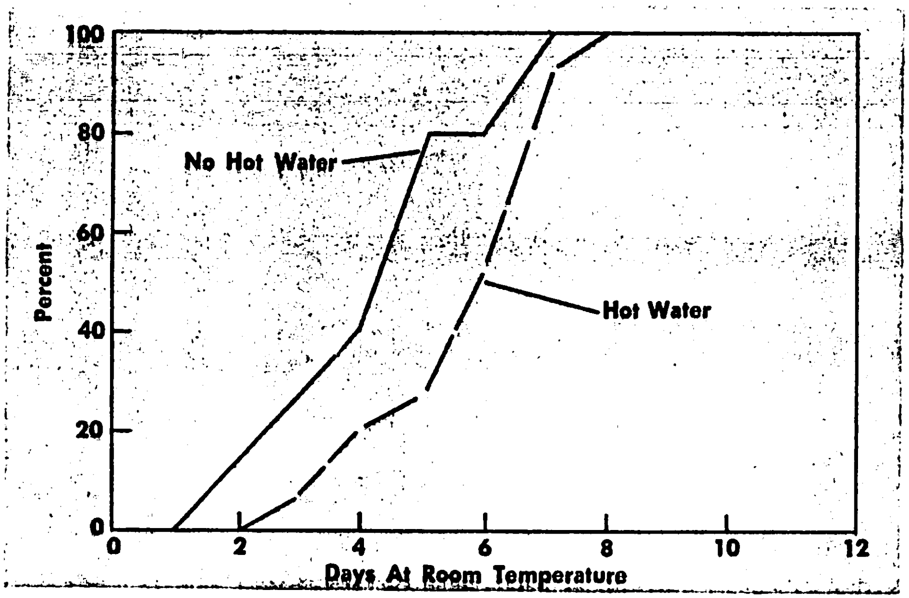


FIGURE 2*e*. The effect of initial storage under 1.5 percent oxygen at 55°F for 6 days on the incidence of unsalable fruits (decayed and/or overripe) in hot-water treated and untreated papayas subsequently stored at room temperature (6 to 25 percent yellow fruits, 15 per treatment).

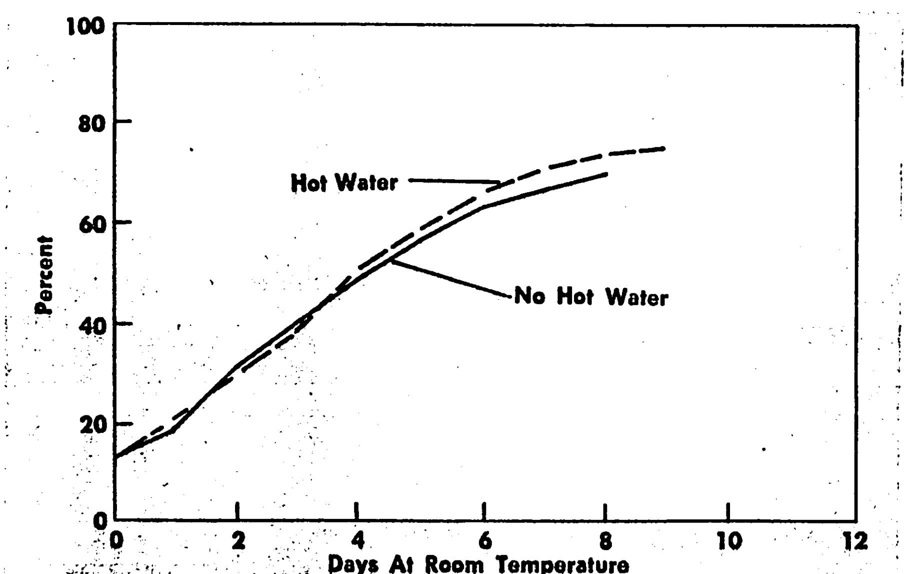


FIGURE 2*f*. The effect of initial storage under 1.5 percent oxygen at 55°F for 6 days on weight loss in hot-water treated and untreated papayas subsequently stored at room temperature (6 to 25 percent yellow fruits, 15 per treatment).

The rate of surface coloring was the same for the two lots of fruits (figure 2*a*). Hot-water treatment delayed the rate of ripening (figure 2*b*), the rate of overripening (figures 2*b* and 2*d*), and the rate of decay development (figure 2*c*). Thus shelf life was extended by the hot-water treatment as indicated by the delay in the occurrence of unsalable fruits due to decay or overripening or both (figure 2*e*). The loss of fruit weight was similar for both lots (figure 2*f*).

The next series of experiments investigated the effects of 1 percent oxygen and of air on hot-water treated fruits held at 55°F for 6 days followed by room temperature storage. In one experiment (12 to 25 percent yellow fruits, 30 per treatment) the rate of surface coloring was slightly delayed by the low oxygen tension but the rate of ripening in 1 percent oxygen and in air was identical. Decay incidence was lower in 1 percent oxygen. The percent loss in fruit weight was similar for the two lots.

Similar results were obtained in another experiment (6 to 33 percent yellow fruits, 15 per treatment) except that in this instance the rate of overripening was also delayed by initial storage at a low oxygen level. As a consequence, the percentage of unmarketable fruits was lower for fruits initially stored in 1 percent oxygen than for those stored in air. The average number of salable days at room temperature for fruits stored under 1 percent oxygen was 4.6 and for those under normal air, 3.7. The difference between the two means, which is statistically significant ($P = .05$), represents an increase in shelf life of approximately 24 percent due to initial storage in low oxygen.

These experiments indicated the effectiveness of the hot-water treatment for controlling postharvest decay in fruits stored under low levels of oxygen, thus extending shelf life.

Effect of CA Storage on Fumigated Fruits

The shelf life of fumigated fruits stored under low oxygen levels was the same as for those stored under normal air at 55°F. This is shown in the results of a representative experiment involving fumigated fruits, 6 to 33 percent yellow, 15 per treatment. The fruits were initially stored in 1 percent oxygen and in air at 55°F for 6 days followed by room temperature storage (figure 3).

Effect of CA Storage on Hot-water Treated, Fumigated Fruits

Thus far, it has been shown that initial storage under low oxygen levels does not alter the shelf life of fumigated or untreated papayas subsequently stored at room temperature, primarily because of the high incidence of storage decay. However, the data showed that hot-water

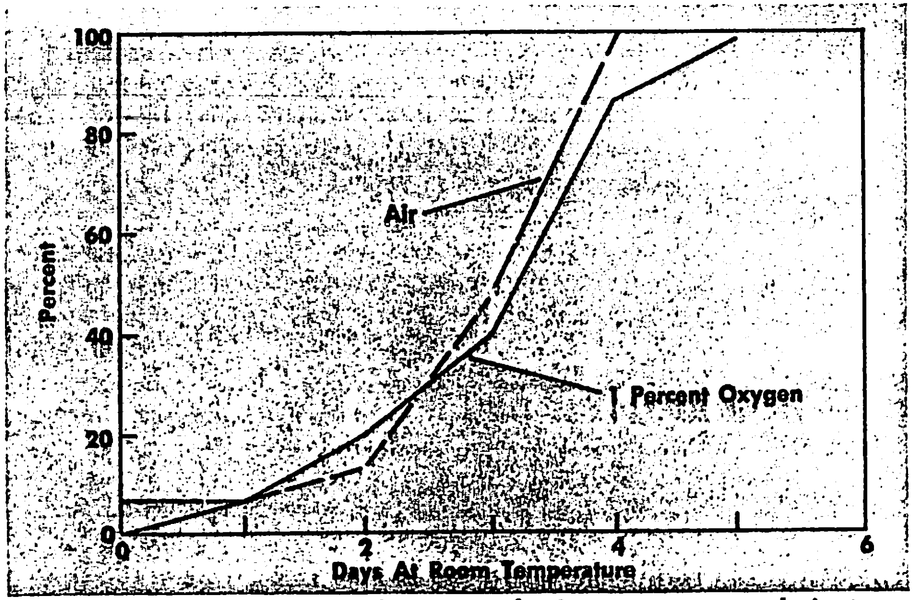


FIGURE 3. The effect of intial storage under 1 percent oxygen and air at 55°F for 6 days on the incidence of unsalable fruits (decayed and/or overripe) in fumigated papayas subsequently stored at room temperature (6 to 33 percent yellow fruits, 15 per treatment).

treatment was beneficial to fruits stored under low oxygen level because the shelf life of these fruits was extended as compared with that of similarly treated fruits stored under normal air. In the next series of experiments the effect of CA storage on hot-water treated, fumigated fruits was investigated. As most of the papayas for the export trade are given this treatment, most fruits used in these investigations were similarly treated.

In a typical experiment, 0 to 25 percent yellow fruits were hot-water treated and fumigated and then stored under 1.5 percent oxygen and air at 55°F for 6 days. The results (figure 4) show that upon removal to room temperature conditions, CA storage increased the salable life of the fruits. Fruits initially under CA storage were marketable, on the average, for 4.9 days and those under air 4.1 days at room temperature (the difference in the means was significant at P=.05).

In another experiment, 15 fruits, 6 to 33 percent yellow, were initially stored under 1 percent oxygen at 55°F for 6 days. Upon transfer to room temperature conditions, these fruits showed increased shelf life. The average number of marketable days for the fruits under 1 percent oxygen was 4.3 and for those under normal air, 3.5 (the difference was significant at P=.05). The daily percentage of unsalable fruits stored at room temperature is shown in figure 5.

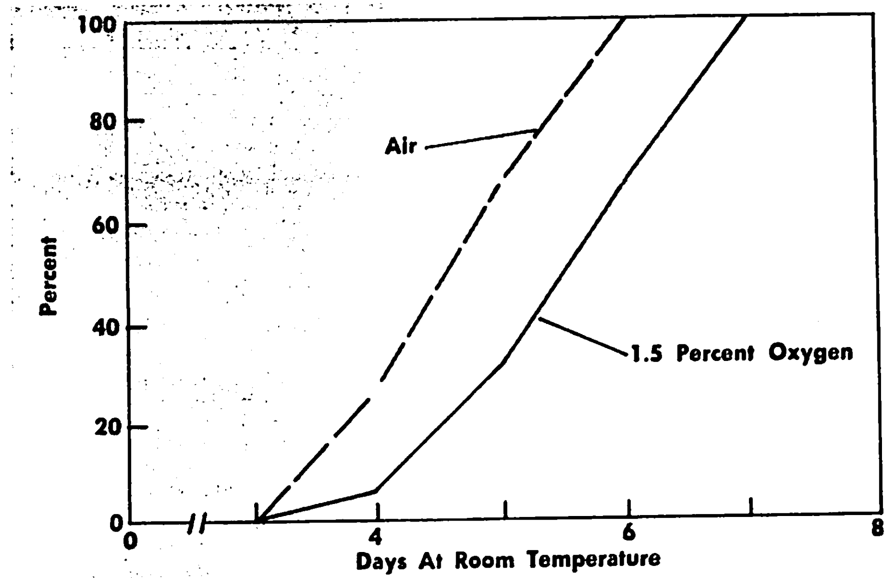


FIGURE 4. The effect of initial storage under 1.5 percent oxygen and air at 55°F for 6 days on the incidence of unsalable fruits (decayed and/or overripe) in hot-water treated, fumigated papayas subsequently stored at room temperature (0 to 25 percent yellow fruits, 15 per treatment).

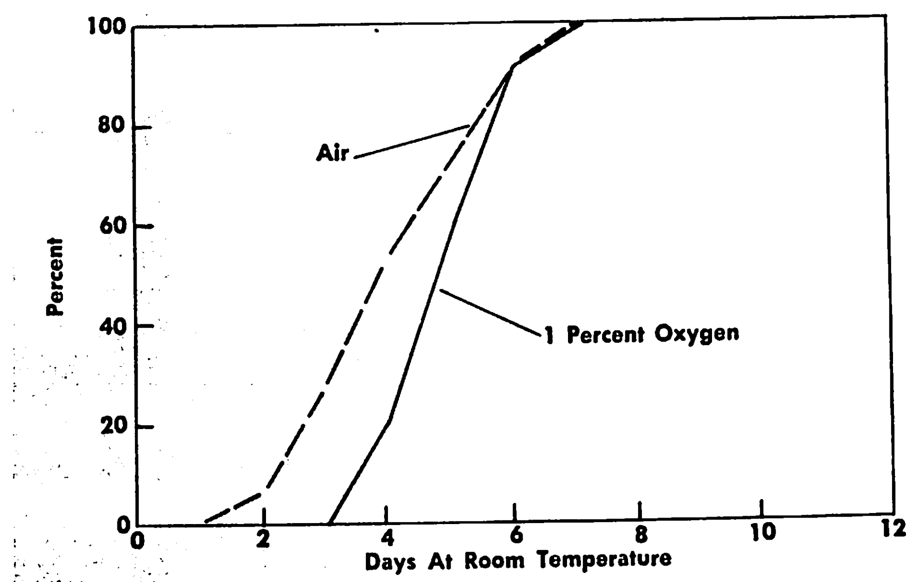


FIGURE 5. The effect of initial storage under 1 percent oxygen and air at 55°F for 6 days on the incidence of unsalable fruits (decayed and/or overripe) in hot-water treated, fumigated papayas subsequently stored at room temperature (6 to 33 percent yellow fruits, 15 per treatment).

In several experiments, CA storage was conducted at higher temperatures (60°F and room temperature or 75 to 85°F). In one of these, 15 fruits, 0 to 25 percent yellow, were initially stored under 1 percent oxygen or in air at 60°F for 6 days prior to storage under ordinary conditions at room temperature. The average shelf life of fruits initially stored in 1 percent oxygen and air was 4.4 days; at room temperature it was 3.3 days. The added shelf life of 1.1 days due to CA storage was significant at P=.05. This extension is related to the daily percentage of unsalable fruits (figure 6).

In experiments conducted at room temperature, reduced oxygen tensions decreased the rate of ripening. However, oxygen levels below approximately 5 percent caused unsightly, blotchy surface coloring (uneven yellowing) to develop. This was not observed at 55 or 60°F.

Comparison of the Effects of Different Treatments

The relative merits of different treatments may be judged from the results of an experiment in which 15 fruits, 6 to 33 percent yellow, were initially stored under 1 percent oxygen and in air at 55°F for 6 days followed by room temperature storage. The results on shelf life are tabulated in table 1.

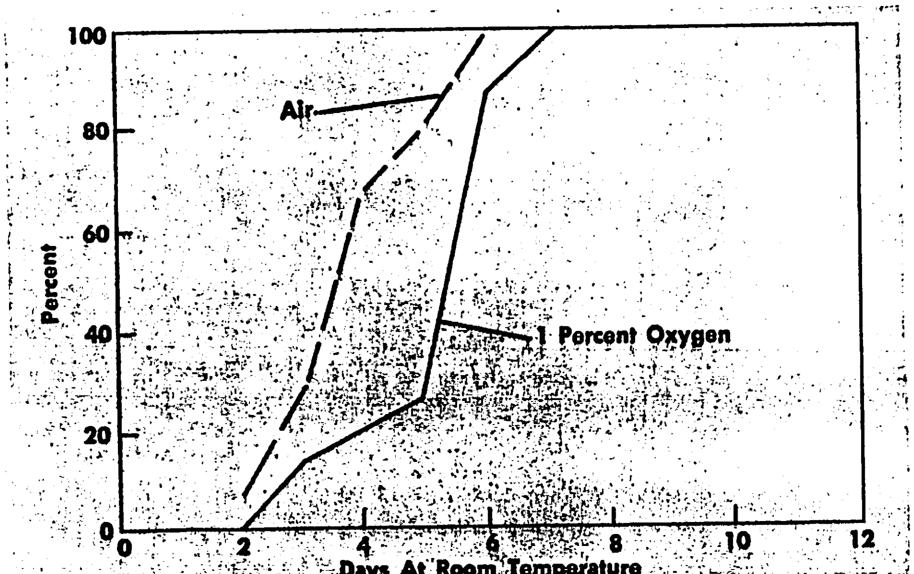


FIGURE 6. The effect of initial storage under 1 percent oxygen and air at 60°F for 6 days on the incidence of unsalable fruits (decayed and/or overripe) in hot-water treated, fumigated papayas subsequently stored at room temperature (0 to 25 percent yellow fruits, 15 per treatment).

It is seen from table 1 that regardless of the initial oxygen level in the storage chamber, the average number of marketable days was similar for the untreated and the fumigated fruits. Hence, fumigation alone did not influence the shelf life of the papayas stored under low oxygen level or in air. When used alone, the hot-water treatment significantly extended the shelf life of fruits stored in 1 percent oxygen and in air. Furthermore, hot-water treated fruits stored under 1 percent oxygen had greater shelf life than those in air. The shelf life of fruits subjected to the combination hot-water fumigation treatment was similar to that of fruits hot-water dipped only (table 1).

Effect of Oxygen Concentration

An attempt was made to establish an optimum concentration of oxygen in the storage medium for shelf-life extension of hot-water treated, fumigated fruits. Since 55°F is the optimum storage temperature for partially ripe papayas (2), most of the experiments involving oxygen level were conducted at this temperature, but some were conducted at 60°F or room temperature.

TABLE 1. The effect of pre-storage treatments on shelf life of papayas initially stored under CA at 55°F for 6 days followed by storage at room temperature

Treatment	Storage	Average number of salable days at room temperature as determined by decay and overripening*
None	1% oxygen	2.3
None	air	2.9
Fumigation only	1% oxygen	2.5
Fumigation only	air	2.3
Hot water only	1% oxygen	4.5
Hot water only	air	3.7
Hot water + fumigation	1% oxygen	4.3
Hot water + fumigation	air	3.5

*Difference of 0.8 between treatment means necessary for significance at P=.05.

In many preliminary studies conducted at room temperature, oxygen levels between 1 and 5.5 percent delayed ripening of partially ripe fruits, but these concentrations caused an undersirable, blotchy surface coloring. At 60°F, oxygen concentrations of 1 to 2 percent effectively extended the shelf life as compared with storage in air. However, at 60°F, only at 1 and 1.5 percent oxygen was shelf life longer than that in air at 55°F. At 60°F, 0.5 percent oxygen caused surface scalding which probably exposed the fruits to secondary infection by decay organisms. In some preliminary tests conducted at 55°F, oxygen levels of 1 and 1.75 percent extended the shelf life with the lower level being the more effective. Oxygen levels above 1.75 percent were ineffective in other tests and 0.5 percent was again detrimental. In several experiments at 55°F, 1 and 1.5 percent oxygen extended the shelf life to approximately 5 days compared with 4 days for storage in air. Thus the desirable level of oxygen for extension of shelf life at the optimal storage temperature of 55°F was 1 to 1.5 percent for partly ripe, hot-water treated, fumigated fruits.

Effect of Temperature During CA Treatment

Normal, partly colored papayas are injured by chilling at temperatures below 55°F (2). Temperatures above 60°F accelerate ripening and thus shorten the shelf life. Therefore the use of CA for partly colored fruits is limited to the temperature range of 55 to 60°F. The lower temperature is more effective than the higher for extending shelf life. As indicated above, low levels of oxygen (1 to 1.5 percent) maintained at 55°F could be used to further extend shelf life.

Effect of Degree of Ripeness of Fruit to be Treated

In general, tests indicated that the riper the fruit when stored, the less the benefit to be derived from CA storage, that is, with an increase in the stage of ripeness, the difference in shelf life between the treated and the control lots diminishes. The results of representative tests (table 2) showed that only with fruits up to about 50 percent colored could benefit from CA storage be observed.

Effect of CA Storage on Quality

Edible quality in papayas may be described in terms of sugar content, flavor, and aroma, and the effects of low oxygen storage on these factors were investigated. After initial storage in 1 percent oxygen and in air at 55°F for 6 days, the fruits were ripened at room temperature, then halved longitudinally and deseeded. One-half was used for sensory (flavor and aroma) evaluation by a taste panel. The other half was halved crosswise and juice from the quarter at the exposed blossom end was used to deter-

TABLE 2. The effect of intiail degree of ripeness on shelf life of hot-water treated, fumigated papayas initially stored in 1 percent oxygen at 55°F for 6 days followed by storage at room temperature conditions (15 fruits per treatment for each test)

Test	Average initial surface color (%)	Average number of marketable days at room temperature after initial storage for 6 days at 55°F	
		1% oxygen	Air
1	0-10	5.3*	4.0*
2	50	3.4*	2.5*
3	60	1.6	1.2
4	90	.5	.6

*Difference between corresponding 1 percent oxygen and air significant at P=.05.

TABLE 3. Effect of initial CA storage at 55°F for 6 days on quality of papayas subsequently ripened at room temperature (12 to 25 percent yellow, 30 fruits per treatment)

Pre-storage treatment	Initial storage condition	At edible-ripe stage at room temperature	
		Average total soluble solids (%)*	Average flavor and aroma
Hot water only	1% oxygen	13.5	Normal
Hot water only	air	13.7	Normal
Hot water + fumigation	1% oxygen	13.7	Normal
Hot water + fumigation	air	13.8	Normal

*Determined with Bausch and Lomb juice refractometer.

mine percent total soluble solids, which is an index of sugar content. The results of one of two similar experiments (table 3) indicated that CA storage did not affect the edible quality of papayas.

Simulation of Shipment Conditions

After determining the optimum stage of ripeness (0 to 10 percent yellow), optimum oxygen level (1 to 1.5 percent), and optimum temperature (55°F) for extending the shelf life of fresh papayas, attention was directed toward simulating refrigerated marine and rail shipment conditions. Fruits subjected to the current commercial practice of combining the hot-water and the fumigation treatment were stored under CA for 6 or 12 days. After CA storage, the fruits were removed to room temperature conditions for daily observations. The results of a representative 6-day CA storage experiment (10 percent yellow fruits, 30 per treatment) are shown in figures *7a*, *7b*, *7c*, *7d*, *7e*, *7f*, *7g*, and *7h*.

The relationships of the various factors studied after the fruits were removed to room temperature after CA storage are shown in figures *7a* and *7b* for fruits initially stored under 1 percent oxygen and air, respectively. In both cases, as was expected, the increase in surface color development correlated with the increase in the percentage of edible-ripe fruits. Also, with the progress of storage the percentage of edible-ripe fruits decreased and the percentage of overripe fruits increased. Clearly, fruits decayed after becoming edible-ripe and overripening occurred after the decay set in. In all circumstances, some loss in fruit weight took place in storage. In fruits stored in air, the percentage of unsalable fruits was due wholly to decayed fruits (figure *7b*), while in fruits stored under 1 percent oxygen, unsalability was due to both decayed and overripe fruits (figure *7a*).

The data may be plotted to permit ready comparison of the factors as they varied for fruits stored initially in 1 percent oxygen and in air. The 1 percent oxygen level decreased the rate of surface coloring (figure *7c*). Fruit ripening occurred at the same rate under the two conditions (figure *7d*). However, those stored in air overripened slightly more rapidly than those stored under 1 percent oxygen (figures *7d* and *7f*). The low oxygen level significantly decreased the rate of incidence of decay (figure *7e*). The rate of weight loss was similar for the two lots (figure *7h*). The 1 percent oxygen level significantly extended the shelf life by decreasing the percentage of unsalable fruits with storage time (figure *7g*).

Fruits stored initially under 1 percent oxygen were on the average marketable for 5.2 days following removal from CA storage, compared with 3.9 days for those stored in air. The highly significant (P=.01) difference of 1.3 days between the two lots represents a 33.3-percent increase in shelf

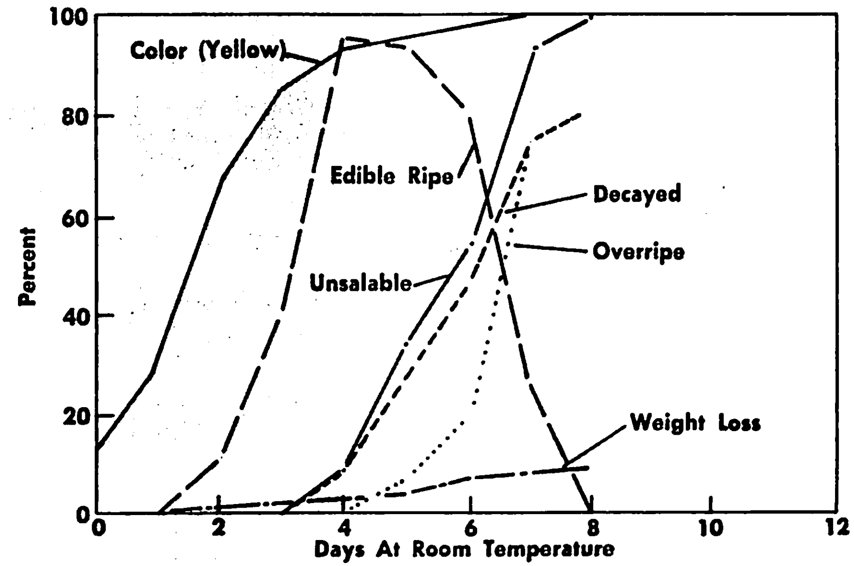


FIGURE *7a*. The relationship among various factors associated with shelf life of hot-water treated, fumigated papayas initially stored under 1 percent oxygen at 55°F for 6 days followed by storage at room temperature (10 percent yellow fruits, 30 per treatment).

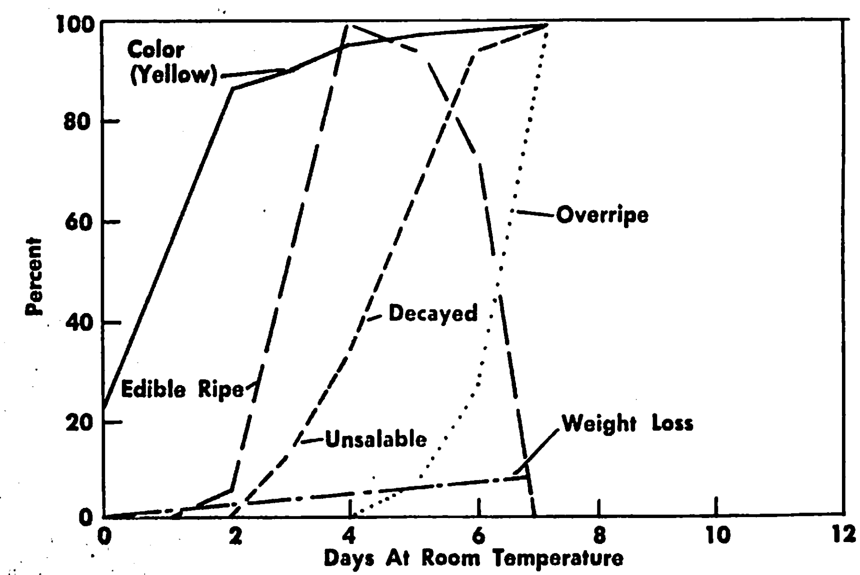


FIGURE *7b*. The relationship among various factors associated with shelf life of hot-water treated, fumigated papayas initially stored in air at 55°F for 6 days followed by storage at room temperature (10 percent yellow fruits, 30 per treatment).

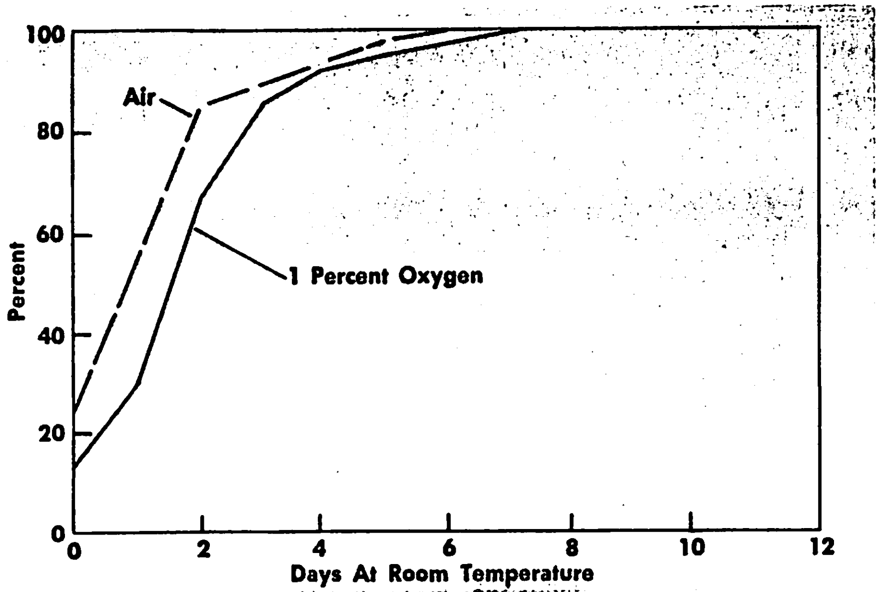


FIGURE 7*c*. The effect of initial storage under 1 percent oxygen and air at 55°F for 6 days on the rate of coloring in hot-water treated, fumigated papayas subsequently stored at room temperature (10 percent yellow fruits, 30 per treatment).

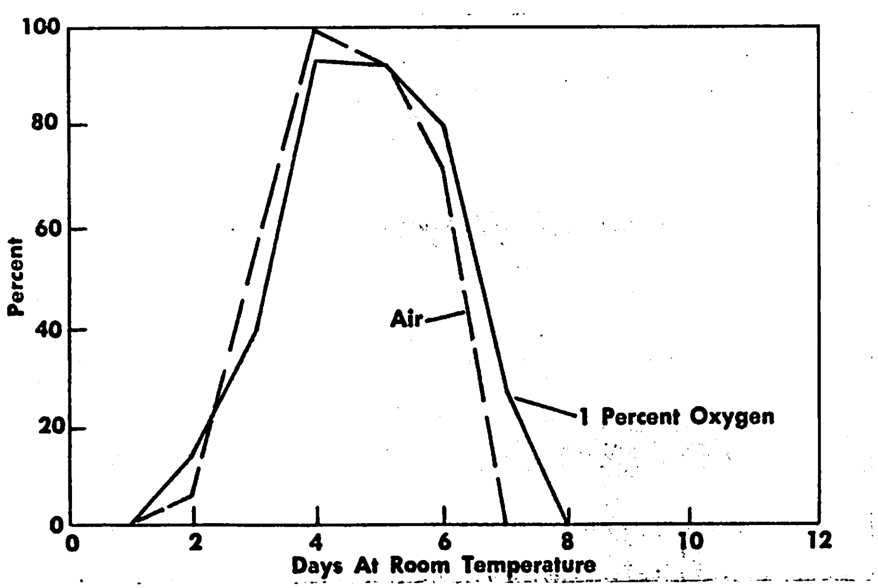


FIGURE 7*d*. The effect of initial storage under 1 percent oxygen and air at 55°F for 6 days on the percentage of edible ripe fruits in hot-water treated, fumigated papayas subsequently stored at room temperature (10 percent yellow fruits, 30 per treatment).

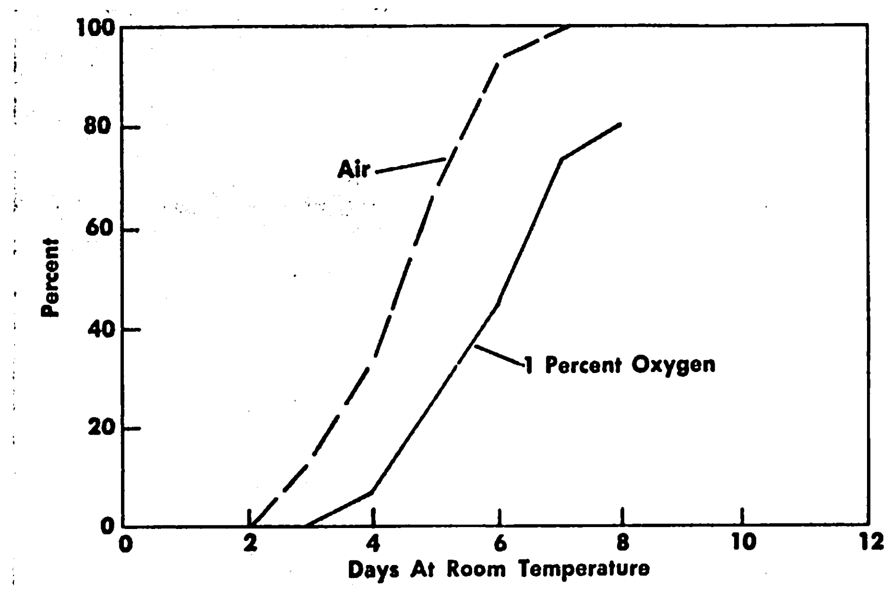


FIGURE 7*e*. The effect of initial storage under 1 percent oxygen and air at 55°F for 6 days on the incidence of decayed fruits in hot-water treated, fumigated papayas subsequently stored at room temperature (10 percent yellow fruits, 30 per treatment).

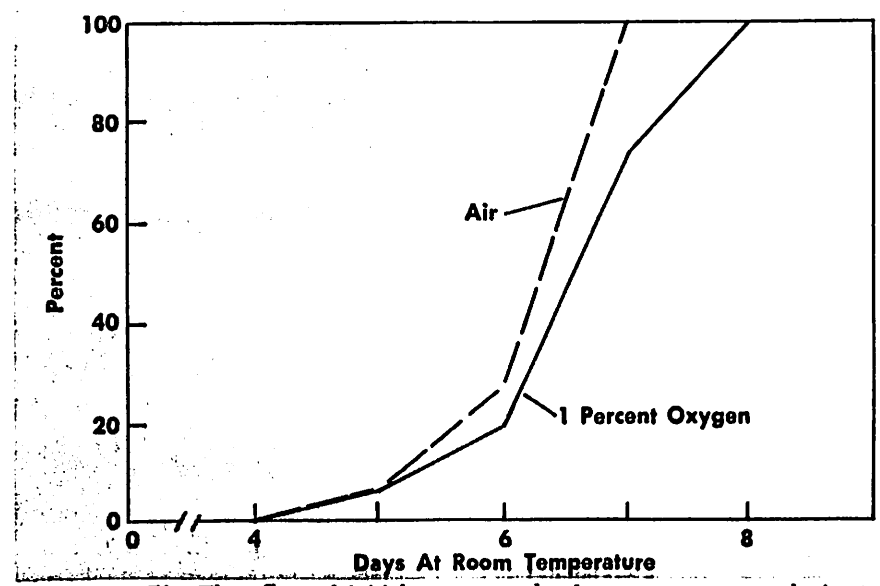


FIGURE 7*f*. The effect of initial storage under 1 percent oxygen and air at 55°F for 6 days on the rate of overripening in hot-water treated, fumigated papayas subsequently stored at room temperature (10 percent yellow fruits, 30 per treatment).

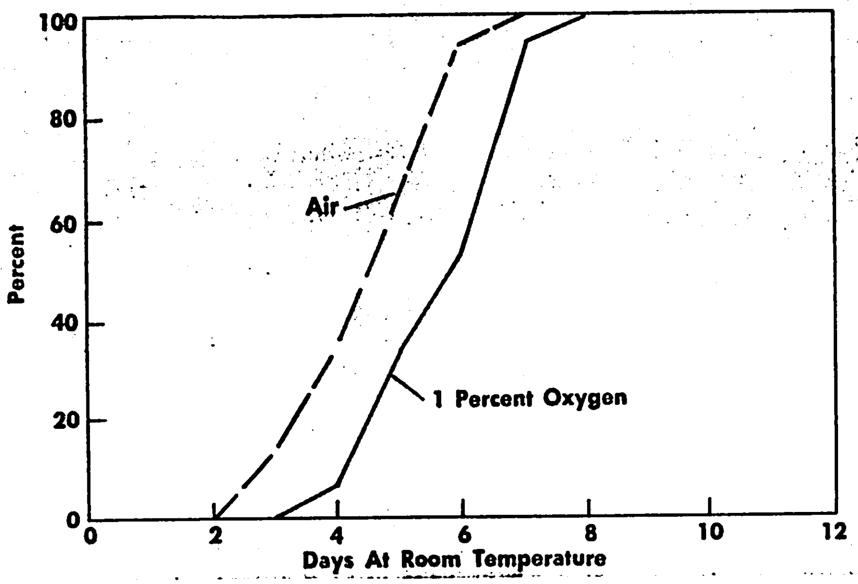


FIGURE 7g. The effect of initial storage under 1 percent oxygen and air at 55°F for 6 days on the incidence of unsalable fruits (decayed and/or overripe) in hot-water treated, fumigated papayas subsequently stored at room temperature (10 percent yellow fruits, 30 per treatment).

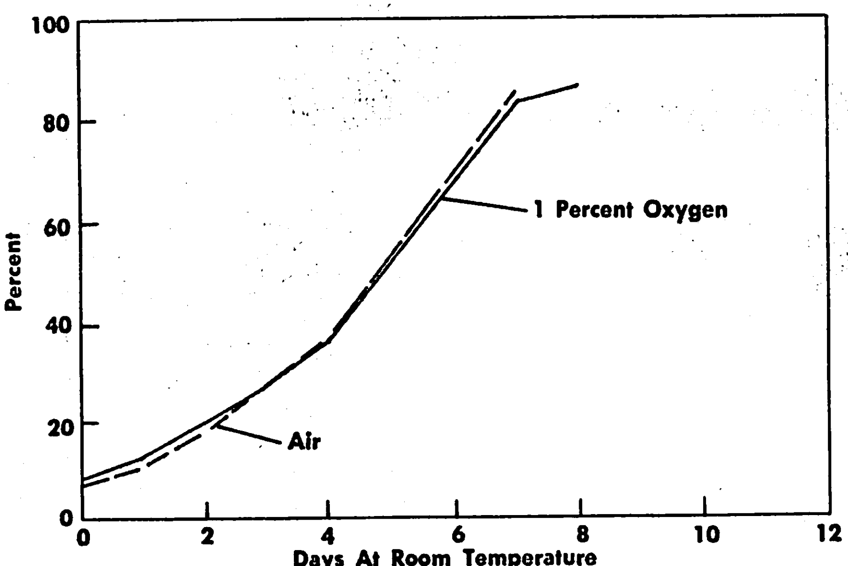


FIGURE 7h. The effect of initial storage under 1 percent oxygen and air at 55°F for 6 days on weight loss in hot-water treated, fumigated papayas subsequently stored at room temperature (10 percent yellow fruits, 30 per treatment).

life at room temperature due to the low initial oxygen level in the storage medium at 55°F.

In an experiment involving an initial 12-day CA storage under 1 percent oxygen at 55°F, it was shown that for this period of CA storage, the 1 percent oxygen concentration was too low in that it caused surface scald. Furthermore, weight loss was significantly greater in CA than in air. Thus in subsequent 12-day CA storage experiments, the oxygen level was maintained at 1.5 percent, which was proved to be the minimum effective level for extension of shelf life without causing detrimental surface or other effects. Fruits subjected to the hot-water treatment followed by fumigation were used and another variable, a humidified atmosphere (nitrogen was bubbled through water prior to entry into the fruit chamber), was introduced in order to minimize fruit weight loss. The results of one of three experiments are shown graphically in figures 8*a*, 8*b*, 8*c*, and 8*d*.

Humidification did not affect the rate of surface coloring in fruits originally stored under 1.5 percent oxygen (figure 8*a*). Fruits under the low oxygen level colored less rapidly than those under air. Humidification slightly accelerated the rate of ripening in fruits stored under 1.5 percent oxygen as indicated by the rate of overripening in the humidified and nonhumidified CA storage (figure 8*b*). However, the rate of ripening in either case was significantly less than that in air.

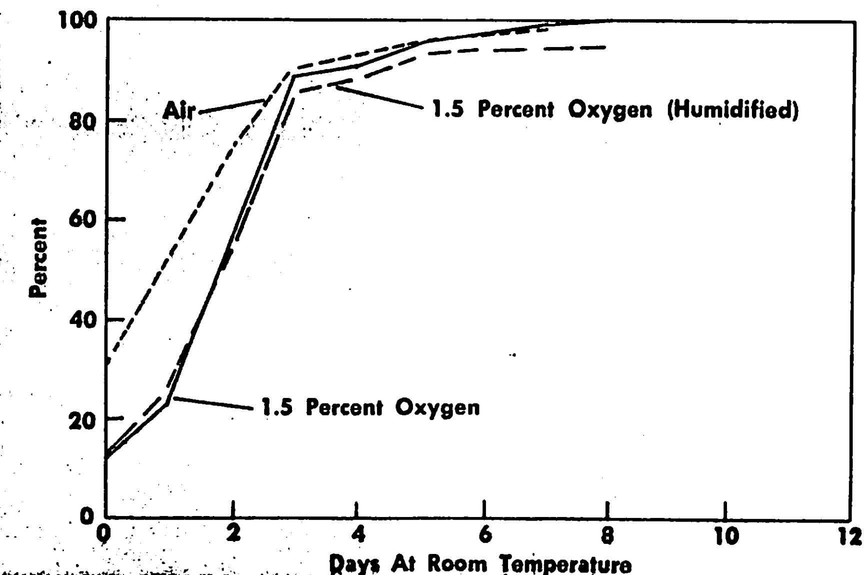


FIGURE 8*a*. The effect of initial storage under 1.5 percent oxygen and air at 55°F for 12 days on the rate of coloring in hot-water treated, fumigated papayas subsequently stored at room temperature (10 percent yellow fruits, 15 per treatment).

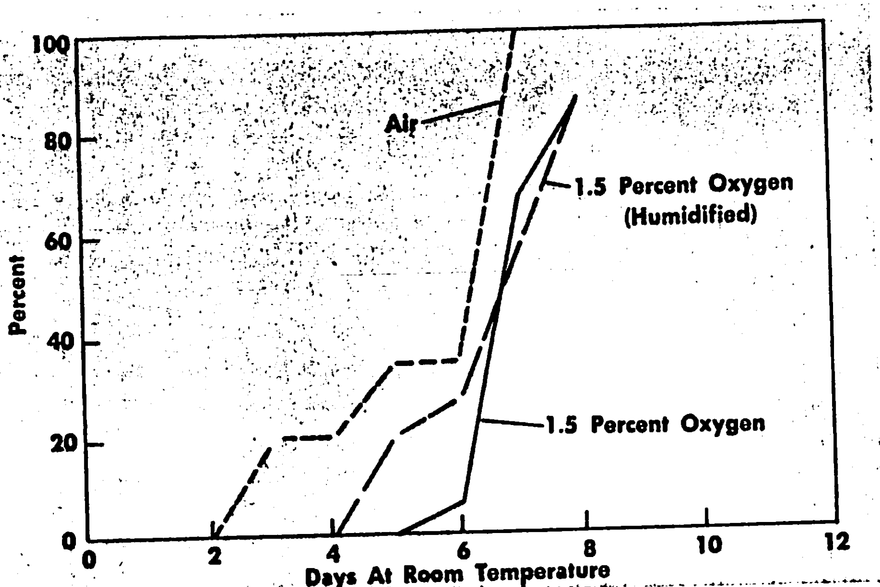


FIGURE 8*b*. The effect of initial storage under 1.5 percent oxygen and air at 55°F for 12 days on the rate of overripening in hot-water treated, fumigated papayas subsequently stored at room temperature (10 percent yellow fruits, 15 per treatment).

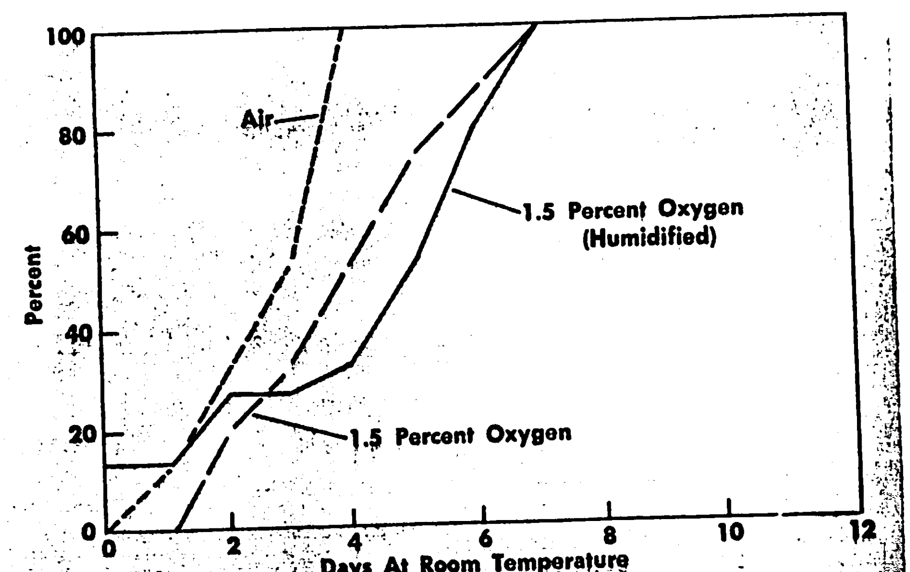


FIGURE 8*c*. The effect of initial storage under 1.5 percent oxygen and air at 55°F for 12 days on the incidence of decayed fruits or unsalable fruits in hot-water treated, fumigated papayas subsequently stored at room temperature (10 percent yellow fruits, 15 per treatment).

CA storage significantly reduced the decay incidence (figure 8*c*); however, the non-humidified storage appeared to be slightly more effective than the humidified one in this respect. Since the percentage of unsalable fruits was wholly due to the incidence of decayed fruits, the curves in figure 8c also represent the data for the percentage of unsalable fruits. The average number of marketable days after removal from CA storage was 3.7, 3.3, and 2.0 for fruits initially stored under 1.5 percent (non-humidified), 1.5 percent (humidified), and air, respectively, with those stored under the two low oxygen levels having significantly ($P=.05$) greater shelf life than the control lot. The difference in shelf life between the humidified and non-humidified fruits was not statistically significant. The extension in shelf life effected by the initial 12-day storage period under 1.5 percent oxygen was at least 65 percent.

Humidification reduced weight loss in fruits stored under low oxygen level (figure 8*d*). In the humidified atmosphere, the fruits lost less weight than those stored in air.

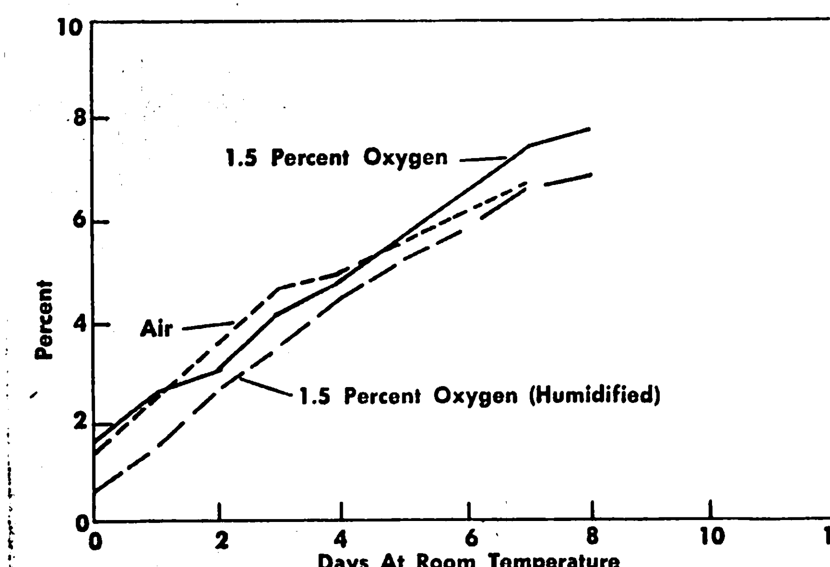


FIGURE 8*d*. The effect of initial storage under 1.5 percent oxygen and air at 55°F for 12 days on weight loss in hot-water treated, fumigated papayas subsequently stored at room temperature (10 percent yellow fruits, 15 per treatment).

DISCUSSION AND CONCLUSION

The results of these studies indicate that the desirable stage of ripeness . CA storage of papayas is 0 (mature green) to 10 percent yellow; this stage gives the maximum shelf life. However, in practice the use of mature-green fruits is not recommended, since there is always the danger of using immature fruits that do not ripen normally. The optimum storage temperature is 55°F. At this temperature, the rate of ripening is delayed without injuring the fruits. For shelf-life extension, 1 to 1.5 percent is the desirable oxygen concentration range. This oxygen range extends the shelf life beyond that gained by cold storage by delaying the incidence of decay even in hot-water treated papayas. Therefore CA storage complements the hot-water treatment in controlling storage decay.

These findings also apply to fumigated fruits. Thus for hot-water treated, fumigated fruits in storage under CA at 55°F for 6 days, the desirable oxygen level is 1 percent. For storage extended to 12 days under CA at 55°F, humidified, 1.5 percent oxygen is preferable. In either case, the extension of shelf life, after removal of fruits from CA storage to normal room temperature storage, is slightly over one day. Although these results were obtained under CA conditions in which the required levels of oxygen were maintained with continuously purging mixtures of air and nitrogen with no possibility of a buildup in carbon dioxide concentration in the storage atmosphere, it is assumed that any system that maintains the required level of oxygen (balance nitrogen) will produce similar results. The shipping of papayas from Hawaii by marine or marine-rail transportation under CA storage to the mainland is therefore practicable.

LITERATURE CITED

(1) Akamine, E. K. 1959. Effects of carbon dioxide on quality and shelf life of papaya. Hawaii Agr. Exp. Sta. Tech. Prog. Rep. 120.

(2) Akamine, E. K. 1960. Temperature effects in fresh papayas processed for shipment. Hawaii Agr. Exp. Sta. Bull. 122.

(3) Akamine, E. K., and T. Arisumi. 1953. Control of postharvest storage decay of fruits of papaya (*Carica papaya* L.) with special reference to the effect of hot water. Proc. Amer. Soc. Hort. Sci. 61: 270–274.

(4) Couey, H. M. 1965. Modified atmosphere storage of Nubiana plums. Proc. Amer. Soc. Hort. Sci. 86: 166–168.

(5) Grierson, W., H. M. Vines, M. F. Overbacher, S. V. Ting, and G. J. Edwards. 1966. Controlled atmosphere storage of Florida and California lemons. Proc. Amer. Soc. Hort. Sci. 88: 311–318.

(6) Hardenburg, R. E. 1964. Developments of post-harvest use of controlled or modified atmospheres for quality retention of horticultural crops, p. 7–16. *In* Report of Proceedings of Eastern Experiment Station Collaborators' Conference on Post-harvest Physiology, Eastern Utilization Research and Development Division, Agr. Res. Serv., U. S. Dep. Agr., Philadelphia, Pa., Oct. 27–28, 1964.

(7) Kapur, N. S., *et al.* 1962. Gas storage of mangoes. Food Sci. 11(8): 228–231.

(8) Porritt, S. W., and J. L. Mason. 1965. Controlled atmosphere storage of sweet cherries. Proc. Amer. Soc. Hort. Sci. 87: 128–130.

(9) Schomer, H. A. 1967. Principles of controlled atmosphere storage, p. 69–71. *In* Proc. Fruit and Vegetable Perishables Handling Conference, Univ. of California, Davis, March 20–22, 1967.

(10) Smock, R. M. 1966. Recent advances in controlled atmosphere storage of fruits. HortSci. 1 (1): 13–15.

(11) Smock, R. M., and G. D. Blanpied. 1965. Effect of modified technique in CA storage of apples. Proc. Amer. Soc. Hort. Sci. 87: 73–77.

Hawaii Agricultural Experiment Station, College of Tropical Agriculture, University of Hawaii
C. Peairs Wilson, Dean of the College and Director of the Experiment Station
G. Donald Sherman, Associate Director of the Experiment Station
Res. Bull. 144—June 1969